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Salmon Aquaculture Review

Technical Adviory Team Findings and Recommendations

Report

PART A

This paper was prepared on behalf of the Environmental Assessment Office by:

The Technical Advisory Team

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SUMMARY OF TECHNICAL ADVISORY TEAM RECOMMENDATIONS

A. Escaped Farm Salmon

1. Allow both Pacific and Atlantic culture, but restrict the species farmed to take into account local site conditions.

2. Continue to develop techniques and methods which will prevent salmon escapes.

3. Move to all-female or non-reproductive Atlantic salmon to prevent risks of colonization.

4. Require farms to maintain standardized information collection and reporting systems that allow improved tracking of escapes.

5. Require farms to develop and implement "escaped salmon recovery plans".

6. BCSFA should develop a broodstock program to minimize risks of genetic dilution of Pacific salmon.

7. Continue and possibly expand the Atlantic Salmon Watch Program to allow more observations of Atlantic salmon in freshwater.

8. Adopt the practice of genetic and physical marking of farmed Pacific salmon to enable monitoring of genetic dilution among native Pacific salmon stocks.

9. Require escaped salmon estimates to be reported widely.

10. Conduct experiments to distinguish whether chronic net pen losses are due to escape rather than undocumented mortality.

11. Establish and enforce a numerical standard for escaped salmon.

12. Prohibit the farming of transgenic salmon except in closed, land-based systems.

13. Conduct research into salmon imprinting.

14. Prohibit salmon farming in freshwater lakes having important indigenous populations.

B. Fish Health

1. Clarify and rationalize institutional structures and roles respecting fish health.

2. Develop enforceable standards of practice of managing farmed salmon health, as a condition of the salmon aquaculture licence.

3. Develop voluntary fish health management and quality assurance programs to enhance health and productivity.

4. Expand the application of existing regulatory tools.

5. Strengthen disease control and surveillance programs.

6. Improve requirements for fish disease reporting.

7. Improve the quality of, and access to, fish health databases.

8. Strengthen regulations, policies and programs respecting disease testing, fish and egg importation, and fish transfer.

9. Enhance fish health inspection practices at fish processing facilities.

10. Minimize the probability of human exposure to drugs and pesticides used at salmon farms.

C. Waste Discharges

1. Establish enforceable performance standards for benthic and water quality conditions in and around fish farms.

2. Establish siting criteria that prevent or mitigate waste discharge impacts.

3. Assess existing farms for compliance with approved standards within one year.

4. Develop a “code of practices” to prevent and mitigate waste impacts.

5. Undertake focused research projects to fill key information gaps respecting waste discharge issues.

6. Establish more rigorous, systematic and accountable waste discharge monitoring systems and procedures.

7. Experiment with integrated, multi-species aquaculture operations at salmon farming sites.

8. Evaluate operations in freshwater habitats.

D. Aquatic Mammals and Other Species

1. Require all existing salmon farms to have a “predation control plan” within two years, and incorporate approved predation control plans into the aquaculture operating licence.

2. Phase-out the use of Acoustic Deterrent Devices (ADDs) at all intensive fish culture operations over two years.

3. Strictly control the killing of predators at farm sites.

4. Locate fish farms an appropriate distance from seal and sea lion haul out sites.

5. Restrict the practice of "night lighting", pending the results of further research.

E. Salmon Farm Siting

1. Require an assessment of all proposed salmon farm sites.

2. Require an assessment of all existing salmon farm sites.

3. Revise and expand salmon farm siting criteria.

4. Prepare integrated coastal zone management plans.

5. Establish local advisory "working committees" to enhance the referral system.

6. Improve the quality of coastal resource inventory mapping.

7. Continue to improve upon biophysical capability models.

8. Require reclamation plans as part of the aquaculture development plan.

9. Develop and implement a combination of enforceable performance standards and voluntary codes of practice.

10. Develop and implement an effective monitoring program

11. Develop and implement visual design guidelines.

12. Pursue new technology and practices to minimize resource impacts and user conflicts.

F. Institutional Framework

1. Base the salmon aquaculture regulatory and management system upon the principles of sustainability, with the aim of protecting the environment and fostering a sound economy and social well-being.

2. Adopt a coordinated, integrated and participatory regulatory framework for salmon aquaculture.

3. Implement the regulatory and management system in a fair and consistent manner and enforce all regulatory requirements.

4. Strengthen monitoring and reporting responsibilities as a basis for proper management of salmon aquaculture.

5. Implement cost recovery of salmon aquaculture management.

6. Encourage the development of an enhanced role for First Nations in salmon aquaculture.

7. Develop a method for monitoring and reporting on implementation of salmon aquaculture management reforms.

8. Structure the salmon aquaculture management framework to encourage the adoption of technology that prevents environmental and ecological risks and multiple use conflicts and encourage development of value-added high quality product.

I. MAJOR FINDINGS OF THE TECHNICAL ADVISORY TEAM

Overview

Background

The provincial Salmon Aquaculture Review (SAR) was initiated in 1995 by the provincial government to address the following key issues of public concern respecting the salmon aquaculture industry in B.C.:

- escaped farm salmon
- fish health
- waste discharges
- aquatic mammals and other species

- **salmon farm siting.**

Previous investigations into provincial salmon aquaculture practices and policies occurred in 1986 (Gillespie Inquiry), 1988 (Ombudsman Report), and 1992 (Minister's Aquaculture Industry Advisory Council (MAIAC)). Various steps were taken to implement the recommendations of these investigations. Following the report of MAIAC, the Salmon Action Plan was established to review the province's broad policy framework for the industry. The Environmental Assessment Office (EAO) was requested to examine the five key issues because of continuing questions and to provide advice to the Ministers of Environment, Lands and Parks and Agriculture, Fisheries and Food for use in their policy development under the Salmon Action Plan.

The provincial EAO was assigned responsibility to conduct the SAR under the authority of section 40 of the **Environmental Assessment Act*****. The EAO was asked to examine the current regulatory system for managing salmon aquaculture in B.C., to examine the effectiveness of the methods in use to prevent or mitigate adverse effects of salmon aquaculture, and to make recommendations for improvement.***

To assist in this task, the EAO retained an independent Technical Advisory Team (TAT) to prepare technical Discussion Papers on the key issues (see Attachment 1). In addition, a broadly based Review Committee, comprising representatives of all key interests, was established to provide a forum for discussion of the issues, and to provide TAT with critical comment during development of the Discussion Papers. The Discussion Papers were prepared over approximately an eight-month period on the basis of a review of the available literature, through consideration of written submissions from Review Committee and other members of the interested public, and through participation in meetings of the multi-party Review Committee at which drafts of the Discussion Papers were considered. In addition, the Discussion Papers benefited from local observational information collected at public open

houses and through interviews in the Broughton Archipelago study area, written comment provided by the public and members of the Review Committee, and review by other experts.

The TAT Discussion Papers contain conclusions respecting the Review issues, but they do not contain recommendations due to the TAT's desire to produce a single, integrated set of

recommendations. This paper contains a summary of the TAT's main findings, and the TAT's recommendations to the EAO for addressing the issues that it was assigned to review.

The EAO was directed to prepare a report by June 1997, making recommendations to the Ministers.

Conclusions of Technical Advisory Team

1. Needed Changes

Greater openness, consultation and information sharing are required of government to improve accountability and public trust. The public is dissatisfied with the present lack of access to information on salmon aquaculture activities. Management agencies have taken significant steps to follow up with the findings and recommendations of past reviews and advisory processes. These have been insufficiently tracked and reported so that members of the public have little or no appreciation of what steps toward implementation of recommendations have been made.

At times the manner in which existing policies, procedures and guidelines for managing the industry have been implemented appears inconsistent with stated management policies and objectives. In addition, tensions among management agencies have hindered a cooperative and corporate approach to the management of the industry and the development of efficient and effective management systems. The result is that there is a substantial lack of public trust, particularly by First Nation communities, in the industry, and in the agencies that are responsible for regulating the industry.

Regulatory and management efforts must be directed at the resolution of conflicts and impacts before siting and operational decisions are made.

A combination of measures are necessary to improve the effectiveness of the province's management regime

- standardized siting criteria
- expanded information collection
- strengthened monitoring
- more extensive public participation and reporting

- **minimum standards for husbandry practices and consistent enforcement.**

Participatory coastal planning in a context of dealing with processes which identify the specific locations that are suitable for salmon aquaculture and other uses, and which

prescribes policies and procedures for integrating coastal uses, is essential to address many of the public's concerns about salmon aquaculture.

2. Local Impacts and Concerns

In the early 1980s government and industry faced serious challenges especially in the Sechelt area. The industry grew rapidly in unsuitable locations, resulting in significant economic losses and subsequent industry restructuring and relocation. There are currently significant localized problems associated with the industry which are causing some adverse impacts on the environment, and on individuals and communities. The history of the industry in the Sechelt and today's local concerns have led to a significant negative perception about the industry among many individuals and groups. Many people remain concerned about the potential long-term effects of salmon aquaculture on B.C.'s aquatic environment. Given their preferences, priorities, and the reliance on coastal

resources, many feel that any risks to the aquatic environment and traditional coastal lifestyles are not worth taking. The current weakened state of many wild fish stocks has heightened concerns about salmon farms.

In the 1980s policies with respect to involvement of First Nations in provincial decision-making processes changed. Decisions regarding a number of farms operating today were made during this time. There is dissatisfaction among First Nations regarding certain of those decisions, concerns about the impacts of salmon farming on resources on which they are reliant and dissatisfaction regarding the level of economic benefit to their communities from the salmon aquaculture industry.

Summary Conclusions

Based on the information available, the TAT's overall conclusion is that salmon aquaculture, as practised today at current levels of production, presents a low ecological and environmental risk to the province of British Columbia. In some locations, however, significant adverse effects from salmon aquaculture have occurred, including impacts to the benthos in the vicinity of salmon farms, conflicts with other coastal uses, and concerns about the safety of consuming wild seafoods that are harvested near salmon farms. This is of particular concern to First Nations. Some changes are needed in the way that the salmon aquaculture industry is managed in B.C. in order to ensure that adverse effects are prevented or mitigated, and to ensure a sustainable approach to salmon aquaculture.

There remain information gaps and uncertainties respecting the effects of salmon aquaculture on aquatic ecosystems, suggesting that the industry should be managed with diligence, in a way that identifies and prevents impacts, and continuously adapts management policies and practices on the basis of new information. Where information was incomplete or inadequate to come to a definitive conclusion with respect to an in issue, the TAT generally dealt with that uncertainty in a precautionary way in making their recommendations.

There remain substantial public concerns about salmon aquaculture which need to be recognized in the design of an acceptable management system for salmon aquaculture in B.C.

Whether or not B.C.'s salmon aquaculture industry will expand in the future will in large measure be determined by government's ability to address these matters. The TAT make no comment on future growth for the industry. The TAT's recommendations (see below) are focused on the regulatory and management actions that are considered necessary to protect the essential health of B.C.'s aquatic ecosystems and to prevent and mitigate conflicts and impacts, regardless of the size of the industry.

A. Escaped Farm Salmon

The use of marine cage culture is the standard method of growing out farmed salmon in B.C. In the course of marine and fresh water salmon farming, smolts and adults are lost due to predation, storms, operator error, vandalism, etc. Between 1988 and 1996, 62 major escapes from B.C. marine salmon farms have been reported. In all, over one million fish are estimated to have escaped—approximately 85% Pacific salmon species; 15% Atlantic salmon. These figures do not

include chronic "leakage" which, over time, could be substantial and, in a worst case scenario, could double the estimated number of escapes in recent years.

The assessment of impacts and risks associated with escaped farm fish have been formulated on the basis of historical and current aquaculture activity in B.C. The TAT notes that it is not necessarily a priori that future growth of the industry will lead to greater numbers of escapes. Nevertheless, it is obvious that any substantial increase and/or decrease in escape levels, regardless of causes would, under the current management regime, alter the potential impacts and nature of the risks involved.

1. Genetic Dilution—Pacific Salmon Culture

The risk of genetic damage to wild stocks is potentially high if large numbers of Pacific salmon escape, as occurred in 1989 to 1991, and if successful interbreeding with wild nonspecific stocks occurs over a number of years.

2. Atlantic—Pacific Hybridization

Hybridization between Atlantic and Pacific salmon and trout in B.C. streams is considered highly improbable because survival of crosses in ideal laboratory conditions was either nil or very low. The risk of interspecific hybridization in B.C. streams is judged to be very low.

3. Colonization

Reproductive colonization of Atlantic salmon in B.C. is unlikely, but cannot be ruled out, with continued escapes from fish farms, and low run levels of native species in many B.C. river systems. Colonization of Atlantic salmon in land-locked lakes is more probable than colonization of anadromous Atlantic salmon.

4. Competition Between Escaped and Wild Fish

At current levels of escaped salmon, the inter- and intraspecific competition between farm and wild stocks is not considered to be a threat to wild populations. At high levels of escaped salmon, localized competition could occur both in the marine and fresh water environments.

5. Predation by Escaped Fish

Predation of native stocks by salmon escaping from farms will not affect the stability of wild salmon populations. Furthermore, predation by impounded farm fish on transient juveniles of wild stocks has been shown to be negligible. Night illumination lights do not influence predation by caged salmon on wild fishes.

6. Transgenic Fish

Transgenic fish are not farmed in B.C. salmon farms. They should not be permitted to be reared in waters inhabited by wild fishes, given that they have genetically engineered competitive advantages over wild fishes.

7. Recapture of Escaped Farm Salmon

While recapture of escapes would be a desirable strategy, there are not at present coordinated plans to make escapes information available to First Nation bands or local fishers who might have the opportunity to recover lost fish.

8. Farm Siting

Regulations governing fish farm siting would not appear to offer much protection against potential genetic and ecological interactions between wild and farmed fish.

9. Escape Statistics

Current statistics on escapes do not include chronic escapes of small numbers of salmon.

B. Fish Health

Fish disease is a naturally occurring phenomenon, although our understanding of fish disease and its role in aquatic ecosystems is quite poor relative to other forms of human and veterinary medicine. Fish disease is not uncommon in B.C.'s salmon aquaculture operations, given the exposure of relatively high densities of captive fish to a variety of environmental pathogens and stress agents. To protect economic investments, salmon farmers treat diseased fish with certain drugs that are regulated by government and through codes of practice. In recent years, improved husbandry practices have significantly reduced the incidence of fish disease and the associated use of drugs at salmon farms. Nonetheless, concerns remain about the potential for farmed fish to expose native fish species to exotic diseases; increase the risk of disease transfer to native species; and expose other aquatic species and people to drugs used to treat disease at salmon farms. These concerns are assessed below.

1. Importation of Exotic Pathogens

The probability of serious disease outbreak due to importing pathogens to B.C. is low, but not zero. There is a very low probability that exotic disease will enter the province. If such a low probability event was to occur, the introduction of an exotic pathogen into wild fish populations in B.C. would have the potential to negatively impact wild stocks, particularly those compromised by other factors.

2. Transmission of Disease from Farm to Wild Fish

During the Review, conclusive evidence that indigenous disease agents have been transmitted from farmed to wild fish could not be found. It is nonetheless reasonable to conclude that wild and farmed fish are exposed to and can be infected by the same organisms in B.C. It is also reasonable to assume that some wild fish can be exposed to pathogens of farm fish origin in B.C. However, it is not possible to confidently reach conclusions as to the ecological importance of such exposure, identify wild species at high risk, or accurately estimate the risk of disease in wild fish due to activities of salmon aquaculture in B.C.

The probability of moving infectious agents within the province is higher than for the introduction of an exotic agent. The current system for approval of transfers of fish within the province is insufficiently standardized and monitored. The lack of explicit methodologies for sampling and testing fish, coupled with the lack of staff available to confirm the health status of transferred fish, provides the opportunity for fish with specific diseases or infections to be unknowingly moved throughout the province.

3. Food-Borne Infectious Disease Risks

Data demonstrating that farmed salmon in B.C. present human food-borne infectious disease risks greater than those presented by wild fish was not found during the Review.

4. Disease Surveillance

The low level of government-sponsored fish disease surveillance, control or prevention programs is inconsistent with the way in which other food producing industries and animal health disease issues are addressed by Canadian governments . Given the existing scientific uncertainty, the current level of surveillance is an important limitation of government efforts to identify, prevent or mitigate potential health impacts of salmon farming.

5. Effects of Antimicrobial Drugs and Pesticides on Humans or Other Fishes

No direct evidence of adverse human or fish health effects of antibiotic use in salmon farming could be found. The transference of antimicrobial drug resistance from marine or aquatic organisms to humans is a hypothetically possible yet unproven concern. The incremental increase in antimicrobial resistance in human pathogens that has been postulated to arise from salmon farming would be very small in comparison to alternative sources of resistant organisms.

The risk of human exposure to antimicrobial drug residues in marketed farmed fish appears to be very slightly higher than for terrestrial species. The probability of human exposure to tissue residues of antimicrobial drug residues in wild species captured near fish farms is low and exposure will be largely restricted to areas in close proximity to farms and within narrow time frames. However, drugs used by aquaculture operations could move beyond the immediate vicinity of treated farms if fish escape before the drug withdrawal period expires or if mobile species such as wild fish or crustaceans ingest sufficient drug to develop harmful tissue residues. The likelihood of a severe adverse human health effect resulting from the ingestion of seafood with residues of antimicrobials used in B.C. is also low. However, consumers should be afforded the opportunity to avoid consumption of food products containing drug residues.

Some evidence supports the contention that pesticide use in marine and aquatic environments can have lethal and sub-lethal effects on individual animals.

As B.C. has not allowed pesticide use in salmon farms, the negative effects of pesticide use remains a potential, yet unrealized risk. There are reports of non-target effects associated with ivermectin use, but no reports were found regarding ecological impacts. Data regarding the extent of use of ivermectin in B.C. was unavailable, thus preventing an evaluation of the risks its use presents in B.C.

6. Drug Use Surveillance

While a framework for drug use surveillance exists in B.C., inadequate resources, coupled with insufficient data collection, storage and retrieval systems, prevent timely and regular review by government agencies of drug and pesticide use. The high degree of veterinary involvement and limited number of products that can be used without veterinary prescription is unique in food production and allows for better control and monitoring of patterns of drug use, as compared to other agricultural sectors.

C. WASTE DISCHARGES

Net cage salmon farming operations cause the release of a number of wastes into the aquatic environment, notably uneaten fish food, fish excretory products and organic matter from net-cleaning that enter the water column and/or settle to the bottom. There are concerns with regard to benthic and water quality impacts from fish farms. In addition, concerns remain over the release of medicines and other chemicals used on fish farms into the adjacent aquatic environment, and the potential for humans to ingest those drugs through the consumption of seafood.

These concerns are assessed below:

1. Nature of the Waste

Fish food either in an uneaten form or undigested excreted form by volume is the most significant waste associated with salmon farming. Excreted food waste is in a solid faecal form or dissolved urea, ammonia, CO_2 and H_2CO_3. The major components of these are carbon, nitrogen, and phosphorus. Most wastes associated with salmon farming are organic and readily broken down by marine biota.

Over the past five years, waste output rates appear to have been reduced by about 50% per tonne of production through better husbandry practices and feed formulations. However, production levels have increased by 50% over the last four years. There will continue to be efforts to reduce feed wastage and improve assimilation, since feed represents about 60% of the operation costs of a fish farm. They are estimated at this time to be between 1.15 to 1.5 dry weight of feed to wet weight gain of fish, depending on the method of calculation.

Certain fish diseases and pests are controlled with feed using antibiotics and therapeutants. Other compounds become waste through practices associated with farming but not feed, such as anti-foulants on nets, cleaning agents for equipment.

Other wastes associated with salmon farming include sewage from workers, garbage, fouling organisms from nets and mortalities. Fish offal and blood water are only associated with processing in B.C. which operates under guidelines for waste disposal and handling.

2. Sedimentation and Benthic Effects

Much of the waste enters the sediments in solid form as carbon, nitrogen, and phosphorous. Typically under salmon farms the benthic biota (plant and animal life on the ocean bed) is enriched in the early stages of farm operation due to the high availability of organic material. During periods of enrichment, mobile large animals also come into the zone to feed. The benthic animals in a zone surrounding farm sites are often enriched, being increased in

number and diversity. Over time with higher sedimentation rates than can be assimilated by bacteria and invertebrate fauna (relative to oxygen delivery to sediments), there is increased biological oxygen demand, the biota becomes stressed, and fewer species and eventually numbers of animals are present. Some of the benthic organisms are simply smothered by the sediments and, by changing the nature of the sediments, the waste material may alter the bottom sediment structure or water turbidity so that filter-feeders such as clams no longer frequent the bottom surface.

The enrichment of the sediments can lead to increased biological oxygen demand followed by a decline in the oxygen level in the sediments. This is accompanied by changes in biota, including

bacterial populations. In extreme cases, sediments in which the oxygen is depleted will be devoid of all invertebrate fauna and aerobic bacteria and may produce hydrogen sulfide gases, due to anaerobic bacterial activity, which are unhealthy for most biota associated with the sediments and the farmed fish above. The time frame for such a cycle is dependent on many biophysical factors including level of productivity of the farm, feed conversion efficiencies, currents, temperature, and bottom topography.

Models and empirical studies from other jurisdictions suggest that sediment anoxia can develop at carbon loads greater than about 4 g carbon /m^2 ***per day. An analysis using the existing Ministry of Agriculture, Fisheries and Food (MAFF) discharge model (with some improved assumptions) for 20 fish farms in B.C. suggests that a maximum deposition rate to benthos of between <1 and 8 g C/m***^{2} ***per day exists in B.C. fish farms at the present time. If these data are representative, about 25% of farms are currently exceeding the critical carbon loading limit cited by various researchers. However, the model needs refinement along with a complete evaluation of all farms in B.C. before it is possible to determine what sediment carbon loads are excessive. Factors which cannot be modelled (such as storm events and resuspension of sediments) will modify the relative assimilation capacity of sediments on a site-specific basis.***

Unusually high sediment levels of zinc have been found in sediments under farms because zinc levels are high in the feed (up to 800 mg/g measured in B.C. compared to 100–150 mg/g in marine sediments). The impact of this is unknown. Copper, the main active component of net anti-foulants, has not been measured at unusual concentrations in the sediments below fish farms and has not been measured in excessive levels in fish in cages or the surrounding water. Of the three antimicrobials (oxytetracycline, Romet 30, tribrissen) used in British Columbia salmon farms, oxytetracycline can persist in sediments for up to 500 days after persistent usage. The antibiotic activity appears to cease fairly quickly, or the compound becomes inactive because it is combined with other elements in the sediment and water column or broken down by light.

There is not good information about how these compounds are transferred from the sediments to biota. Although they are unlikely to affect the health of biota, they may be transferred to humans through food species. Some studies show uptake by biota, while others do not. Therefore, the data on these therapeutants is generally incomplete. Most of the compounds are depurated from the shellfish within about 30 days. The main concern is the depression of bacterial activity in sediments and related rates of organic breakdown of settling wastes.

The dynamics of sedimentation are not fully understood. The variables important to understanding sedimentation—volume and composition of waste, water current, water stability, temperature, bottom topography, composition of bottom sediments, biological activity in and above the sediments (shoreline, bottom troughs, etc.) are better known. Modelling will

become an important tool to predicting, with more certainty, the sedimentation characteristics at salmon farm sites and the zone of impact around a site. Models are currently in developmental stages and more baseline data is required at sites, particularly bottom currents and topography. The risk of smothering and organic overload is high under cages and declines with distance.

This type of degradation is:

- preventable by only allowing production limits to the assimilation capacity of sediments
- reversible through allowing the site to recover from sedimentation (takes from several months to five years for full recovery).

Information pertaining to the fate of suspended solids which get carried away from the site, potentially to the intertidal zone in currents, is lacking and could have importance for sandy or gravel shellfish beds on nearby beaches. Each farm site will be different, but high turbidity has been measured downstream of fish farms. Risks to intertidal beaches are as yet unknown but are of concern particularly for First Nations subsistence fisheries.

Compared to pulp mills, mining, log booming, sewage outfalls and stormwater runoff, salmon farming has a lower probability of effecting long-term changes in marine benthic habitats because of the ease with which biota break down organic waste from fish farms.

3. Water Column Effects

Certain wastes from the feed and fish waste enter the environment in dissolved forms (dissolved nitrogen—ammonia, urea, dissolved phosphorus; dissolved carbon). Dissolved nitrogen is an important nutrient to marine plants, especially phytoplankton. Seventy-five percent of the total nitrogen in farm waste may be available to plankton for growth. The presence of plankton blooms is of extreme concern to salmon farmers.

Dissolved nitrogen and phosphorus from salmon farms is considered negligible compared to other nutrient inputs. It is unlikely that most phytoplankton remain in the vicinity of cages long enough to uptake nutrients from the water column of a salmon farm to effect an increase in phytoplankton abundance unless the area has extremely slow currents. The added nutrient loads from fish farms are minor in quantity compared to natural and other sources in the marine environment. There is no evidence of water quality impact of salmon farming on a broad geographic scale, and on a more local scale there has been no demonstrated impact to date. This could change on a local scale if farm density and production increase substantially.

Oxygen depletion can potentially be an impact in isolated, poorly flushed basins, particularly on a seasonal basis. Understanding the flushing characteristics of a basin is required if intensive fish culture is likely to occur. Studies on the Sunshine Coast area concluded that salmon farm operations there had no overall effect on the water quality from ammonium or

oxygen. Models for other areas suggest that there is no risk of adverse water quality around existing salmon farms.

There is a concern about the potential presence of harmful phytoplankton cysts in sediments where salmon farms become or are located because these may act as seed for blooms. However, this possibility has not been studied to date.

4. Impacts of Salmon Farms on Freshwater Habitat

Hypernutrification, especially through addition of phosphorus from salmon farm waste, has been noted in freshwater streams from hatcheries and oligotrophic coastal lakes from hatcheries and lake cage culture. This is of particular concern when considering locating cages in low productivity British Columbia lakes. There are two lakes in British Columbia with lake cage culture.

Sediment impacts are of less concern due to existing high total organic carbon in the two lakes currently used for smolt culture, and often thick organic layers. In addition, the lack of significant commercial or food resources living in sediments or reliant on deep sediment fauna makes the sediment impacts in freshwater of less concern than in the ocean. However, remineralization of nitrogen and phosphorus from sediments during lake turnover could affect water column productivity.

5. Other Impacts

The material sloughed off nets is an additional organic source to the environment. The impacts of this practice are not well known, but if any, are expected to be localized. Net cleaning can also add considerable turbidity to water and may wash up intertidally. Net cleaning operations should therefore be carefully located and timed to correspond to off-shore tidal cycles.

Disposal of offal and morts by composting and ensiling is an acceptable practice. There are reports of illegal mort disposal. There have been complaints about stun and bleed operations and inadequate garbage and debris disposal at farm sites.

D. Aquatic Mammals and Other Species

A number of fishes, aquatic mammals and birds are attracted to salmon operations as a potential source of food. Economic losses to salmon farmers from predation may be considerable, prompting salmon farmers to attempt to control predation, primarily through a variety of noise-making and net construction technologies, as well as through the trapping and killing of predators.

1. Effectiveness of Acoustic Deterrent Devices (ADDs)

Although ADDs (i.e., sound generating devices which, because of some combination of intensity, frequency, or other characteristic(s), are aversive to aquatic mammals and keep or drive them away from an area or structure) are reportedly effective for up to two years, effectiveness is variable among farm sites in B.C. and appears to diminish with time. Attacks by pinnipeds (seals and sea-lions) still occur even with the use of ADDs. It is thought that effectiveness is related to an animal's prior experience. It is assumed that animals that continue to attack sites with ADDs are those which have experienced success in the past and that these animals are sufficiently motivated by previous success and hunger to withstand the intense ADD signals.

The success of pinnipeds in obtaining food at salmon farms is a function of the predator net system or type of net pen, net rigidity, material and mesh size and the motivation of the animal, which may be related to availability of other prey choices, whether wild fish stocks or fish at other farm sites.

ADD signals are intended to cause pain at close range. It is not known whether pinnipeds which continue to attack have habituated to the signals, or whether they have experienced hearing damage. Based on variable effectiveness among farm sites and diminishing

deterrence response with time, ADDs are not considered a long term or a desirable primary method of predation control.

2. Impacts of ADDs

The long-term impacts of high intensity signals from ADDs on aquatic mammals are not known; however, pinnipeds that are not deterred by ADDs may experience hearing damage at close range. Harbour porpoise respond to ADDs by avoiding exposure to the ADD signal by altering normal movement patterns. This could result in appreciable habitat loss in acoustic exclusion zones, impediments to normal movements and loss of access to foraging habitat.

Declines in the number of sightings of baleen whales and killer whales in the Broughton Archipelago have been reported and appear to coincide with the introduction of ADDs. It is not clear whether these two events are related; however, observations in Newfoundland indicate that humpback whales may vacate areas where ADDs are operating.

The impact of ADD signals may include interference with communication signals, interference with passive listening by means of acoustic masking, and the possibility of hearing damage.

3. Killing of Aquatic Mammals Around Farm Sites

An assessment of the population effect of the practice of killing mammal predators around salmon farms is not possible, given current information limitations. Department of Fisheries and Oceans (DFO) records show large numbers of harbour seals and sea lions killed over short time intervals. Killing of such magnitude may affect the stability of local populations.

4. Other Predator Control Technologies

Improvements in and maintenance of physical barriers between farm fish and predators should provide long-term effective means of predation control. It is important to install such systems from the beginning of farm operations, before aquatic mammals establish predatory behaviour.

Efforts to reduce predation by aquatic mammals and birds are best applied through improved predator net systems. Several factors can appreciably reduce predation problems. These are:

- mesh size
- rigidity of the net material in both the predator and the grower net
- size and shape of the net pen
- adequate buffer zones between the grower and predator net

- **installation of top nets.**

5. Interaction Between Birds and Fish Farms

Birds prey on smaller juvenile fish, causing mortalities and stress in fish from harassment by the birds. There is little knowledge about the effects of deterrent practices at salmon net-cage operations on bird populations. However, as with aquatic mammals, the killing of birds as a control measure can have significant impact on local colonies.

6. Prawn Fishery Interactions

Interactions between commercial prawn fishing and commercial salmon net-cage operations include specific physical conflicts (e.g., tangling of fishing lines with anchoring structures) and the reduction of prawn fishing areas due to the areas occupied by salmon farms. There is no information concerning the biological interaction between salmon aquaculture and prawns.

7. Night Lights

Night lighting enhances growth of salmon in net cages. The data from organized studies on this topic in B.C. show that fish in the net cages do not consume significant amounts of wild fish that may be attracted to the net cages by the lights at night. However, limited past research into this interaction, coupled with conflicting anecdotal information, suggests that further scientific study of this issue is warranted.

E. SALMON FARM SITING

Most of B.C.'s 75 active salmon farming grow-out sites are located on Crown aquatic land. The farms are concentrated mainly in the colder, sheltered waters between north Vancouver Island and the mainland, and in the protected sounds on Vancouver Island's west coast. Although a very small percentage of the provincial coastline is occupied by salmon farms, there are significant concerns about fish farm siting among public interest groups.

Siting decisions are made by government in response to individual site applications from salmon farming proponents. Applications are referred to government agencies and interest groups to identify concerns, then the Ministry of Environment, Lands and Parks (MELP) decides whether to grant a tenure. There is a significant level of agreement that one of the primary problems with siting decision-making is that the criteria and rationale for decisions have been unclear.

The industry is now subject to more stringent policies and procedures than were in place in the 1980s when the industry experienced rapid expansion and then restructuring. There is better information, most relevant groups are now contacted for referrals, and some planning efforts are underway. The majority of farms currently in place were sited before these benefits existed. Because of the moratorium on the issuance of new marine tenures, the current status of decision-making systems has not been tested, but there remain concerns.

1. Biophysical Effects of Siting Decisions

Fish farm siting decisions have a bearing on the potential for fish escapes, disease transference, waste discharges, and interactions with aquatic mammals and other species. (see previous sections)

2. Socio-cultural Effects of Siting Decisions

Although the total area occupied by salmon farms is a tiny fraction of the provincial coastline, there are a number of strongly held perceptions about the negative impacts of salmon aquaculture. These may be explained primarily by the fact that, although the coastline is vast, many users have interests in the same locations (i.e., areas close to population centres, offering protection, fresh water, accessible shoreline, etc.). As well, although those affected by salmon farms are few, the impacts when they have occurred have had a significant effect on the individuals concerned, especially First Nations.

Proximity Effects

Recreationists and tourism operators are mobile and can choose to avoid salmon farms to some degree, but in some regions they cannot avoid all farms unless they are willing to restrict their range The perceptions of impacts can be strong because of the importance of the quality of recreational experience often desired.

Although there are no formal guidelines for minimizing visual impacts, fish farm proponents are advised to design fish farms to minimize visual impacts. Farms which blend with the surroundings are preferred, but any structures can be offensive to those seeking a pristine environment.

Some effects such as production of garbage have been improving with better husbandry practices.

Some proximity effects remain unregulated. There is no requirement to contact upland owners who may be within visual or audible range of a proposed site. There are no guidelines or regulations governing noise or smell.

Effects on Communities

Economic effects of salmon aquaculture on communities are generally positive, through direct and indirect employment and income. However, the benefits to First Nations and some small communities have been non-existent to minimal.

Non-economic effects on communities overlap with proximity effects and resource use conflicts. Government regulations to address conflict are centred around the referral process. Although that process has improved in recent years in terms of the groups contacted and repeat contacts, it is not a process which lends itself to consensus-building or conflict resolution.

Resource Use Conflicts

The number and intensity of resource use conflicts are generally in proportion to the density of fish farms in an area.

In the Broughton Study Area, the number of recreation sites affected by fish farms ranges from 5% to 20% depending on the method of analysis and the type of recreation use. Half of the larger recreational use areas and routes are highly or moderately affected by fish farms. While the aquaculture industry is a source of interest to some tourism operators, most report that it has had negative effects on their operations in the area. The general impression is that salmon farming and recreation can coexist provided that salmon farms are sited and designed to blend with the surroundings, that fish and wildlife are not harmed, that farms do not impede access along or to the shore, that noise and pollution are minimized, and that the number and density of farms are limited. To provide for a range of recreation opportunities, there must be areas with no farms (protected areas) and areas where different levels of aquaculture are acceptable.

Fish farms directly affect a relatively small portion of commercial and sport fishing locations because of the large areas used for fishing salmon, ground fish, crab and prawns. However, a significant number of fish farms in the Broughton area affect what are considered to be

prime prawn fishing areas. The level of concern is likely related to favourite, highly accessible fishing spots being lost to fishing. The fouling of fishing gear caused by fish farm equipment which is not removed from unused sites can cause significant irritation and cost to fishers.

Impacts on shellfish resources are relatively limited in geographic extent, however, there exists the potential of human consumption of shellfish that contain drugs.

Fish farms have had few impacts on archaeological resources. The siting process has generally not involved archaeological impact assessments.

The effects of fish farms on navigation have not been quantitatively evaluated, but it is expected that these effects are relatively limited in number. Where navigation impacts do occur, they cause a high level of annoyance and potential cost or harm to other coastal users.

Because of the level of different types of use in many coastal areas, competition for space and conflicts are unavoidable. The major user groups all appear to feel that there is inequity in access to Crown land. There is an inherent challenge in attempting to address resource use conflicts through the referral process. To date, there have been few interest-based, consensus-seeking planning processes, conducted at a regional level, to address competing demands and to achieve an acceptable balance of uses. Broad strategic direction from government to ensure that siting decisions respect overall goals is lacking. Mapping and monitoring of resources are not sufficient to understand and address conflict.

First Nations Perspectives

First Nations are concerned about infringements on Aboriginal rights, health, sustenance resources, and the fact that fish farms are being located within their territories. Fist Nations are still not being appropriately served by the siting decision-making process. While First Nations vary to some degree in their perspective on the industry, they all desire involvement in the decision-making process.

3. Site Selection

Siting Guidelines/Criteria

There appear to be significant gaps in the existing siting criteria. For example, the current siting guidelines fail to adequately define the resources that are to be avoided. There are no defined criteria for identification of environmentally sensitive areas, wildlife areas, and areas used by red- or blue-listed species.

Current siting guidelines are not legally enforceable, and do not appear to have been followed in all cases. Better procedures are required in the approval process for siting to ensure that guidelines are followed.

The consideration of “cumulative effects” and “carrying capacity” is central to the issue of site selection. To responsibly allocate public resources, it is necessary to determine, to the degree possible, the capacity of the natural environment to assimilate wastes and the tolerance of tourists to the presence of industry and other uses, including tourism. These thresholds are difficult to determine, and past approaches appeared to consider resources infinite and impacts unlikely.

Site selection suffers from a lack of direction. With no plan that designates preferred areas, aquaculture is sited in an ad hoc, reactive manner. The current system does not include proactive planning which would allow for establishing objectives, evaluation of options, consensus-building and analysis of highest and best use which is best done regionally (as opposed to decision-making on an individual site basis).

After considering biophysical requirements, industry needs and the limitations resulting from environmental and socio-cultural factors, there may not be many additional sites meeting present criteria in some areas of the coast. This will be particularly true in areas where there are already significant concentrations of farms or where recreational use is high.

Site selection considerations for salmon farming include biophysical criteria, good water quality, suitable physical characteristics, adequate protection, appropriate biological factors, avoidance of aquatic mammals, and sites for fallowing. Salmon farming operations need a sufficient concentration of farms within an area to sustain local support services for the farms, and to provide operators with the flexibility to use safer farming practices such as single year class sites and fallowing. Farms require security in relation to natural environmental conditions and human intrusions to protect the health and safety of the fish.

New/Evolving Technology

New technology could increase the number of suitable fish farming sites, because of technologies which can enable farms to withstand more exposed sites. For example, if fish farms focused more on sites in wide channels and less on bays, conflicts with recreational and settlement uses could be reduced.

Evolving salmon farm technology will have future implications for fish farm siting. Potential new technology for salmon aquaculture at the prototype stage of development is the use of enclosed systems. These could reduce environmental impacts and further increase the geographical range of farming operations. Land-based technology for salmon grow-out is still too expensive for the industry to be feasible. In the future, however, land-based systems may provide opportunities to reduce impacts on marine resources and users, although upland impacts would need to be addressed.

4. Regulatory Structure

There are different jurisdictions involved in managing salmon aquaculture. Their respective roles are sometimes overlapping, and the responsibilities and regulations are complex. Although B.C. is not unique in this respect, the number of agencies and the complexity of regulations poses a challenge for managers and for the industry.

The agencies responsible for managing aquaculture have experienced difficulties in collaborating in management of the industry. This has impeded information sharing, analysis and decision-making in the past. There are indications that collaboration may be improving.

The lack of a broader structure for coastal management and planning which could provide guidance for siting aquaculture and other uses is a major issue. There is no coast-wide strategy which defines goals and objectives for B.C.'s coastal zone. There are few plans which set community-based, environmentally sound objectives, policies and designations for future use of coastal areas.

5. Information Sources

A major problem facing siting for salmon aquaculture has been the lack of consistent available data sets on coastal resources. To identify the most appropriate locations for aquaculture, there is a need for mapping which combines biophysical, socio-economic, cultural and industry criteria. There are no prescriptive plan designations based on those criteria and community input.

Data has consistently been lacking on specific sites under consideration. For example, there is no comprehensive information on the resources which exist at and near sites before the farm is introduced. This type of information is critical to responsible decision-making and to serve as a benchmark for monitoring.

There are information sets that have become available since the moratorium which have not yet been used for siting decision-making (e.g., coastal land use information assembled by the Land Use Coordination Office). The need for a coordinated, corporate system of information on coastal resources is well documented. To be useful in the siting process, the data must be

easily available at a reasonable cost. Regional, reconnaissance level data (e.g., 1:250,000) is useful for regional planning, but much more detailed information is required for siting of individual fish farms.

The Coastal Resource Interests Studies (CRIS) mapping that was prepared between 1987 and 1992 is a valuable source of information on coastal interests, but it has a number of limitations. A number of existing fish farms are located in "No Opportunity" zones because, as a matter of government policy at the time, fish farm applications that were filed before the CRIS maps were released were not subject to the CRIS limitations (i.e., they were "grandparented in"). This is a major concern for people who contributed to the CRIS process because they were left with the perception that their input was not treated respectfully.

Although the existing salmon farm capability maps have proved to be an extremely useful tool in siting decisions, they do not provide information on the assimilative capacity of sites or regions. That information has not been generated for B.C.

6. Regulations and Approval Processes

Government agencies, public interest groups and salmon farming industry groups have all raised numerous specific concerns about the regulations governing the industry, inadequacies in the information base, referral process limitations and decision-making procedures respecting siting. In general, these concerns are about perceived inequity, inadequate communication, arbitrariness, timeliness, incompleteness, rigidity, and inconsistency in the current methods, processes, practices and procedures for siting fish farms.

F. Socio-economic Impacts of Existing Salmon Aquaculture in B.C.

The following assessment of socio-economic impacts of existing salmon aquaculture in B.C. is based on the existing British Columbia situation (i.e., existing regulatory/management systems, number of salmon farms, levels of fish production). Impacts due to biophysical effects are summarized from information and conclusions contained in Technical Advisory Team Discussion Papers on the key SAR issues.

1. Scale of B.C. Production/Industry Characteristics

B C 's farmed salmon production (25,000 tonnes dressed weight in 1996 from 79 grow-out sites) is relatively small (4.3% of world market) compared to other world producers. The industry has concentrated into fewer, larger firms in recent years (currently 16 companies).

The firms are largely vertically integrated, often involved in hatchery, transportation, processing and/or sales as well as grow-out operations.

The industry generated revenues of $167 million in 1996 and provided some 2,200 person years of direct and indirect employment, located mainly on Vancouver Island.

2. Subsidies to Industry/Government Revenue

The level of government support to salmon farming in B.C. is quite small. There are no direct subsidies and indirect government support is estimated at $3.65 million annually, much less than in most other agricultural industries or in the commercial salmon industry. The industry generated about $4 million in government revenues in 1996 through taxes and fees.

3. Impact on Wild Salmon Prices

World-wide production of farmed salmon has depressed the price of wild salmon and displaced some wild salmon frozen markets. B.C.'s farmed salmon production alone, however, has had a relatively insignificant effect on salmon prices, given that B.C. production represents less than 5% of the total world farmed supply and less than 2% of the world farmed and wild supply combined. If B.C. farmed production were to disappear, any price impact would likely be short-lived as other countries which compete with B.C. (particularly Chile) expand their production and sales into the vacated markets.

4. Impacts Due to Biophysical Effects

The biophysical effects of a major disease outbreak on wild salmon resources could be very significant, requiring the forgoing of catch and /or enhancement of wild runs. The TAT has concluded, however, that the likelihood of widespread impacts due to disease from fish farms is low—no such effects and consequent economic or social impact have been identified in B.C. to date. It is likely there will continue to be escapes and possible colonization in the wild, but this is not likely to have any significant economic consequences in terms of reduced quantity or value of wild catches.

There are some impacts of salmon farming on other fishery resources. Generally, the percentage of resources affected is small, but the impacts can be very significant to individuals and communities affected. The uptake of antibiotics by clams and other impacts on this resource is of particular concern to Aboriginal communities.

Marine commercial tourism operators in the Broughton study area (employing about 270 people, including over 80 local residents) are mostly negatively affected by salmon farming, although some report positive impacts. Tourism activity has been growing rapidly, more than doubling over the past five years. While some operations may have grown more rapidly in the absence of salmon aquaculture, it would appear that despite the negative impacts, salmon farming has not significantly reduced economic activity in this sector as a whole. It is more likely to have caused operators to find other routes or anchorages within the study area, or to divert to other areas along the coast. There are, however, concerns about the potential impacts on future growth in the tourism industry.

These conclusions also apply generally to non-commercial marine recreation use, with the main impact to date being the reduced quality of experience.

Other impacts have been reported on upland property, archaeological resources and navigation and safety. Generally the impacts are small because of the remoteness of the sites and the limited number of conflicts, though again they are very significant to the individuals affected. The extent of impacts on archaeological resources is not well known because of the absence of site surveys prior to fish farm licensing.

5. Economic Impacts of Salmon Farming on Broughton Study Area Communities

Salmon farming and related activity in the Broughton area has generated some 200 direct jobs, 21% of which are held by Broughton study area residents. There is some, but only minor indirect benefit to the study area communities from salmon farming purchases of services and supplies, as most of these are provided from larger centres such as Port Hardy or Campbell River.

Overall, the impacts on the study area communities are relatively small, accounting for only 2% of the total employment of the area. However, the jobs do provide some offset to declining resource industries and do offer some growth potential.

6. Impacts on First Nations Communities

Overall, First Nations have been negatively affected by salmon farming. Access to clam resources (an increasingly important component of First Nations' diets due to declines in other stocks) have been reduced; farms have been sited near their communities and in their traditional territories

despite First Nations objections; and First Nation participation in the employment and business opportunities afforded by salmon farming has been very limited. Total employment from First Nations accounts for some 4% of salmon farming jobs in the study area and 5% of the salmon farming jobs created province-wide.

II. TECHNICAL ADVISORY TEAM RECOMMENDATIONS

Based on the above findings, the TAT advises the EAO to carefully consider the following recommendations when developing its recommendations to the Ministers. These recommendations are the measures that the TAT feels are necessary to address gaps and weaknesses in the current salmon aquaculture management system1, and ultimately to contribute to the maintenance of sustainable aquatic ecosystems in B.C.

The TAT recommendations have been formulated to address potential or observed environmental, biological or socio-cultural and economic problems resulting from salmon farming. In many instances, the character and extent of the risks involved cannot be quantified and the recommendations are, at times, designed to minimize or prevent risks even though such risks may be low. Recommendations involving siting requirements frequently involve minimum distances, based on existing requirements. The scientific bases of existing siting requirements are most often undocumented. Therefore, adjustment of recommended criteria respecting distances, depths, etc., based on improved knowledge of biophysical and environmental conditions is expected.

The TAT feels that the following recommendations are generally practical and feasible, given current technology and capacities. In many cases, it is expected that the recommendations would be phased in to allow appropriate time for planning and adjustment. The TAT has not, however, undertaken a detailed socio-economic analysis of the impact of the recommendations. Integration of environmental, economic and social goals is not a role that has been assigned to the TAT—the EAO will take the full range of factors into account when developing its recommendations to the Ministers. Ultimately, the government, when making salmon aquaculture policy decisions in response to the EAO recommendations, will integrate these goals.

In some cases, the TAT's recommendations relate to programs and functions that are the responsibility of the federal government. While it is understood that the scope of the Salmon Aquaculture Review is limited to provincial salmon aquaculture management responsibilities, there are nonetheless some significant overlaps with federal regulatory responsibilities. The TAT's recommendations respecting these responsibilities should be considered as advisory, and part of an integrated package of proposals for ensuring sustainable salmon aquaculture in B.C.

A. Escaped Farm Salmon

1. Allow both Pacific and Atlantic culture, but restrict the species farmed to take into account local site conditions.

Both Pacific and Atlantic salmon aquaculture should continue to be permitted in B.C.; however, when approving salmon aquaculture licences, care should be taken to ensure that:

- all salmon aquaculture facilities are located and designed to minimize possible escapes

- **locations of salmon farms are selected on the basis of having minimal impact upon natural populations, especially populations considered to be weak, so that gene flow with native populations is minimized (e.g., salmon farms raising chinook salmon should not be located in the vacinity of important chinook streams)**

2. Continue to develop techniques and methods which will prevent salmon escapes.

The recommendations by the B.C. Salmon Farmers Association (Reply comments to EAO Salmon Culture Review, March 10, 1997) constitute, if implemented, a positive move in this direction. The ultimate goal should be technology that contains fish and does not permit their escape into the wild.

3. Move to all-female or non-reproductive Atlantic salmon to prevent risks of colonization.

Atlantic salmon culture should move to all-female or sterile fish production within an eight-year phase-in period. All-female or sterile fish production would greatly reduce potential risk of colonization, which is viewed by the TAT as being low but possible.

Ongoing research is evaluating growth performance of all-female Atlantic salmon and all-female triploid Atlantic salmon (sterile) at a salmon farm near Campbell River (E. Donaldson, retired DFO, pers. comm.). Results to date suggest that regular male fish grow faster than females, but some males will mature at a younger age. Growth of all-female fish appears to be similar to regular females. Performance of all-female triploid fish will likely be less than other test groups because all-female triploid fish are more susceptible to crowding stress, slower growth, and jaw deformities. This experiment will likely be completed in 1998 when the fish reach maturation, but funding for the project is presently inadequate. Preliminary results suggest that production of all-female Atlantic salmon may be a more viable option for the farming industry compared to all-female triploid Atlantic salmon.

4. Require farms to maintain standardized information collection and reporting systems that allow improved tracking of escapes.

All farms should be required to maintain a standardized computer-based information system that contains numbers of salmon transferred to each farm, numbers of mortalities, numbers of escapes, numbers of recovered salmon, numbers harvested, and date and size of fish at each event. Although discrepancies may be expected, this approach might allow agencies to gain a better grasp of farm activities and fish escapes.

5. Require farms to develop and implement "escaped salmon recovery plans".

Each farm should be required to have in place a plan to recover escaped salmon, and should be required to implement that plan when escapes exceed an established number. Pending the

availability of better information, it is suggested that recovery plans should be required to be implemented where escapes exceed an estimated 500 salmon having an average weight of 1 kg or more. This requirement is especially aimed at reducing numbers of farmed Pacific salmon that might interbreed with wild stocks. The recovery plan should be reviewed by government agencies as part of the farm licensing process.

6. BCSFA should develop a broodstock program to minimize risks of genetic dilution of Pacific salmon.

Three approaches to a broodstock program are offered in order to minimize genetic dilution of Pacific salmon populations. One approach is to use broodstock from local stocks in order to minimize genetic effects. This approach, however, can be impeded by low availability of local stocks.

Alternatively, farmed salmon could be allowed to domesticate so that interbreeding with wild salmon might enable maladaptive genes to be lost more quickly. Domestication might also involve selection for spawning periods distinct from those of wild populations, thereby causing farmed and wild populations to be reproductively isolated.

A third alternative to the broodstocking program is production of sterile Pacific salmon. Several methods have been developed to produce sterile (triploid) salmon, but performance evaluations of sterile fish in large scale net pen operations have not been conducted. Research is needed before this can be a viable option.

These three approaches should be thoroughly discussed and evaluated in an effort to develop guidelines for broodstock management of farmed Pacific salmon.

7. Continue and possibly expand the Atlantic Salmon Watch program to allow more observations of Atlantic salmon in freshwater.

The Atlantic Salmon Watch program should be continued and possibly expanded to allow more observations of Atlantic salmon in freshwater. The effort should focus on specific streams known to have Atlantic salmon. A primary goal should be to determine whether the fish successfully spawn. One approach might be to observe spawning behaviour in a spawning channel or stream where adults and potential offspring could be easily controlled.

8. Adopt the practice of genetic and physical marking of farmed Pacific salmon to enable monitoring of genetic dilution among native Pacific salmon stocks.

Cultured Pacific salmon stocks may be distinguished from indigenous native populations through molecular genetic (DNA, allozyme) characteristics. Such "genetic marks" are either an intrinsic distinguishing characteristic of the respective populations, or can be straightforwardly induced without altering the performance of the culture stock. Genetic

profiling of key wild and cultured stocks would permit monitoring for possible introgressions or displacement by escaped farm salmon.

Physical marking of farmed Pacific salmon with coded wire tags or an externally visible tag would be beneficial when trying to identify numbers of escaped salmon entering salmon streams. This information would be useful for evaluating the potential impact of introgressions or displacement by escaped farm salmon.

9. Require escaped salmon estimates to be reported widely.

The government agency responsible for maintaining escaped salmon records, such as MAFF, should distribute information about escaped salmon on request.

10. Conduct experiments to distinguish whether chronic net pen losses are due to escape rather than undocumented mortality.

A single experiment of this type was conducted in Puget Sound during the early 1970s (Moring, 1989). This experiment should be repeated in B.C. so that chronic escapes or "leakage" can be estimated.

11. Establish and enforce a numerical standard for escaped salmon.

A performance-based standard should be established respecting the numbers of "permitted" escaped salmon. A three-year running average of 15,000 Atlantic salmon, 3,000 chinook salmon and 1,000 coho salmon per year for all of B.C. is suggested as a preliminary standard, pending availability of information which justifies a different standard. This escape limit refers to salmon having an average weight of 1 kg or more. Escape history of each farm and effort to minimize escapes should be considered during re-evaluation of farm tenures/licences (at their time of renewal). Further, a significant penalty should be applied against farms that are proven to fail to report or under-report escaped salmon.

12. Prohibit the farming of transgenic salmon except in closed, land-based systems.

Rearing of transgenic salmon should be prohibited except in closed, land-based systems. The DFO policy on transgenic salmon should be followed.

13. Conduct research into salmon imprinting.

Experiments should be conducted in imprinting with chemicals (such as morpholine) in the hope that artificial chemical cues may be used to attract escaped salmon to a specific site. This approach may lead to greater recovery of escaped salmon.

14. Prohibit salmon farming in freshwater lakes having important indigenous populations.

Farmed salmon should not be reared in lakes where the goal is to preserve indigenous populations. Numbers of escaped farm salmon in lakes can outnumber indigenous fish populations and may adversely impact these land-locked populations. Colonization of land-locked Atlantic salmon is viewed to be more likely than anadromous forms, assuming both sexes are farmed. Lakes supporting farmed salmon operations should use best available

technology to minimize escaped salmon. Outlet streams should be monitored for emigrating farmed salmon smolts.

Rationale and Priority of Key Recommendations Involving Escaped Salmon

Highest priority should be placed on minimizing or eliminating, if possible, escapes from salmon farms. Improved management and regular inspection of cages, including use of prop guards on farm vessels, high quality net materials, predator nets, etc., are some approaches that might reduce escaped salmon. Recovery plans for escaped salmon could reduce potential interactions with wild salmon, if they are implemented quickly and properly.

We recommend that salmon farms in B.C. continue to farm primarily Atlantic salmon rather than switching back to Pacific salmon. As discussed in the report, we view the risk to wild salmon populations in B.C. to be greater from farmed Pacific salmon compared to Atlantic salmon. This view is based on the greater likelihood of adverse genetic effects of interbreeding farm and wild Pacific salmon compared to successful colonization of Atlantic salmon and subsequent competition with Pacific salmon. Importantly, colonization by Atlantic salmon can be controlled by use of all-female Atlantic salmon, although some research is still needed before this technique can be applied on a commercial scale. Production of all-female Atlantic salmon using the technique under investigation by DFO would greatly reduce potential reproduction because 100% of the fish are female (E. Donaldson, retired DFO, pers. comm.). In contrast, viable sterilization techniques for Pacific salmon are not likely to succeed in farms because fish performance appears to be reduced and because sterilization may not be 100%. Furthermore, the recommendation involving all-female Atlantic salmon is based, in part, on fish health recommendations that would reduce the risk of exotic disease caused by importation of Atlantic salmon eggs (see Fish Health section). The fish health recommendations, if implemented, would likely reduce egg importations in addition to providing enhanced mechanisms to identify and control a disease outbreak before it could be transferred to wild salmon.

Production of all-female Atlantic salmon may not eliminate potential redd superimposition, behavioral interactions on spawning grounds or predation on juvenile salmon in marine waters. However, at current levels of observed escaped salmon in B.C. we do not expect adverse effects to be caused by all-female Atlantic salmon on the spawning grounds or in marine waters. These topics are covered in the discussion paper.

Minimizing or eliminating escaped Pacific salmon is a high priority, especially given the potential for successful interbreeding with wild chinook and coho stocks and the weak status of many salmon stocks in B.C.. However, in order to minimize potential genetic effects of escaped Pacific salmon we have recommended that a broodstock plan be developed for farmed Pacific salmon. Various approaches to the broodstock plan should be discussed by DFO, MAFF, MELP, and salmon farmers. The approach that we favour is one that minimizes or eliminates potential gene flow by selectively breeding farm salmon for spawning periods that minimize overlap with most wild salmon stocks. This approach might require initial use of broodstock from wild stocks having unique spawn timing. The feasibility of this approach needs to be evaluated.

The proposed recommendations are intended to address the key issues of potential colonization by Atlantic salmon and genetic effects by farmed Pacific salmon in a number of ways. If some of the key recommendations can be successfully implemented, then the need for some of the other recommendations may not be needed. For example, if numbers of escaped salmon can be significantly reduced through improved technology and greater precautionary measures, then the need for all-female production of Atlantic salmon, development of a broodstock program for farmed Pacific salmon, marking of farmed Pacific salmon, etc. would be reduced. Similarly, recommendations related to escaped Pacific salmon would not be needed if production of farmed Pacific salmon was significantly reduced or annual escapes were minimal. However, accurate monitoring of escaped salmon would be needed in order to justify decisions to eliminate certain recommendations.

B. Fish Health

As a general recommendation, provincial and federal health agencies should amend their regulations, guidelines and procedures towards a proactive policy of disease prevention—one which further reduces the risk of transmission of parasites/pathogens from farmed to wild stocks; improves upon the ability to detect and respond to fish diseases; minimizes the use of drugs in salmon farming; and generally makes health regulations for salmon farming equivalent to those in place for other animal husbandry sectors. To this end, the following specific recommendations should be acted upon.

1. Clarify and rationalize institutional structures and roles respecting fish health.

(a) The Ministries of Agriculture, Fisheries and Food (MAFF) and Environment Lands and Parks (MELP) should develop a clear understanding of the role of each ministry in marine and fish health issues in order to facilitate the development of comprehensive, complementary, and compatible fish disease prevention, control and surveillance programs.

(b) The federal government should be encouraged to review the implications of the creation of the new Canadian Food Inspection Industry, and reassess the role of the DFO and Agriculture and Agri-Food Canada in managing farmed fish health issues.

2. Develop enforceable standards of practice for managing farmed salmon health, as a condition of the salmon aquaculture licence.

The federal and provincial governments should provide technical and logistical support for the development of standards of practice for health management and disease prevention for farmed salmon. The standards should include:

- disease prevention and management protocols,
- minimum health record requirements,
- outbreak management protocols,
- drug use standards, and

- **disease reporting requirements (see recommendation 5(e) below for details).**

The standards should be reviewed regularly and updated to ensure they evolve to meet changing scientific knowledge and political and public priorities. These standards will further minimize existing risks and prevent potential future risks.

3. Develop voluntary fish health management and quality assurance programs to enhance health and productivity.

The provincial government should develop a voluntary 'High Health Accreditation' program for farms and hatcheries where participating farms receive accreditation if they consistently satisfy established performance criteria. The criteria should address:

- specific health promotion programs,
- integrated disease management protocols intended to reduce reliance on chemical therapy, and

- **growth and productivity goals.**

Participating farms should be required to annually provide data to MAFF to maintain their accreditation. This data should be subject to audit by the ministry. The province should consider existing models for swine and poultry as a basis for an accreditation program.

4. Expand the application of existing regulatory tools.

The federal government should utilize the Health of Animals Act to regulate and control diseases of farmed salmon at a national level, particularly when disease issues have implications for international trade, public health or Crown resources. To make this feasible, the federal government should provide additional fish health field and technical support to

deliver and enforce policies and programs derived from the Health of Animals Act, particularly those relating to surveillance for and response to reports of exotic diseases, and food safety concerns. This may include accreditation programs for veterinarians which provide training in disease management and regulations. As in terrestrial agriculture, accredited veterinarians could deliver government fish health programs to industry, thus reducing demands on government.

5. Strengthen disease control and surveillance programs.

(a) The provincial and federal government should couple the development of disease control and disease surveillance programs so that the results of surveillance can be readily used to reduce disease risks. Specifically:

- **the provincial fish health program should examine existing disease surveillance and control programs in use for other food producing industries, as templates for similar programs for salmon aquaculture, and**

- **the provincial and federal government should provide sufficient training and resources to existing and additional fish health personnel so that results of surveillance can be evaluated and acted upon in a timely fashion, and necessary disease management programs effectively implemented.**

(b) Additional personnel should be dedicated to supporting the Fish Health Veterinarian to allow for effective design, implementation and auditing of disease control and surveillance programs.

(c) The Animal Health Centre should expand its involvement in fish diagnostics to provide the complete spectrum of diagnostic services needed to support the Fish Health Veterinarian. At a minimum this would require the creation of a provincial fish pathologist position to provide services to industry and government commercial aquaculture programs, as well as to support provincial enhancement programs.

(d) The provincial government should continue its plan to design and implement a fish disease prevention and surveillance program as part of its Salmon Action Plan. As part of this, the following actions should be undertaken:

- **Explicit surveillance objectives should be established. These would identify the problems or questions that the results of surveillance programs are intended to address, identify how surveillance data will be assessed and used, and determine the jurisdictional responsibilities for collecting and acting upon surveillance data.**

- **A consensus conference of federal and provincial agencies involved in regulating the industry, industry and the public should be held to identify shared fish health goals, to outline the objectives of surveillance programs needed to address those goals, and to assign responsibility and jurisdiction for collecting, summarizing and disseminating the information needed to reach those objectives**

- **DFO should expand existing programs examining interactions of wild and farmed fish to include an evaluation of the potential that various wild species have for exposure to pathogens or parasites of farmed fish origin in order to identify priority and or sentinel species for surveillance.**

- **Information from disease screening programs from federal and provincial enhancement programs should be combined with results of surveys of commercially raised fish into a unified fish health database so that disease threats to wild stocks can be more completely assessed.**

- **Processing plant inspections of slaughtered fish should mirror federal inspection programs applied to other food producing species so that ongoing surveillance of diseases of special concern can be conducted.**

- **Existing fish health agencies should solicit input and expertise from other government agencies, particularly Agriculture Canada and/or the proposed new federal food agency, and academia, in order to increase their capacity to design sampling strategies for surveillance programs.**

(e) An initial active surveillance program should be undertaken to identify the distribution and relative frequency of existing disease, pathogens and parasites in commercial and enhanced stocks as well as to identify populations at risks. An active surveillance program must precede the implementation of a passive surveillance program, so that the scope and priority of health risks can be determined. This will allow for proper allocation of surveillance resources. After establishing a baseline disease database, the province should continue periodic active disease surveys in order to update and reassess disease priorities.

Farms should be required to seek a diagnosis from a recognized laboratory when the daily mortality rate is threefold larger than the mean daily mortality rate for the previous month. This threshold is proposed as an interim measure until active surveillance identifies the specific diseases to be placed under routine passive surveillance and those that should become reportable as a condition of the licence. The results of laboratory investigations should be reported to the Chief Veterinarian, who should provide annual regional summaries of these reports. Regions used for reporting purposes should reflect the regional aggregation of the industry.

(f) MAFF should support active surveys of causes of morbidity and mortality of farmed fish throughout their life-cycle by a program of farm-level disease surveys as well as assess sub-clinical diseases through methods such as review of broodstock and smolt screening programs or slaughter checks.

(g) The provincial government should expand its capacity to diagnose fish diseases as well as to provide professional and technical fish health staff needed to generate active surveillance data and validate industry generated information.

(h) The Animal Disease Control Act and Regulations should be amended to accommodate any fish disease reporting requirements identified.

6. Improve requirements for fish disease reporting.

(a) The federal government should recognize all fish diseases, pathogens or parasites that are foreign to Canada as reportable, regardless of the importation status of the fish from which the diagnosis was made. In this regard:

- **DFO should be encouraged to adapt existing foreign disease policies and programs for terrestrial species for exotic fish disease surveillance and response.**

- **provincial and federal fish health agencies should provide staff training in risk assessment and disease outbreak investigations, or similar expertise should be accessed from other agencies or academia so as to broaden the capacity to investigate and manage reports of previously unrecognized or foreign diseases.**

- **requirements to monitor and report the health status of imported fish should include and be extended to the period of time after which the fish have been released from quarantine and isolation and enter sea water. The frequency and nature of sampling required should be based on importation risk assessments and the results of surveillance during quarantine and isolation.**

- **reporting requirements for foreign diseases, pathogens and parasites must include fish that have not been imported, and must also apply to non-commercial forms of fish culture.**

(b) In recognition of differing patterns of fish disease found in different Canadian waters, regional reporting requirements should also be considered where preventing the introduction and spread of specific diseases from one region of Canada to another has ecological or economic advantage.

(c) Fish diseases, pathogens or parasites previously unrecognized in B.C. or in its coastal waters should be reported to an expert scientific committee. The purpose of this committee would be to provide timely evaluation of the significance of a newly recognized problem and to develop an appropriate risk reduction response. Members of this committee should have knowledge of fish disease, risk assessment and disease control.

Requirements to report to the expert scientific committee should include commercially reared salmonids, federally and provincially reared fish for enhancement programs, wild fish, and non-salmonid species.

The federal and provincial governments should clarify responsibilities for fish diseases so that it is clear who will receive, interpret and investigate reports to the committee.

7. Improve the quality of, and access to, fish health databases.

(a) The provincial government should develop a comprehensive fish health database in which the results of pathological, microbiological, toxicological and other laboratory tests are stored with and linked to results of field investigations or other diagnostic work conducted by the province's Fish Health Veterinarian.

(b) Fish health data generated through the activities of the Fish Health Veterinarian should be incorporated into the existing diagnostic database of the Animal Health Centre to facilitate rapid and regular evaluation of trends in fish diseases, as well as to locate in a single database all aquaculture health data generated by the province.

(c) A provincial fin-fish aquaculture disease database should be compatible with fish health databases for provincial and federal salmonid enhancement programs.

8. Strengthen regulations, policies and programs respecting disease testing, fish and egg importation, and fish transfer.

(a) Disease prevention and avoidance regulations and policies should utilize risk assessment and management methods analogous to those applied to terrestrial species. The methods should be standardized and explicit so that fish health risks can be evaluated rigorously and consistently.

(b) DFO should be encouraged to recruit additional support in health risk assessment and management to supplement existing fish health programs and to implement recommended changes to existing policies.

(c) The Federal Fish Health Protection Regulations should be modified to improve the consistency of their application, the quality control of testing and sampling, and their capacity to identify and mitigate risks. If this is not undertaken, provincial agencies with policies using the Federal Fish Health Protection Regulations should develop new protocols intended to address the deficiencies of the Federal Fish Health Protection Regulations. The following are key areas for regulatory and policy improvement:

- **recommended diagnostic tests and procedures must be assessed for their clinical performance. Standards for laboratory practices and quality control must be clearly defined. Once the most effective testing protocols are identified, procedures for their use and interpretation should be standardized and not left to the discretion of Local Fish Health Officers.**

- **requirements for the frequency and number of imported fish sampled per imported group should be based on a case-by-case assessment of risk the imported fish represent and should consider factors such as the population size, disease status of fish in the country of origin, movement of fish, medical record through quarantine and isolation, degree of group mixing and interaction, and viability of wild stocks in receiving waters.**

- **in addition to current information required for import requests, importation decisions should be based on a broader risk assessment that should consider:**

  - **the rationale, intended use and benefits of imported stocks (salmonid and non-salmonid),**

  - **the importer's plans and capacity to reduce risks and respond to any detection of foreign or named diseases in imported stocks,**

  - **information regarding the fish disease status of the region or zone in which the imported fish will eventually reside, and**

  - **information regarding the viability or vulnerability of sensitive or commercially important marine or aquatic species that can come into contact with imported fish throughout their life-cycle.**

These requirements should also apply to fish involved in enhancement and stocking programs.

(d) Regional policies should maintain a surface-disinfected egg-only policy for imported salmon which guarantees eggs have been disinfected upon and/or before entry to Canada. All relevant federal and provincial departments must develop shared criteria for assessing risks associated with egg imports. This should include establishing maximum numbers of eggs imported per region per year, and establishing clear criteria for how to consider risks and benefits.

(e) The Federal-Provincial Fish Transplant Committee should clearly define specified health indices that must be met before fish can be considered for transfer and more explicitly detail the information that is required to establish the health status of fish. Each salmon farming company must make historical health records and diagnostic results supporting claims of fish health available for the committee's review upon request. These historical records should be used not only as a means of enforcing fish transfer regulations, but also as a source of historical fish health information.

(f) The Federal-Provincial Fish Transplant Committee should outline the pre-transfer screening procedures required, and identify the quality control standards required by facilities performing those procedures. This may include the implementation of laboratory accreditation program which would set standards for diagnosis and screening and thus ensure a minimum level of quality of diagnostic and screening data. The province should consider expanding the Veterinary Laboratory Act to include laboratories that do not provide a diagnosis, but do provide data that supports diagnostic or disease control efforts, as this would allow the Chief Veterinarian to specify quality control standards and access aggregated disease data.

(g) The Federal-Provincial Fish Transplant Committee should be provided additional resources for auditing and validating industry claims of fish health prior to fish movement. This may be accomplished in part through a supporting accredited veterinarian program.

9. Enhance fish health inspection practices at fish processing facilities.

Food safety programs for salmon should be analogous to those applied to other food producing sectors with respect to surveillance, response and management. In this respect:

(a) Post-slaughter fish inspection programs should be expanded so as to more completely address public concerns regarding the safety of commercially reared farmed salmon.

(b) The proportion of fish slaughtered each year subjected to post-slaughter inspection for drug residues should be increased so that errors associated with estimates of the proportion of samples that are positive is reduced.

(c) Drug treatment records that accompany processed fish should be regularly reviewed and the results summarized so that trends in drug use can be recognized and drug residue sampling programs modified accordingly.

(d) Fish should be examined at slaughter for signs of reportable diseases, diseases of significance for trade, and diseases that may be deemed of public health or ecological significance.

(e) The Ministry of Health (MoH) should periodically review post-slaughter inspection reports in order to evaluate if new public health risks associated with fish diseases or their management have occurred. The MoH should strengthen their working relationship with the MAFF so that disease prevention and management programs address the mandates of both ministries.

10. Minimize the probability of human exposure to drugs and pesticides used at salmon farms.

As chemotherapeutants and pesticides used in salmon farming can enter public waters or marine and aquatic food chains, special precautions should be taken to reduce the probability of human exposure. Specifically:

(a) Industry must make reasonable efforts to inform members of the public when drugs capable of entering wild seafood are being used. In particular, public notifications should be required when fish

escape during a period of treatment or before the prescribed drug withdrawal period has passed. In addition, where local residents utilize nearby wild marine species as a food source, visible indicators that drugs are being used should be required to be placed on treated sites for the period of treatment and drug withdrawal, and notice of the specific drug used should be required to be posted on-site.

(b) Waste discharge models used for future siting decisions should incorporate drug deposition models, information of pathogen survival, duration of biological activity of drugs and other bio-medical indicators pertinent to health risk when establishing minimum distances of marine cages (and lake cages where applicable) from other marine and aquatic food resources or from sensitive habitats.

(c) All drugs used in salmon aquaculture should be administered under veterinary prescription.

(d) The provincial government should sponsor continuing education workshops for veterinarians on the environmental fate and effects of new drugs, as well as on principles of ecotoxicology. The British Columbia Veterinary Medical Association should recognize these workshops as meeting their requirements for professional continuing education.

(e) The provincial government should develop a database of environmental fate and effects information for drugs available for use in salmon farming in B.C. as a resource for veterinarians prescribing products to the industry or enhancement facilities.

(f) The federal and provincial governments and industry should support training and education of undergraduate and graduate veterinary programs involving aquaculture.

(g) DFO should recruit and retain veterinary expertise that can be used to help assess risks to marine resources arising from drug use, to followup on reports of drug residues in fish products, and to develop disease reduction programs which are intended to reduce drug use by the salmon farming industry.

(h) Licensed drug dispensers should be educated regarding the environmental fate of drugs so as to provide appropriate application instructions.

(i) The provincial government should improve its ability to regularly evaluate changing patterns of drug use in the aquaculture industry by reviewing feed prescriptions and medicated feed records as well as federal reports of post-slaughter evaluations of drug treatment records. This information should be shared with DFO and the Bureau of Veterinary Drugs in order to assist in post-slaughter drug residue surveillance.

C. Waste Discharges

In the following section on waste discharges, criteria and standards were set up based on the scientific information available for this review. We recognize that there are gaps in information specifically from B.C. Therefore, the following standards are considered interim only, and are designed to be precautionary in nature. Confirmation, revision or replacement for these standards is expected in the near future as data is available from assessment of

environmental parameters at existing farms (see 3 and 6 below) and improvement of the MAFF model for farm discharges (see 5 below).

1. Establish enforceable performance standards for benthic and water quality conditions in and around fish farms.

(a) Enforceable, impact standards should be established for key benthic and water quality conditions. These standards should apply to all existing and new fish farms throughout the production cycle, regardless of the technology in use on the farm. The standards are aimed at preventing the development of anoxia, but allowing mild enrichment or impact such that sediments will not progressively degrade towards anoxia. In other words, low impacts are expected directly under cages, with minor reductions in community richness and abundance and some extra sedimentation, but within the ability of the benthos to assimilate the organic input on a continuing basis. The following standards are conservative, and are designed to provide a sustainable industry at any level of expansion.

Recommended standards apply to sediments which are not naturally anoxic, as follows:

- redox in surface sediment at <2 cm depth >0 mV throughout the area
- sediment total sulfides (S= <300 mM)

- abundance of Capitella capitala or any other dominant species (< 20% of total abundance)
- total organic carbon (< 4%)
- white ‘matting’ (matting should not exceed 2% of the area beneath cages, based on visual survey)
- water column turbidity in and around cages (to be developed through research—see recommendation 5 below)

- **zinc and copper (B.C. Water Quality Objectives for water and sediments).**

(b) Individual salmon farms should be required to comply with approved benthic and water quality standards within their tenure boundaries. The standards should be identified in licensing documents as an explicit performance requirement.

(c) Where farms exceed approved benthic or water column standards (based on monitoring results—see recommendation 6 below), they should be subject to one or more of the following remediative or consequential actions on a time-sensitive basis, such as upon renewal of tenure (or other time-frame, as appropriate). Emphasis should be placed on remediating the sites with the worst discharge impacts first. If an existing farm is not exceeding the impact standards in 1(a) above or visual surveys indicate that impact is low below the net cages (lots of burrowing and epifauna and no white matting) over the entire production cycle, no remediation is required.

- reduction in approved fish production level to meet sediment carbon loading standards (see 2c below)
- site expansion to facilitate fallowing
- re-orientation or re-configuration of cages on the site
- requirement to amend certain husbandry practices
- farm relocation
- tenure cancellation

- **fine.**

2. Establish siting criteria that prevent or mitigate waste discharge impacts.

(a) Given current technology, farms should be located in accordance with the following suggested siting criteria, in order to minimize waste discharge impacts:

- siting at locations with currents not predominantly onshore
- average surface currents > 10 cm/second; average currents at bottom of nets (about 15 m) >5 cm/second; average currents 1m above bottom at deepest point under cages >3 cm/second (measurements over at least one tidal cycle)
- no salmon farms in areas of heavy natural deposition or natural oxygen depletion
- water depth >30m with bottom sloping offshore

- **avoid biotically sensitive resources (eel grass, kelp beds, shellfish beds, bottom fish spawning areas, estuarine mud flats, sand or gravel beaches, etc.—see Salmon Farm Siting recommendation 1).**

(b) In addition, the following guidelines should be observed when assessing new site applications. These standards may become redundant as new technology is in place:

Based on current technology in use in B.C.

- site farms outside isolated bays to avoid shoreline effects and conflicts with other users

- **silt/clay content should be a mean of <70% naturally beneath cages to avoid depositional areas.**

(c) Production limits for newly sited farms should be set which will prevent the development of waste discharge impacts. The production limits for salmon farms should be established in the production plan for the site and be enforceable as part of the aquaculture licence. Production limits should be aimed at preventing carbon settlement to the benthos in excess of 4 g C/m2 per day or 1.5 kg/m2 per year. This level may be subject to modification based on improved predictions from the MAFF discharge model and the analysis of monitoring data on a site-by site basis (see 3 and 6 below). If a new farm with such production limits can be shown to have less impact than indicated in 1(a) above, then consideration should be given to increasing the production limit on an incremental basis based on impact performance.

(d) Proponents should be required to collect site-level information on the approved siting criteria, as a primary basis for government siting decisions.

3. Assess existing farms for compliance with approved standards within one year.

(a) This process should have priority over granting new sites, to allow decisions about remediation of existing sites to occur. Evaluations should be based on monitoring data collected to date, and additional information to be obtained where necessary. Where existing farms fail to meet approved standards and criteria, steps should be taken (as per recommendation 1(c) above) to correct the situation. Priority should be given to those sites which are known to be impacting sediments, or those with other conflicts outstanding.

(b) Government and industry should share the costs of conducting this assessment of existing salmon farms. Existing farm operators should be responsible for providing government with the necessary information on their level of conformance with approved impact standards (1a above), and for undertaking the necessary remediation actions. Government's role should be to audit information provided by industry, and approve remediation actions. Costs of remediation should be jointly handled between government and industry. For major remediation measures, a reasonable timeframe should be provided.

(c) At farms where it may be appropriate to increase production because impacts are less than the limits noted as per 1(a) above, licence (development plan) amendment proposals should be subject to a complete inter-agency review of the proposal to assess the full range of implications.

4. Develop a "code of practices" to prevent and mitigate waste impacts.

Government and industry should jointly complete the development of a "code of practices" for salmon aquaculture operations which include provisions aimed at preventing and mitigating waste discharge impacts, including:

- feeding practices (timing in relation to tides; monitoring of waste feed, feeding times for drug application)

- net orientation relative to currents should be optimum for husbandry and waste dispersal to mean current flow
- marine net cleaning practices (should be restricted to periods of offshore current flows; preferably in winter months)
- garbage and mort management/disposal procedures
- site cleanup/dismantling

- **drug and chemical application and usage.**

5. Undertake focused research projects to fill key information gaps respecting waste discharge issues.

(a) The MAFF discharge and siting model should be improved as a basis for siting and licensing decision-making by incorporating total water column currents (at least one tidal cycle), general bottom topography, distribution and timing of drug usage, and performance criteria (see recommendation 1 above).

(b) To ground-truth and improve the MAFF siting and discharge model, a study should be undertaken of sediment carbon and particle accumulation relative to feed usage, currents, etc., for a full salmon production cycle and during the fallowing period at a set of representative farms in B.C. Appropriate technology should be used for these studies.

(c) Water column turbidity around farms and modelling of dispersion of suspended particles should be studied relative to current patterns and farm production, as a basis for establishing an ambient turbidity standard for salmon farms.

(d) Research should be undertaken to assess the viability and safety of bivalves at beaches near existing farms where shoreline deposition effects from farms are in question, and in relation to antibiotic usage.

(e) In efforts to assess regional carrying capacities, studies of regional (basin level) flushing capacities for oxygen and ammonia and phosphorus should be undertaken for selected areas where deep water exchange is unknown and may be limited (e.g., Clayoquot Sound). Also, potential cumulative effects on sediments should be considered.

6. Establish more rigorous, systematic and accountable waste discharge monitoring systems and procedures.

(a) Salmon farms should be required to monitor benthic and water quality conditions relative to the approved performance standards (see recommendation 1 above) and information required by regulators to judge effects on the environment. Monitoring should therefore assess:

- sedimentation rates
- sediment eH, sulfides
- total abundance and taxa number under cages and at suitable reference location
- percent abundance of dominant species
- sediment and water column zinc and copper

- sediment total organic carbon

- extent of bacterial matting showing anoxia
- water column turbidity downstream of cages.

(b) Monitoring frequency requirements should be based on adherence to standards. Minimum monitoring requirements should include sampling at the time of heaviest and longest term usage of a site each cycle. It should also include monitoring at the time a new cycle is begun on site. Additional monitoring requirements for non-compliant or problematic sites should be determined at the discretion of the regulating agency. For farms with a proven record of standards compliance and no changes in production, monitoring can be reduced to a core suite of factors known to be correlated to acceptable benthic effects at the site in question (such as eH, sulfides, TOC, visual surveys).

(c) Salmon farmers should be required to input their monitoring results into a standardized database spreadsheet in a format suitable for incorporation into the MAFF siting and discharge model.

(d) One agency should be assigned responsibility to receive salmon farmers' monitoring data and to incorporate it into a centralized monitoring database. Detailed site specific reports should be produced for ministries and interested parties on an as-needed basis, and annual summary reports on monitoring results and trends should be produced for agencies and the public.

(e) Trained, third party observers should be used to attend monitoring and to collect data to ensure consistency and quality control. Government and industry should cost-share development and maintenance of this program.

(f) Industry monitoring results should be subject to audit by government.

7. Experiment with integrated, multi-species aquaculture operations at salmon farming sites.

Pilot projects should be undertaken to establish the feasibility and appropriateness of culturing shellfish and seaweed in combination with salmon aquaculture. This could help reduce nutrient loading to sediments and contribute to ecological sustainability.

8. Evaluate operations in freshwater habitats

(a) No new lakes should be permitted for smolt cage culture until specific lakes under consideration have been thoroughly evaluated to predict hypernutrification effects.

(b) Consideration should be given to the concept of using "waste" lakes such as the ICM pit at Port Hardy for smolt culture since they have bottomless "sinks" to absorb nutrients and prevent turnover and resuspension of waste nutrients from sediments to the water column.

(c) Water quality criteria (particularly for phosphorus) should be developed for dissolved waste discharges from lake cage operations (based on feed and FCR ratios). These are currently in place for hatchery discharges and some models are available for predicting outputs.

Note: Also, see Fish Health recommendations respecting proposals for minimizing drug and pesticide discharges, and Salmon Farm Siting recommendations regarding siting criteria.

D. AQUATIC MAMMALS AND OTHER SPECIES

1. Require all existing salmon farms to develop and implement a “predation control plan” within two years, and incorporate approved predation control plans into the aquaculture operating licence.

(a) Every salmon farm should be required to develop and implement a “predation control plan” that identifies the specific predator net systems or other physical barriers to predators that will be used at the farm site to prevent/minimize predator problems. Predation control plans should include measures sufficient to prevent predation problems from occurring in the first place. As it appears with pinnipeds, “experienced predators” are more difficult to deter.

(b) Predation control plans should form part of the aquaculture operating licence, and thus be enforceable. Government agencies should prepare a listing of best-available anti-predation net systems and other technologies, and appropriate husbandry guidelines, to assist operators in preparing appropriate plans.

(c) Predation control plans should be developed and in force at all salmon farms in B.C. within a two year period.

2. Phase out the use of Acoustic Deterrent Devices (ADDs) at all intensive fish culture operations over two years.

(a) The use of all existing ADDs (i.e., sound generating devices which, because of some combination of intensity, frequency, or other characteristic(s), are aversive to aquatic mammals and keep or drive them away from an area or structure) should be phased out over a two-year period to coincide with the development of predation control plans at each salmon farm (see recommendation 1 above).

(b) No new ADDs should be authorized in B.C.

3. Strictly control the killing of predators at farm sites.

(a) Killing of predators (mammals and birds) at farm sites by farm staff should be permitted only if the predator is inside the predator nets or growing nets and is actively attacking fish stock or is about to do so.

(b) Where this occurs, only farm staff that have completed the provincial fire-arm safety course should be allowed to kill predators.

(c) Any predator kills must be recovered and recorded, and reported to the appropriate government staff (e.g., provincial conservation officer, or DFO fisheries officer, depending on species and associated management jurisdiction).

(d) Where a farm is having ongoing problems with persistent predators, operators should contact the local provincial conservation officer or DFO fisheries officer (as appropriate) who may, at their discretion, trap or kill individual predators, and who may require operators to make changes to their “predation control plan”.

(e) Government staff should keep records of all predator kills at farm sites and should summarize these data annually (by quarter), as a basis for monitoring the general effectiveness of predation control plans.

4. Locate fish farms at an appropriate distance from seal and sea lion haul out sites.

A siting guideline should be adopted which requires the location of seal and sea lion haul outs to be considered as a criterion in salmon aquaculture siting decisions (see Siting of Salmon Farms recommendation 1). This guideline should be applied to existing salmon farms at the time of their site tenure review.

5. Restrict the practice of "night lighting", pending the results of further research.

The practice of "night lighting" at fish culture operations (i.e., photo period manipulation to enhance fish growth) should be restricted to those existing farms that have been approved to conduct this activity. No new approvals should be issued. A final policy on "night lighting" should await the conclusions of additional scientific research into the effects of this practice on local biota.

E. Salmon Farm Siting

Recommendations for salmon farm siting are intended to guide farms to locations where they will have minimal effects on environmental resources and other coastal users while also meeting the needs of salmon farmers. The ideal management framework would involve integrated coastal plans identifying areas which are suitable and acceptable for salmon farms, and performance-based standards which would require farms to minimize impacts.

Unfortunately, neither of those options is available in the short term. The first areas on the coast which are to undergo planning are the Central Coast and Queen Charlotte Islands, and plans for those areas are not expected for at least two years. The use of performance-based standards requires defined measures of impacts and a strong monitoring system. Measures of impacts are available, but an appropriate monitoring system will take time to be developed.

The following recommendations are therefore provided within the context of current possibilities. Some of the recommendations may become redundant as coastal plans and monitoring systems are developed.

1. Require an assessment of all proposed salmon farm sites.

a) An assessment of all proposed salmon farm sites should be conducted to determine the resources and uses which could be affected by farms, and the potential impacts of farms on environmental resources and human populations and user groups. The assessment should be conducted by the proponent, unless government becomes involved in pre-selection of appropriate sites. The information should be assembled and the assessment should be conducted by qualified individuals.

(b) As part of the assessment, salmon farming proponents should be required to submit information on environmental resources and human use in the area surrounding the proposed site. Information should be required from the following three sources:

> **(i) resource inventory information collected by government, e.g. mapping of fish and wildlife habitat, recreation resources and use, and commercial use (see recommendation 7), and use and interest mapping, e.g. Coastal Resource Interests Studies, tourism resource inventories;**

(ii) information derived from site inspections, including upland and dive surveys; and

(iii) local consultation.

Human uses and anadromous salmon streams should be mapped 100 m upland and 3 km in all other directions from the proposed site. All other environmental resources should be mapped 100 m upland and 1 km in all other directions from the proposed site. Dive surveys should extend a minimum of 30 m in all directions from the outer boundary of the tenure. Resource values, uses, and current patterns should be mapped at a scale of 1:5,000 or larger. The information must include the siting criteria (see recommendation 3).

2. Require an assessment of all existing salmon farm sites.

(a) An assessment of all existing salmon farm sites should be required to determine the resources and uses which could be affected by farms, and the impacts of farms on environmental resources and human populations and user groups. The information should be assembled and the assessment should be conducted by qualified individuals.

(b) As part of the assessment, salmon farming proponents should be required to submit information on environmental resources and human use in the area surrounding the site. Information should be required from the following three sources:

(i) resource inventory information collected by government, e.g. mapping of fish and wildlife habitat, recreation use, and commercial use (see recommendation 7); and use and interest mapping, e.g. Coastal Resource Interests Studies, tourism resource inventories;

(ii) monitoring information derived from site inspections, including upland and dive surveys; and

(iii) local consultation, including comments from the public to government agencies regarding the farm.

Human uses and anadromous salmon streams should be mapped 100 m upland and 3 km in all other directions from the proposed site. All other environmental resources should be mapped 100 m upland and 1 km in all other directions from the proposed site. Dive surveys should extend a minimum of 30 m in all directions from the outer boundary of the tenure. Resource values, uses, and current patterns should be mapped at a scale of 1:5,000 or larger. The information must include the siting criteria (see recommendation 3).

(c) Existing salmon farms should be evaluated in terms of the degree to which they comply with the siting criteria (recommendation 3) and with the proposed waste discharge performance standards (see Waste Discharge recommendations 1-3), as a basis for identifying current problems arising from inappropriately sited salmon farms. The assessment and the waste discharge recommendations take precedence over meeting the siting criteria.

(d) Where existing farms are assessed by management agencies as causing undesirable impacts or conflicts, the development and implementation of remediation plans should be required, potentially involving steps to reduce salmon production at the site, expand the site boundaries to allow for fallowing,

amend farm husbandry practices, or relocate the farm to a more suitable site. If they are not causing undesirable impacts or conflicts, existing farms do not need to be relocated to comply with the siting criteria.

(e) The review of existing farms should begin immediately and be completed within one year. No production increases at existing farms should be allowed until this assessment is completed. Any relocations of existing salmon farms that may be necessary as a result of this review should occur before the granting of new sites in a regional district.

3. Revise and expand salmon farm siting criteria.

(a) Criteria for siting new salmon farms should be revised and expanded to minimize biophysical impacts and user conflicts, and to promote healthy and successful salmon production. The recommended criteria reflect requirements to:

(i) locate farms a specified distance from important biological or socio-cultural resource values and features;

(ii) locate farms at sites that have an inherently high capacity to assimilate and disperse salmon farm production wastes;

(iii) conform with approved land use/coastal resource plans, studies and zone designations; and

(iv) engage in consultation processes and fieldwork to acquire specific, local information on potential impacts and conflicts, and to identify ways to prevent or mitigate those impacts and conflicts.

The recommendation is to adopt minimum distance criteria as enforceable standards. This reflects TAT's judgement based on the best available information and the need to adopt a precautionary approach given uncertainties and risks. Site-specific assessments may require greater distances in some cases to avoid anticipated negative impacts.

Further monitoring and research respecting these criteria are recommended as a basis for either confirming or adjusting distance criteria.

In addition, as salmon farming technology and practices change and as comprehensive integrated coastal management plans are prepared that designate geographic areas of the coastal zone for various uses, the criteria should be amended, eliminated or replaced as appropriate.

(b) All of the recommended siting criteria are similarly important and should be applied consistently in making new salmon farm siting decisions. Government should adopt the appropriate mechanisms for ensuring that all criteria are implemented.

5. Establish local advisory "working committees" to enhance the referral system.

Local working committees, comprising government and non-government representatives, should be set up as a forum for providing advice on salmon aquaculture siting. Membership should include the primary agencies involved in siting salmon farms as well as First Nations and local representatives. Committees should have interaction with, but not members from, the salmon farming industry. Existing local committees which are involved with other planning processes should be used as a basis for forming the committees where appropriate, e.g. Advisory Planning Commissions, community associations, LRMP committees (see Institutional Framework recommendation 2). Other agencies and interest groups which are not members of the working committee should have the opportunity to comment on applications through referrals.

6. Improve the quality of coastal resource inventory mapping.

Government should continue to improve upon inventories and mapping of coastal resources (at map scales ranging from 1:250,000 to 1:20,000) as a key tool for coastal planning and salmon farm siting decision-making. The information should incorporate federal and provincial data bases, local and traditional knowledge, and mapping conducted by professionals which is submitted by industry. This information should be available to agencies and other interested parties at reasonable costs. Information should be assembled on the following resources:

Biophysical: Marine and terrestrial fish and wildlife habitat, including:

- **fish and wildlife concentration areas (e.g., seal and sea lion haul outs, bird concentrations, herring spawn areas, shellfish beaches, special salmon habitat such as nursery areas, upland mammal habitat such as bear concentration areas);**

- **salmon-bearing streams, classified to identify quantity of salmon runs, and historic runs where possible;**

- **intertidal habitats (e.g., estuaries, eel grass beds, mud flats);**

- **subtidal habitats (e.g., reefs, kelp beds); and**

- **habitats of red- or blue-listed species.**

Socio-cultural: Significant use areas and sites with special designations, including:

- **settlements, anchorages, recreation sites and routes, commercial/sport/Aboriginal fishing locations, log handling sites, wildlife viewing locations, scenic areas, traplines;**

- **archaeological/historical sites4;**

- **First Nations reserves and areas of use and spiritual importance; and**

- **existing and proposed parks, marine protected areas, and ecological reserves.**

7. Continue to improve upon biophysical capability models.

Government should continue to work towards development of effective mapping and evaluation systems for determining biophysical capability, regional carrying capacity and site-specific assimilative capacity, to be used in the process of making siting decisions. These are to take account of the latest farm technology.

8. Require reclamation plans as part of the aquaculture development plan.

A reclamation plan should be required and approved as part of the aquaculture Development Plan for existing and new salmon farms. The plan should identify steps involved in removal of all equipment and restoration of abandoned sites, plus a cost estimate for the reclamation. Farmers should be required to post a reclamation bond of an amount that is adequate to cover full costs of reclamation. (For existing farms, require an increase in the current bond if the estimated cost of reclamation is higher than the bond.) A post-reclamation inspection should be conducted to ensure that reclamation has occurred in accordance with the reclamation plan.

Measures should be taken to restore the condition of existing sites where reclamation has not occurred, particularly by removing equipment which is hazardous.

9. Develop and implement a combination of enforceable performance standards and voluntary codes of practice.

(a) Within one year, performance standards should be developed to minimize potential proximity effects (e.g., maximum day/night noise levels; maximum lighting levels; masking of all lights from the water, residences and recreation use areas; garbage containment, no unapproved alteration to the upland.) These standards should be enforced through inclusion in the aquaculture operating licence, with the consequence for non-compliance being lack of licence renewal.

(b) Within one year, a code of practice should be developed and widely publicized (e.g., through the B.C. Salmon Farmers Association) for impacts which are difficult to measure to further minimize proximity effects. The code should include guidelines respecting: equipment storage; odour control; minimization of air pollution from generators, boats, and other equipment, courtesy to the public in emergencies, etc.

10. Develop and implement an effective monitoring program.

An effective monitoring program should be developed and implemented to track conformance with performance standards and codes of practice, and to determine the impacts of farms on environmental resources and other coastal user groups. The information should be used as a basis for adjusting the standards and guidelines, promoting consistent implementation of them, and for refining the siting recommendations. Monitoring systems should involve the preparation and distribution of an annual summary of monitoring findings, a trained third-

party observer, and immediate notification of the appropriate government agencies and salmon farmers if problems are identified. The monitoring program should be coordinated with recommendation 6 in waste discharges.

11. Develop and implement visual design guidelines.

Visual design criteria for fish farm structures should be developed and used as guidelines in the process of developing and approving site plans. Some recommended criteria are:

- limit height of structures and cluster them in one part of the site;
- place structures on the side of the site closest to the shoreline;
- arrange structures to minimize visual exposure to important visual sightlines (e.g., at end of channel with significant boat traffic);

- *use colours, especially for above-water structures, that blend with the surroundings; and*

- **keep improvements on the site compact, i.e., covering the smallest area possible.**

12. Pursue new technology and practices to minimize resource impacts and user conflicts.

Research and development should be promoted by the industry and government into new technologies that reduce the potential for impacts on resources and user conflicts (e.g., siting in more exposed sites away from high use bays and channels, enclosed system technology to mitigate some conventional conflicts). Incentives should be used as appropriate.

F. Institutional Framework

The following institutional design recommendations are provided to ensure effective and efficient implementation of the preceding recommendations respecting the SAR technical issues.

1. Base the salmon aquaculture regulatory and management system on the principles of sustainability, with the aim of protecting the environment and fostering a sound economy and social well-being, and develop a strategic direction for salmon aquaculture in British Columbia.

(a) The provincial government should expressly state that the regulatory and management framework for managing salmon aquaculture is based on principles of sustainability aimed at protecting the environment and fostering a sound economy and social well-being, and adaptive management (for example, as reflected in government's "Sustainable Environment Charter" and "Provincial Land Use Charter").

(b) The provincial government should develop and adopt an overarching "strategic direction" for salmon aquaculture in British Columbia that is consistent with sustainability principles. This strategic direction should be consistent with the recommendations contained in this report, and should describe broad principles, goals, objectives and policies that provide guidance to coastal zone planning processes and constitute part of the province's corporate policy for salmon aquaculture.

2. Adopt a coordinated, integrated and participatory regulatory framework for salmon aquaculture.

(a) The provincial government should ensure that there is a coordinated and integrated regulatory framework that encourages the effective participation of all appropriate government (federal, provincial, local and First Nations) agencies involved in regulating and managing salmon aquaculture in B.C.

(b) The process used to solicit input into siting and licensing salmon aquaculture operations, including evaluation of proposals to substantially alter existing operations such as proposed production increases or tenure boundary increases greater than 35%, should be improved to better take into account the input from all interested parties in a transparent and timely manner, and should incorporate measures to gather relevant local knowledge.

(c) The provincial government should reestablish an ongoing advisory committee. It should comprise representatives of all key government and non-government interests, to advise agencies responsible for siting and licensing decisions, and to enable a forum for dialogue and information exchange among the range of interests. The Minister's Aquaculture Industry Advisory Council, established in 1987, is a model that can be built on.

(d) Local working committees should be formed to provide advice on siting and licensing proposals, and to enable a forum for dialogue and information exchange among the range of interests. These working groups should be balanced and inclusive in their membership. Existing "community resource boards" might supply this service where they are in place.

3. I mplement the regulatory and management system in a fair and consistent manner and enforce all regulatory requirements.

(a) The salmon aquaculture regulatory and management system, including all legal and policy requirements and corresponding roles and responsibilities, should be clearly documented and made accessible to all interested parties.

(b) Regulations, policies and procedures should be implemented and enforced in a neutral, fair, and timely manner.

(c) The provincial government should develop and implement an efficient and effective system for resolving disputes that arise in connection with the management of salmon aquaculture.

4. Strengthen monitoring and reporting responsibilities as a basis for proper management of salmon aquaculture.

(a) The provincial government should establish protocols and schedules to carry out the monitoring and inspections identified as being necessary to properly manage salmon aquaculture and should ensure adequate resources are available for monitoring and inspections..

(b) Improvements should be made to the systems used for salmon farm monitoring and reporting to government on a variety of issues (drug use, disease, waste, escapes, etc.) to ensure that all information is compiled in a standardized manner and can be quickly and effectively distributed to other interested parties in and out of government.

(c) The potential for developing a system of qualified third party observers to assist in monitoring functions at salmon farms should be investigated.

5. Implement cost recovery of salmon aquaculture management.

The provincial government should investigate avenues for ensuring that costs of regulating and managing the salmon aquaculture industry are shared by the industry.

6. Encourage the development of an enhanced role for First Nations in salmon aquaculture.

The provincial government and the salmon aquaculture industry should investigate and implement various ways to address First Nation concerns regarding enhancing First Nation economic opportunities (e.g., cooperative monitoring, escaped salmon recovery, incorporation

of local information into decision-making, joint venturing, etc.). (The role of the First Nations in the regulatory framework is noted above in 2(a)).

7. Develop a method for monitoring and reporting on implementation of salmon aquaculture management reforms.

The provincial government should develop and implement a procedure for monitoring and reporting publicly on the status of implementation of all recommendations adopted by the province following the Salmon Aquaculture Review.

8. Structure the salmon aquaculture management framework to encourage the adoption of technology that prevents environmental and ecological risks and multiple use conflicts and encourage development of value added high quality product.

(a) The management framework for salmon aquaculture should be structured to encourage the development of innovative technology that reduces or eliminates environmental and ecological risks and multiple use conflicts associated with salmon farming.

(b) The provincial government should encourage the production of salmon aquaculture products that are of the highest quality and should promote adding value to the resource wherever possible.

III. ATTACHMENT 1

Technical Advisory Team Members and Contributions to Salmon Aquaculture Review

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Co-author of discussion paper for Key Issue B:
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7. **Linda Nichol**
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SALMON AQUACULTURE REVIEW

ESCAPED FARM SALMON: ENVIRONMENTAL AND ECOLOGICAL CONCERNS

DISCUSSION PAPER

PART B

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EXECUTIVE SUMMARY

The use of marine cage culture of salmon grew rapidly following its commercial applications in Norway during the early 1970s. Cage culture of salmon in British Columbia (B.C.) is now several decades old and has, since its inception, gone through a series of changes designed to improve the economic state of the industry and respond to government and other interest groups' ecological and environmental concerns. Salmon farming is currently considered high-tech industrial aquaculture, globally producing over 500,000 mt annually.

B.C. cage culture extends from the Strait of Georgia to Bella Bella, including waters between Vancouver Island and the mainland and along Vancouver Island's west coast. About 121 tenures are reported, and somewhat over 85 operational farms, comprising between 10 and 30 cages/pens, operate throughout these waters. The marine farms are supported by 11 hatcheries and two freshwater lake pen-rearing areas for smolts. During 1995, 8.5 million smolts were reared and salmon production exceeded 20,000 mt. Most of the product is exported abroad.

In the course of marine and freshwater farming, smolts and adults are lost due to operator error, predation, storms, vandalism, etc. The Ministry of Agriculture, Fisheries and Food (MAFF) has required reporting of farm fish losses since 1991, but some records are available for earlier periods. Between 1987 and 1996, 62 major escapes from B.C. marine farms have been reported, of which 34 involved chinook salmon, 25 involved Atlantic salmon, two involved coho salmon, and one involved steelhead trout. In all, an estimated 1,078,368 farm salmon have been reported lost; this total is made up of 878,125 chinook salmon, 154,554 Atlantic salmon, 13,113 coho salmon, and 32,576 steelhead trout. These losses do not include "leakage" which, over time, could be substantial and in a worst case scenario double estimated escapes in recent years.

Several escapes from freshwater facilities have also been noted, including 7,000 pre-smolts into Morstrom Lake and 941 juvenile salmon into Lois Lake. In 1996, 40,000 young Atlantic salmon are estimated to have escaped from a pen in Georgie Lake. Sampling of escaped salmon in Lois and Georgie lakes indicated that previously unreported escapes may have occurred.

Extensive recoveries of Atlantic salmon have been reported since the onset of 1990. Between 1987 and 1996, 7,394 Atlantic salmon were reported taken in marine waters of B.C. Marine catches peaked in 1994 at 4,543 fish, but have declined to less than 1,000 fish per year in recent years. Recoveries in marine waters have also been reported in the State of Washington (2,363 fish) and Alaska (223 fish), even though farming of Atlantic salmon in Alaska is not allowed. In all, a total of 9,980 Atlantic salmon have been reported caught from Washington to Alaska. Widespread recoveries have also been noted in freshwater systems (718 since 1990), including rivers throughout the Vancouver Island area and Washington State. Reports, of course, only represent a portion of the total population of escaped Atlantic salmon inhabiting the region. No spawning of escaped Atlantic salmon has been documented in B.C. or Washington streams, but observations have been limited. Ripe Atlantic salmon have been observed in streams, but no juveniles produced as a result of spawning activities in the wild have been captured.

A variety of potential impacts may develop as a result of escapes from marine and fresh water commercial aquaculture, including (1) genetic dilution and alteration of the gene pool that leaves the wild stock less competitive in its own habitat, (2) hybridization between Atlantic and Pacific salmon, (3) colonization of Atlantic salmon, (4) predation on wild salmon by escaped farm salmon, (5) competition between farm and wild stocks for space and on spawning grounds, (6) interactions of wild salmon with genetically altered transgenic salmon, and (7) transmission of disease from farm to wild stocks. Factors to be considered in examining the risk involved with escaped salmon include the species of farm salmon that escape from the cages, the number and size of escaped salmon, their post-escape behavior and survival, and the population status and life history features of wild stocks impacted. This paper evaluates the risk of escaped salmon to wild salmon in each of the above impact categories, except (7) transmission of disease from farm to wild stocks. Transmission of disease from farm to wild salmon is addressed by the paper on Fish Health.

The population status of 5,448 salmon stocks in B.C. was recently evaluated. Of these stocks, 2% were classified as extinct, 11% as high risk, 1% as moderate risk, and 4% as special concern. These estimates are very sensitive to classification ranges and may change sharply with minimum changes in category criteria. For example, a recent re-analysis of the data for outer Vancouver Island indicated that stocks may be in worse condition than suggested in the initial study. Nevertheless, the initial stock status evaluation suggests concern for many stocks in B.C., a result that is generally unrelated to salmon farming. Georgia Strait had the highest number of known stocks in the extinction to special concern categories (212 stocks), followed by the west coast of Vancouver Island (144 stocks), and Johnstone Strait (108 stocks). The areas north of Vancouver Island, including the transboundary stocks, had 487 stocks falling in the extinct to special concern categories, while 97 stocks in the Fraser River fell in these categories.

The authors conclude that native salmon stocks closest to salmon farms are likely to be at higher risk then those stocks inhabiting areas located farther from large farms, although some escaped salmon are known to stray long distances. Escapes of larger, older salmon may disperse more than those that escape shortly after entering into saltwater cages. Spawning of escaped Pacific salmon with local stocks is highly probable, but effects are difficult to predict and depend on the level and duration (number of years) of interbreeding and on genetic characteristics of the interbreeding stocks. The effects of continued gene flow between farm and wild stocks are likely to reduce genetic diversity, but the consequences on fitness or productivity of wild populations are less predictable. It is concluded that the risk of genetic damage to wild stocks is potentially high if large numbers of farm Pacific salmon escape, as occurred in 1989 to 1991, and if successful interbreeding with wild conspecific stocks occurs over a number of years.

Hybridization between Atlantic and Pacific salmon and trout in B.C. streams was considered highly improbable because survival of crosses in ideal laboratory conditions was either nil or very low. The risk of interspecific hybridization in B.C. streams is judged to be very low.

We believe that colonization of anadromous Atlantic salmon in B.C. is unlikely (i.e., reproductive colonization), but we cannot rule out the possibility that with a continued population of Atlantic salmon maintained by escapes and low run levels of coho, chinook and other species in many B.C. river systems, colonization might occur. No long-term, self-sustaining anadromous Atlantic salmon runs have been established outside their native range, although many attempts have been made throughout the world, including B.C. and Washington State. Colonization of Atlantic salmon in land-locked lakes is more probable than colonization of anadromous Atlantic salmon.

The level of competition between cultured Atlantic and wild salmon stocks will depend on the number of escapes and whether or not colonization resulting from successful spawning occurs. At current levels of escaped salmon, the inter- and intraspecific competition between farm and wild stocks is not considered to be a threat to wild populations. At high levels of escaped salmon, localized competition could occur both in the marine and freshwater environments.

Predation of native stocks by salmon escaping from farms is unlikely to affect wild salmon populations in B.C.. Furthermore, predation by impounded farm fish on transient juveniles of wild stocks has been shown to be negligible. Ongoing studies have shown that escaped Atlantic salmon captured in marine waters feed less often then native salmon and no juvenile salmon have been observed in their stomachs. A recent study of predation of wild prey by caged salmon in B.C. suggests that farm salmon consume little wild prey and no salmon were consumed by the caged fish even though juvenile salmon were observed in the area. This result is consistent with the observation of relatively low feeding rates of escaped Atlantic salmon recaptured in marine waters. Night illumination lights did not influence predation by caged salmon on wild fishes.

We view the risk to wild salmon populations in B.C. to be greater from escaping Pacific salmon compared to escaping Atlantic salmon. This view is based on the greater likelihood of adverse genetic effects of interbreeding farm and wild Pacific salmon compared to successful colonization of Atlantic salmon and subsequent competition with Pacific salmon. Furthermore, colonization by Atlantic salmon can be controlled by use of all-female Atlantic salmon, as suggested in the TAT recommendations provided in a separate document. In contrast, sterilization techniques for Pacific salmon require considerable research before successful transfer of this technology can be made to salmon farms. Thus, switching from a predominance of Atlantic to Pacific salmon in B.C. net pen culture, as proposed by some members of the Review Committee, would likely increase risk to wild Pacific salmon stocks.

Transgenic salmon, which are genetically altered fish, are not raised in B.C. salmon farms. In spite of tremendous growth potential of transgenic salmon, both the British Columbia Salmon Farmers Association and the International Salmon Farmers Association have issued statements rejecting the use of transgenic salmon. Researchers of transgenic salmon have noted that transgenic salmon should be reared only in fully contained systems, even though the fish can be sterilized. The current draft policy of the Canadian Department of Fisheries and Oceans requires that transgenic organisms be sterile and that a detailed risk assessment be performed where there is a possibility of access to natural ecosystems. Because transgenic salmon can be developed with characteristics that may give them competitive advantages over wild fishes (tremendous growth rates, disease resistance, etc.), we recommend that transgenic salmon should not be allowed to rear in waters where there is possibility of access to natural ecosystems.

Current regulations regarding cage culture of salmon require reporting of escapes, but this reporting has generally involved relatively large catches. Escapes of small numbers of salmon from farms, which may be chronic, are not reported. Further, recapture of escapes is desirable and there does not appear to be a coordinated plan to make information available to First Nations bands or fishermen who might have the opportunity to recover lost fish. Regulations governing siting would not appear to offer much protection against potential genetic and ecological interactions between wild and farmed fish.

A number of recommendations are described in the TAT recommendations document as a means to control potential adverse effects of escaped salmon interactions with native salmon. Recommendations include farm siting and improved technology to minimize numbers of salmon escaping from net pens and the effects farm fish might have on salmon stocks, reproductive containment of Atlantic salmon to prevent risk of colonization, development of escaped salmon recovery plans, establishment of an information system to track salmon entering and leaving the farm, development of a broodstock program for Pacific salmon, continuation and expansion of the Atlantic Salmon Watch program, improved availability of escaped salmon information, experiments to determine whether chronic losses are due to escape rather than undocumented mortality, maintenance of tight controls on transgenic salmon, research into imprinting in order to enhance recovery of escaped salmon, and restrictions on rearing of farmed salmon in freshwater lakes.

I. INTRODUCTION

"Enclosure culture," a term encompassing cage and pen culture, is thought to be of comparatively recent origin (Ling 1977). Like many other forms of aquaculture, it is thought to have its beginning in Asia. Pantulu (1979) notes that the oldest records of cage culture come from Southeast Asia, where fishermen kept catfish and other commercial fish in bamboo or rattan cages and baskets. The fish were fed "kitchen scraps" and were found to grow rapidly. The farmer kept the fish until ready for market and then sold or bartered them for needed goods.

There is frequent confusion regarding the terms "cage culture" and "pen culture" in fish farming. Both terms are often used interchangeably in Canada and the U.S. (Novotny 1975, Saxton *et al*. 1983). Pen and cage culture are types of aquaculture which involve holding organisms captive within an enclosed space while maintaining a free exchange of water. The two methods, however, are considered distinct from one another. A cage is totally enclosed on all sides, or all sides except the top, whereas in pen culture the bottom of the enclosure is formed by the lake, river or seabed (Beveridge 1984).

Cage farming of salmon is a relatively new branch of an ancient form of animal husbandry. Salmon farming today is said to be "the outgrowth of trout culture, which developed in Denmark around 1890" (Heen *et al*. 1993). The farming of salmon progressed relatively slowly until the expansion of saltwater trout farming in the late 1960s and early 1970s. In 1965, A/S Mowi started rearing salmon in a closed-off part of the sea and salmon farming was underway. Floating pen (cage) culture is stated to have started on the Norwegian Island of Hitra (Edwards 1978), and the pioneering work of cage culture set the stage for today's greatly expanded industry. Since its introduction as a commercial venture in Norway, salmon cage culture has spread broadly over the Northern Hemisphere, including Iceland, the Faeroe and Shetland Islands, Canada, United States, and Japan and into several countries in the Southern Hemisphere.

Farmed salmon has increasingly become a major component of world salmon production, now constituting about one-third of the total salmon harvested (Figure 1). The rapid growth of salmon aquaculture is reported to be due to a number of factors, including the expanding recognition of the nutritional value of fish as a protein source, a stronger tendency to dine out, and the capacity to deliver a high quality, fresh, and competitively priced product on demand (Monahan 1993). In British Columbia, initial efforts to farm salmon began in the early 1970s, but major expansion was delayed until the mid-1980s. Production peaked in 1991 and has since plateaued at about 23,000 mt of processed product (Figure 2).

In the course of cage salmon farming, both young and adult salmon are known to escape to the surrounding environments. For example, several hundred thousand farm animals comprised of several species are reported to have escaped each year from B.C. farm cages during the years 1989 through 1991 (C. Backman, MAFF, pers. comm.). However, since the transition from growing Pacific salmon (largely chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) to Atlantic salmon (*Salmo salar*) in the early 1990s, the numbers reported lost annually have fallen substantially below 100,000. Losses occur largely as a result of operational errors, vandalism, predators and weather damage to the cages and during handling and transportation of the stock. The consequences of lost or escaped farm salmon in the B.C. coastal regions raise a variety of questions regarding their potential impacts on native salmon stocks and other species indigenous to the region.

This paper examines the observed and potential consequences of escaped farm salmon in the B.C. coastal regions in terms of genetic and/or ecological impacts on native salmon populations. The authors were particularly requested to:

1. Identify and assess the risk of adverse effects that escaped farm salmon may have on native fish and their spawning and rearing areas.
2. Evaluate the adequacy of current and proposed methods, processes, practices and procedures used to prevent and mitigate adverse effects of escaped farm salmon.

Figure 1. World production of salmon from wild salmon and salmon farms, 1973-1995.

Source: FAO Annual Statistics

Figure 2. Annual production of farmed salmon (mt) in British Columbia.
Sources: NMFS 1992, R. Hardy, Univ. of Idaho, pers. comm., DFO 1997.

3. Recommend improvements to present methods, processes, practices and procedures used to prevent or mitigate adverse effects of escaped farm salmon.
4. Evaluate the adequacy of current methods, processes, practices and procedures used to license the use of Atlantic and Pacific salmon.
5. Recommend improvements in current methods, processes, practices and procedures used to license the use of Atlantic and Pacific salmon.

In this report, the authors have concentrated the review on farm salmon-rearing technology and escape modes and numbers and their potential genetic and ecological effects on native salmon stocks. **There is wide concern by the public and various environmental groups that transfer of exotic diseases may also be a major risk to wild populations, and because of the importance given this topic, disease transfer is addressed separately in the Fish Health discussion paper.** Furthermore, this paper does not address genetic and ecological effects of government-operated aquaculture activities, e.g., hatcheries and spawning channels. Information, documents, papers and data reviewed by the authors include reference sources identified by the Environmental Assessment Office (EAO) literature search, contributions from scientists contacted, interviews and comments by the Technical Advisory Team (TAT) and Review Committee (RC) members, the Broughton Local Information Report, and other submissions made to the EAO during the review process.

II. AQUACULTURE IN BRITISH COLUMBIA

A. SALMON FARMING IN BRITISH COLUMBIA

Background

The farming of salmon in B.C. for commercial markets is now several decades old, but development of highly industrialized culture techniques occurred largely in the 1980s. During this period, important changes occurred in the size and design of cage systems, as well as in husbandry practices (Winsby *et al*. 1996). In this respect, the B.C. salmon aquaculture industry and its practices remain in a period of transition, responding to greater experience, new information, tightened regulations, new materials, technologies, and nutrition and health care practices (B.C. Salmon Farmers Association (BCSFA) 1996).

Since the inception of commercial salmon aquaculture, B.C. salmon farmers have attempted to alter their practices to ensure quality products are produced at a competitive price. Since the beginning of B.C. cage culture, major shifts in the locations of farming have occurred in response to multi-use conflicts, as well as bio-environmental siting concerns. As a result there has been a general movement of farming out of the Sunshine Coast region to more northerly areas, with concentration in areas adjacent to the Broughton Archipelago and along the central western Vancouver Island coast. During the early development period, B.C. farmers generally reared coho and chinook salmon. However, rearing of coho largely declined because timing factors made farm coho salmon less competitive with the traditional commercial catches and because coho are more difficult to grow, according to some farmers. As coho were phased down, farmers increased their production of chinook. The dominance of chinook salmon, however, also lasted only a few years, and following the mid 1980s, chinook and coho salmon were largely replaced with Atlantic salmon, particularly in the Broughton area. By 1994, Atlantic salmon made up over 70% of the overall B.C. farm salmon product.

It is highly likely that responses to bio-environmental factors, market trends, disease control, new technology, government regulation and multiple-use conflicts will continue to bring about changes in the character of the emergent salmon farm industry.

A variety of salmon aquaculture types have been practised since the late 1800s in Europe and North America. Hatcheries became a popular tool to supplement and enhance wild production and/or to mitigate losses resulting from industrial development and overfishing. Although hatchery releases of eggs, fry and smolts into rivers and lakes as a substitute for wild production is now under serious review, public hatcheries have played a major role in salmon management over much of the twentieth century. “Ocean ranching” of salmon is a form of private aquaculture which differs from cage farming in its philosophical approach, capital and labor requirements. “Ranched” young salmon are reared in private hatcheries and then released into the ocean where the fish are expected to find their own food (Monahan 1993). Harvest occurs when the ranched salmon return to their release sites. Private salmon ranching is not practised in B.C., but is or has been employed extensively in Oregon, Alaska and Japan.

Although many B.C. residents are familiar with the “growing-out” phase of salmon farming (cage culture of salmon in marine environments (salmon aquaculture encompasses the rearing of salmon under controlled and supervised conditions from the egg to the market. Eggs collected from wild or farm broodstock are hatched and reared in fresh water while the “growing-out” of the farm products occurs in the marine environment. The fresh water phase of rearing the young may last from six months to two years, while grow-out may last 14 to 25 months, depending on the species. The goal of the farmer is to grow marketable quality products which are competitively priced using practices that protect the fish from disease and predation and minimize losses due to vandalism, storm damage, etc. Maintaining the environmental quality of the farm sites has also become an increasingly important role of the farmer.

General Organization of Farms

Monahan (1993) divides industrialized salmon farming into six product stages (Figure 3). Biological steps include the first four modes: (1) access to farm broodstock eggs or the collection of eggs from other sources, (2) hatcheries which incubate and hatch the eggs, (3) the rearing of the young through smoltification—the physiological changes which accommodate the transition from salt to fresh water, and (4) “grow-out” farms where the animals are monitored for feed intake, growth, disease and general health. Animals may escape to the surrounding fresh water and marine environments in all of the biological production phases.

Cage culture is the only aquaculture system employed by commercial farms in the B.C. marine areas. Karlsen (1993) states that “the main advantages of this open mesh net system...are low capital costs, ease of operation, simple and well proven technology and options for gradual expansion of plant facilities.” Although square cages are dominant in the B.C. salmon farm industry, recent research in Norway has concentrated on farm layouts including the shape and position of cages. Figure 4 shows three different cage layouts using square and circular nets. The shape of the cages in Norway can be circular, octagonal, hexagonal, square or rectangular. Each layout arrangement will differ in its anchor arrangements, as well as cage access. The current trend in Norway is for more spread-out positions of cage units with cages 50 m to 100 m apart. There has also been a trend to rotate cage sites frequently. Both trends appear to be related to minimizing ecological impacts of wastes.

A typical B.C. farm layout will be situated relatively close to shore (about 100 m) and cover an area of about 0.8 ha. From 10 to 30 cages will be deployed, most often in two parallel rows. A major access wood or metal decking (four to six feet wide) runs between the cage layouts, and minor access walks run between adjacent cages. Each cage is surrounded by steel fencing rails fastened to the walkway from which the net cages are suspended.

Because the salmon farms are typically floating, self-contained facilities, they are held in place with extensive use of anchors which secure the farms’ geographic position and minimize bellowing of nets. Figures 5 through 7 illustrate general cage structures, support elements and layouts of B.C. cage farming (Heen *et al*. 1993, Ombudsman 1988, Winsby *et al*. 1996, BCSFA 1996).

In recent years land-based salmon farms have been built in several locations in Europe. This involves the grow-out of marketable salmon in land-based facilities using pumped saltwater in ponds.

Figure 3. Stages of aquaculture development.

Source: Heen et al 1993.

Figure 4. Different types of net cage arrangements.

Source: Heen et al. 1993.

Figure 5. Clustered net pens and anchor systems.

Source: Ombudsman, 1988.

Figure 6. Net pens along the B.C. coast.

Source: BCSFA 1996.

Figure 7. Net pen and fencing.

Source: BCSFA 1996

At present, the land-based farms account for less than 1% of European production, but Karlsen (1993) believes that “the magnitude of the problems faced by many floating cage farms today, relating to the problems of operating at sea, pathogens, environmental contamination and the difficulty of finding suitable locations, may encourage more interest in land-based facilities.” Black (MAFF, pers. comm.) notes that without some form of subsidy these operations are not generally financially viable. The TAT, however, remains uncertain regarding the environmental consequences of land-based salmon farming in B.C., and in particular whether current levels of escaped salmon warrant movement to land-based culture.

Pen Structure

The local B.C. industry primarily utilizes square steel cages which are most often 12 m by 12 m or 15 m by 15 m. The square (or sometimes rectangular cages) are supported by floats made of hollow fiberglass, foam or light-weight concrete (Ombudsman 1988, Winsby *et al*. 1996, BCSFA 1996). A net is hung from each cage, ranging in depth from 6 m to 30 m (usually 15 m). Frequently, the bottom of the net is made of double web construction. Flotation collars with nets are generally referred to as “pens.” About 65% of farms are reported to use a predator guard net which is suspended around the perimeter of the set of cages (BCSFA 1996).

Materials used in the floating cages include plastic (high density polyethylene), rubber, steel, aluminum, wood and concrete (Karlsen 1993). Economic factors and structural requirements appear to be of greatest importance in a farmer’s choice of material for construction. Plastic and rubber are used for cage flexibility, while steel and other materials are used for structural strength. As a result of the tendency for the cage nets to become fouled with marine organisms, such as mussels and other attaching invertebrates, kelp, seaweed and debris, some farmers have the net webbing dipped in an anti-foulant before installation. Although highly toxic foulants were used at one time, this practice has been banned by the BCSFA and by the federal government. Currently, a copper-based anti-foulant (cuprous oxide) is used by a number of farms. Completed studies indicate that this material does not have negative environmental impacts (Peterson *et al*. 1991, Lewis and Metaxas 1991).

Each cage may accommodate up to 20,000 fish and continued efforts are made to maintain specific stock densities. Stocking densities are reported to range from about 8 kg/m3 to 18 kg/m3 for Atlantic salmon and 5 kg/m3 to 10 kg/m3 for chinook salmon (BCSFA 1996).

Operational Mode

In the forming of a business venture to farm salmon, the owner/operator must make a number of decisions regarding (1) species to be cultured, (2) siting of the farm, (3) cage sizes and layouts, farm support features and processing needs, (4) capital and labor needs, and (5) logistics for transfer of product. The farms may be vertically integrated (i.e., all stages of operation are controlled by the owner/operator (and one company may own several farms.

On receipt of smolts from the hatchery, inventories are taken and the juveniles sorted by stock and year class. Receipt of smolts is timed with the anticipated harvest of grow-out stocks. Farming tasks begin immediately. Heen *et al*. (1993) identify a number of important activities performed at cage farms or associated with overall farm operations. These tasks may include feeding, dead fish collection and removal, growth control and assessment, fish handling and treatment, cage maintenance, farm damage control, staff training and processing, and marketing. Added to these on-site activities are transportation of fish to and from the farms and at times the movement of cages to new or different sites. These tasks are discussed briefly below.

A more detailed description is provided by the report titled, “The Environmental Effects of Salmon Net Culture in British Columbia,” by Winsby *et al*. (1996) and the BCSFA (1996) report, “Common Approaches to Salmon Farming in British Columbia.”

Feeding

Feed strategies vary among farms, depending on site and experience, and continue to be the subject of inter-farm debates. Feed consists mostly of sized, extruded pellets.

Feeding may be done by hand or by automatic feeders which spread the feed. More recently, feed barges have been put into use. The barges are brought alongside the net cages, plastic pipes are joined to an automatic rotary coupler, and feed is blown to individual or several cages using remote control timing to meet programmed feed schedules. This is accomplished using a person skilled in observing and handling fish or by an automatic fish feeder. Underwater cameras or other systems may be used to observe food intake and prevent excess food delivery. Those who hand feed claim this method will result in less over-feeding and allows the farmer to maintain a better feel of fish health and behavior. Farmers set their own feeding schedules for cages. Feeding may occur several times a day or as seldom as twice a day. The low feeding schedule allows the farm technicians to tend more pens. The number of feedings per day is an issue debated among growers. Some advocate a few large feedings per day and others recommend more frequent feedings of smaller volume per feeding (Winsby *et al*. 1996).

Dead Fish Removal

Some fraction of farm fish will die throughout their life history. Deaths will begin in the hatching of eggs and continue during rearing and smoltification until the fish are ready to be processed for market. During every production cycle, even under favorable conditions, perhaps from 0.1% to 0.5% of fish will die, per month (Winsby *et al*. 1996). In some instances farmers may lose their entire crop. Thus, the screening of cages and checking of nets for dead fish constitutes an important farm task. Most dead fish sink (about 90%) and because of the net shapes, dead fish normally collect near the bottom centre of the net cages. Dead fish are collected by divers or by lifting the nets. Removal of mortalities by divers outside the net is stated to result in less stress to the living fish (Monahan 1993). Dead fish are collected in bags and taken to a "mort" container adjacent to each farm site. Periodically a marine transport collects and delivers the fish to a composting facility.

Methods for disposal of dead salmon have included burying, ocean dumping, incinerating, acid silaging, production of fertilizer and composting. During the early period of B.C. salmon farming, dead fish were disposed of in pits dug close to farm sites or hauled away to nearby landfill sites. These disposal methods were not considered appropriate and the industry is reported to have since experimented with disposal methods that take advantage of the high nitrogen content of salmon (Winsby *et al*. 1996). Production of silage and more recently compost are methods that are now most generally used for dead fish disposal. Main disposal locations for dead farm salmon are shown in Figure 8.

Growth and Assessment

Farmers of course wish to maximize growth with minimal feed cost and losses of fish. In order to evaluate how well this goal is being achieved, farm operators count and weigh the fish at selected intervals. Samples of the cage population are taken and accurately weighed and measured. This information is then coupled with mortality records and food quantities to calculate weight gain versus food intake (BCSFA 1996).

Fish Handling Treatment

Caged fish must be handled in order to accommodate internal transport and redistribution of the fish population for size grading, medical treatments and salmon lice removal. Stress from handling can adversely affect weight gain and increase fish mortality. Development of bar graders and automatic sizing equipment are important new developments which have reduced the handling stress imposed on fish. Other husbandry activities include control of cage population density, water flow throughout the cages and oxygen levels and anti-infection procedures, such as disinfecting nets, maintaining clean clothing and boots, etc.

Farm and Cage Maintenance

Because the nets frequently foul with living organisms such as mussels, barnacles, tunicates, algae, kelp and debris, it is necessary to change nets every month or two during peak periods of fouling. Few changes typically occur during fall and winter months, although the rate and nature of fouling may vary considerably between sites. The challenge to the farmer is to accomplish net changes while minimizing stress and fish losses, as well as cost to the farmer. At times two nets may be linked together and the fish moved from the fouled to the clean net. The transfer without fish loss, however, is a problem. A second method includes sinking a net under the attached cage net and raising it around the containing net, then spilling fish into the lower net. Finally, some farmers may use deep nets, portions of which may be lifted, dried and cleaned. Various techniques are used to clean the fouled nets, including use of businesses specializing in net cleaning. Current cleaning technology includes net washers which may be located on a barge or on shore away from the cages, offsite and onsite pressure washers, submarine pressure washers using scuba divers, and dropping the nets to the sea floor, where various sea life will remove the organic material from the nets (Winsby *et al*. 1996).

Farm Damage Control

Cage damage control has become an increasingly important component of the farmer's duties. Damage to cages and nets from weather, predators, handling, etc., can result in substantial loss of fish and hence erosion of potential earnings. Further, fish loss has become an important concern of the public because of fears that escaping fish may transfer disease to wild stocks and cause potential genetic and ecological damage. Daily inspections are made of the farm cages and predator control nets to detect any damage and correct problems that could involve fish escapes or threats to net populations. Divers are used to examine underwater portions of cages, anchors, mooring lines and overall structure. In many countries where salmon farming occurs, government bodies and investors are promoting higher standards for fish farm structures and equipment. Companies specializing in farm inspections are reported to be becoming more common (Monahan 1993), and insurance companies are insisting on higher standards for cage construction.

Figure 8. Main disposal locations for dead fish from salmon farms in British Columbia.

Source: Winsby et al. 1996.

Staff Training

The increasing sophistication of salmon aquaculture in conjunction with concerns over potential risks to wild stocks has placed a greater demand on growers to train personnel in a variety of specialties. Training is reportedly available in community colleges and technical schools.

Selection of Stock

Stocks of Pacific salmon used on B.C. farms have their origin in various natural and hatchery stocks of the region. The federal government allowed limited access to coho and chinook stocks. Coho, chinook, pink (O. *gorbuscha*), sockeye (O. *nerka*) and steelhead (O. *mykiss*) farming has been attempted, but commercial success is limited to coho and chinook. Stocks were selected, when available, from runs in close proximity to farm sites. However, some transportation of stocks from other areas has occurred. For example, some companies applied to the government to collect eggs from chinook and coho from the Fraser River north to the Yukon River. Eggs for Atlantic salmon have been and continue to be imported from rivers in the Canadian Maritimes and northern European rivers (Table 1).

As the industry expanded, so did the demand for eggs. This, among other factors, led to the formation of the BCSFA, which acted as the chief seller of wild stock eggs to the industry. With the introduction of new technologies and further growth of the industry, some companies established their own broodstock and juvenile rearing programs. In order to create and ensure self-reliant egg and smolt supplies, individual companies purchased or built hatcheries and selectively chose broodstock having high reproductive attributes. Companies also applied for access to lake systems for the purpose of rearing juveniles as a means of reducing costs.

Table 1. Total Atlantic salmon eggs imported into B.C. from 1985 to 1996.

Sources: Winsby et al. 1996, R. Ginetz, DFO, pers. comm.

Broodstocks are generally stripped of their eggs and milt during autumn or early winter. Frequently, this is accomplished at a collection point away from the normal broodstock growout site in order to avoid introduction of pathogens to the environment. The carcasses of the spawned out broodstock (males only) for Atlantic salmon are usually destroyed or held for composting (see Discussion Paper on Waste Discharges).

Salmon farmers in B.C. currently operate eleven private hatcheries located mainly on Vancouver Island. Of the eleven, two are recognized as quarantine hatcheries. The hatcheries constitute a vital link in the salmon aquaculture process by providing selected broodstocks and juveniles to the grow-out farms. The hatchery/broodstock system has allowed the industry to operate with less dependence on eggs collected from wild Pacific salmon stocks and/or importation of Atlantic eggs from areas outside of B.C. Eggs are hatched over a three- to five-month period during which they are stored in stacking or circular trays. Once hatched, the juveniles are grown-out in circular tanks for periods up to about eighteen months, depending on company plans. As with marine grow-out farms, the juveniles are graded for size to reduce intraspecific competition for food.

Distribution and Current Level of Salmon Farming

Salmon farming in B.C. is carried out in two or three major environmental stages: the hatching of eggs and rearing of smolt in fresh water environments and the “growing-out” of adults in the marine environment. It has been previously noted that the fresh water stage of farming currently involves eleven hatcheries, mostly situated on Vancouver Island. Eight of these hatcheries use pumped well water which is discharged to filtration beds rather than to streams in order to isolate the hatcheries. Three hatcheries (Kokish, Chemainus and Colonial/Cayegle) discharge into streams through screens. The hatcheries produced 8.5 million smolts in 1995. Rearing in fresh water lakes occurs at Lois and Georgie lakes.

Access to farm sites is administered by B.C. Lands through provincial crown “tenures.” According to the BCSFA (1996), there are currently 103 to 109 tenures allotted in B.C., with approximately 85 currently actively operated. Current government records suggest 121 tenures, while the Suzuki Foundation (1996) documents 147 tenures. The fact that tenure numbers reported by BCSFA are lower than those noted by Winsby *et al*. 1996 (124) and the Suzuki Foundation (147) may reflect recent farm consolidation and some conflict and difficulties in interpreting the records, such as differentiating between active and non-active authorized sites.

Table 2 provides a summary of net cage culture activities as reported by MAFF for 1993, along with capacity of production levels. Recent production of cage farms has been somewhat greater than 20,000 mt of product annually. A summary of industry production capacity by region and species is shown in Table 3. Total capacity during 1993 is estimated by MAFF at 67,164 mt, while production during that year was 25,539 mt. However, the BCSFA notes that this estimate is based on tonnage per cycle, which is presumed to be two years.

Marine “grow-out” farms in British Columbia are concentrated in the upper portion of the Strait of Georgia and Desolation Sound (in the vicinity of Quadra Island), in the Johnstone Strait area (the Broughton Archipelago region), and along the northeast coast of Vancouver Island and the central and northwest coasts of Vancouver Island. Figure 9 illustrates the concentration of sites in the Broughton Archipelago and adjacent areas.

During 1993, major production occurred in the Strait of Georgia and along the west coast of Vancouver Island, while the majority of latent production capacity is reported for the Broughton Archipelago (Johnstone Strait and north coast area). Almost all the production from Johnstone Strait and north Vancouver Island is directed toward Atlantic salmon, while considerable chinook production still occurs along the west coast of Vancouver Island.

Table 2. Summary of net culture activity by region in 1993.

Source: MAFF databases compiled by Winsby et al. 1996.

Table 3. Summary of industry capacity by region as of 1993.

Note: Many sites with valid tenures produce more than one species. Industry capacity determined from farm management plans. Capacity based on full cycle of each species rather than tonnes per year. Source: Winsby et al. 1996.

Figure 9. Location of salmon farms in British Columbia in 1995.
Source: McKinnell et al. 1997.

B. Background on Atlantic Salmon

Because of the importance of Atlantic salmon to B.C. aquaculture and the concern over the introduction of exotic species into the British Columbia region, the following information on the life history of Atlantic salmon is provided:

Atlantic salmon are native to the basin of the North Atlantic Ocean, from the Arctic Circle to Portugal in the eastern Atlantic, from Iceland to southern Greenland, and from northern Quebec south to the Connecticut River in the western Atlantic (Scott and Crossman 1973). Numerous native landlocked populations occur in eastern Canada, especially in Newfoundland, Labrador, and Quebec.

Atlantic salmon have a typical anadromous life history involving reproduction and juvenile rearing in fresh water, emigration to saltwater where they undergo extensive oceanic migrations, and subsequent return to natal streams to spawn. Some aspects of their life history are similar to steelhead trout. Like steelhead (anadromous rainbow trout), they usually spend two years in fresh water (range 1-3) and do not necessarily die after spawning. Also like steelhead, or rainbow trout, they have populations that remain resident in fresh water. Unlike steelhead, but like most Pacific salmon, they are autumn spawners.

Atlantic salmon prefer relatively large rivers with cool water and extensive gravel sections. Entry into rivers can occur throughout the year but generally there are specific runs in the spring, summer, or autumn (Ade 1989). In Scottish streams, early runs occur from late December to early May, summer runs begin in late May, and autumn runs occur in October and November (Mills 1980, 1981). Earlier runs tend to migrate further upstream than late runs. Shortly before or upon ascending rivers, the fish stop feeding and as a result early runs may stay a full year in the river without food (Ade 1989, Mills 1980, 1981). After about three to four weeks in fresh or tidal water, the fish darken in color and orange halos and rusty spots develop on their sides. As spawning approaches, females become pearly-grey to purple-blue, while males turn apricot-orange to deep copper or red and develop a pronounced hook or kype on the lower jaw (Ade 1989).

Spawning occurs during October and November with a peak in late October in eastern Canada (Scott and Scott 1988), from mid-October to mid-November in Maine (Danie *et al*. 1984), and from early November to January in Scotland (Mills 1980, 1981). Spawning may take a week or more during which the female digs several nests. The finished redd, which contains several egg pockets, ranges from 1 m to 6 m long and 0.6 m to 1 m wide (Scott and Scott 1988). On average, females contain 1,500 to 1,800 eggs per kg of body weight (Danie *et al*. 1984). Eggs are 5 mm to 7 mm in diameter. Not all fish die after spawning. Survivors (called kelts) are generally females, and may return to the ocean at once, remain in the river for a few weeks, or descend to saltwater the following spring. The reproduction strategies of Atlantic salmon, ecology, and evolution have been recently described by Fleming (1997).

The eggs incubate in gravel during winter, the rate of development depending on temperature. Hatching occurs in about 110 days at 3.9°C, usually in April (Scott and Crossman 1973). However, the alevins remain in the gravel, absorbing yolk before finally emerging from the gravel in May or June. Atlantic salmon fry typically remain in streams until approximately 65 mm in length. In the maritime provinces, Atlantic salmon smolts enter the sea after two to three years after reaching 127-152 mm in length. Smolts in more northern regions where growth is slower may be older and larger before emigration to sea.

The potential spawning period of Atlantic salmon in B.C. can be estimated from timing of egg-takes of farm raised broodstock. Burt *et al*. (1992) reported that egg takes for north Vancouver Island hatcheries occurred from early November to early January. Atlantic salmon recovered on B.C. spawning grounds displayed full spawning colors during this period. Observations in Zeballos River during October to December 1996 indicated Atlantic salmon were ripe in mid-December (P. Law, MELP, pers. comm.). This timing is similar to the spawning period of Atlantic salmon in their native range, although somewhat later than those in eastern Canada. Thus, if Atlantic salmon were to spawn in B.C., the expected timing would be from early November to late January.

C. REPORTED ESCAPES OF FARM SALMON

Escapes of salmon from farms must be reported to MAFF. Typically, escape reports are received within 48 hours of the escape observation (C. Backman, MAFF, pers. comm.). Storms, holidays, and the need for quantitative measurements may delay reporting somewhat beyond 48 hours. Less obvious escapes can be detected during biweekly dives to recover dead fish within the net pens. Records of suspected but unconfirmed losses are maintained until more thorough examinations of the pens are made.

Marine Net Pens

MAFF has required salmon farms to report escapes of salmon since 1991, but some records were kept prior to this period. Between 1987 and 1996, 62 escapes of salmon in marine waters of B.C. have been reported (Table 4). Of these reports, 34 involved chinook salmon, 25 involved Atlantic salmon, two involved coho salmon, and one involved steelhead trout. An estimated 1,078,367 salmon have reportedly escaped, including 878,125 chinook salmon, 154,553 Atlantic salmon, 13,113 coho salmon, and 32,576 steelhead.

Table 4. Annual reported escapes of salmon from sea pens in B.C.

Year	**No. events**	**Chinook**	**Coho**	**Atlantic**	**Steelhead**	**Total**
1987	3	22,422	0	0	32,576	54,998
1989	16	392,271	0	0	0	392,271
1990	3	165,000	0	0	0	165,000
1991	8	229,500	0	6,651	0	236,151
1992	8	59,632	0	9,544	0	69,176
1993	3	0	12,113	10,000	0	22.113
1994	8	2,300	0	63,809	0	66,109
1995	10	5,000	1,000	51,883	0	57,883
1996	2	0	0	12,667	0	12,667
TOTAL	**62**	**878,125**	**13,113**	**154,554**	**32,576**	**1,078,368**

Source: C. Backman (MAFF) and A. Thomson and R. Ginetz (DFO), pers. comm..

Numbers of escaped salmon by species and region generally reflect the distribution of farming in B.C. Approximately 54% of the escaped chinook salmon occurred on the west coast of Vancouver Island (Table 5). However, after 1989 all chinook salmon escapes have occurred in this area, reflecting the abundance of chinook salmon along inlets of the outer coast in recent years. Nearly all Atlantic salmon escapes have occurred in the Johnstone Strait region where approximately 45% of production capacity (1993) exists; only 6% of escapes have been reported in other regions where the remaining 55% of production occurs (west coast of Vancouver Island). The two escapes of coho salmon occurred in the Strait of Georgia and the single escape of steelhead occurred on the west coast of Vancouver Island in 1987.

Trends over time show two distinct patterns. First, total annual reported escapes of salmon have declined from 165,000-390,000 fish per year during 1989-1991 to 12,667-69,176 fish during 1992-1996. Second, species composition of escapes has changed from 99% chinook salmon during 1989-1991 to 65% Atlantic salmon during 1992-1996, reflecting the significant shift in production from chinook to Atlantic salmon. Atlantic salmon represented 60% of total farm salmon production during 1992-1995. The frequency of reported escape events peaked in 1989 (16 events) due to a major winter storm and again in 1995 (10 events). The number of escape events in 1996 was low (two events).

Escape records of salmon from net pens in Washington are not consistently maintained by government agencies. However, a major escape of Atlantic salmon occurred near Cypress Island, Puget Sound, during July 1996 when extreme high tides caused eight pens to be separated from their moorings (Table 5). An estimated 101,000 Atlantic salmon were lost, of which 66,000 were large fish (2.7 kg-3.7 kg). The operator of the farm noted that a large percentage of the lost fish were killed during the event.

During 1994-1995, average annual escape estimates in B.C. were 57,846 Atlantic salmon, 3,650 chinook salmon, and 500 coho salmon. In 1996, a total of 12,700 escaped Atlantic salmon had been reported; no Pacific salmon were reported lost. In comparison, somewhat over 20,000 mt of farm salmon were sold each year and in 1995 approximately 8.5 million smolts were transferred from private hatcheries to commercial farms.

Table 5. Database of reported escapes from salmon farms in fresh water and marine areas, 1987-1996.

Source: C. Backman (MAFF) and A. Thomson and R. Ginetz (DFO), pers. comm.

It is worthwhile to note numbers of salmon released from public hatcheries in B.C. for comparison to farm salmon production, although salmon spawned and released from public facilities in B.C. are presently managed to minimize genetic differences from local wild stocks. In 1993, public facilities in B.C. released approximately 58 million chinook, 19 million coho, 1 million steelhead, 227 million chum (O. *keta)*, 23 million pink (O. *gorbuscha*), 234 million sockeye (O. *nerka*, spawning channel fish), and 250,000 cutthroat trout (O. *clarki*, Ruggerone *et al*. 1995). Approximately 25 million Pacific salmon originating from wild and salmon propagation facilities have been harvested in coastal waters of B.C. in recent years and an additional 10-20 million fish have escaped to spawn (DFO 1997). Thus, in comparison to total wild and public hatchery production, escaped farm salmon in marine waters of B.C. represent a very small percentage (<0.1%) of the total salmonid population.

Freshwater Net Pens

Only three escapes to freshwater have been reported since record keeping began. In 1994, a transfer truck carrying Atlantic salmon to a lensing facility accidentally spilled an estimated 7,000 pre-smolts into Morstrom Lake near Campbell River (Table 5). A total of 20,000 fish were actually spilled onto a slope leading to the lake, but most died before reaching the lake.

In 1995, 941 juvenile Atlantic salmon escaped into Lois Lake near Powell River. In 1996, an estimated 40,000 Atlantic salmon fry escaped from a small net in Georgie Lake near the Campbell River.

D. FACTORS CAUSING ESCAPES OF SALMON

Factors contributing to salmon escapes from farms are reported to MAFF when known; these are shown for each escape listed in Table 5. Since 1988, approximately 40% of all escapes were related to farm operations, including accidental tearing of the net while harvesting, net weights wearing holes in the webbing, spills during truck transfers, etc. Approximately 32% of escapes are related to weather, including a major winter storm that sunk nets at 15 farms in 1989, and a major *Heterosigma* (algae) bloom that sunk a net pen as a result of dead fish in the bottom of the cage in Kyuquot Sound. Predators, such as seals and dogfish, accounted for 16% of reported escapes, followed by accidents (8%), and vandalism (5%).

When factors related to salmon escapes are ranked by numbers of escaped fish, then weather is most significant (45% of total fish), followed by operations (29%), vandalism (15%), predators (8%), and accidents (3%).

Factors causing salmon escapes have changed in recent years. Between 1992 and 1996, a period of lower reported escapes, farm operations were responsible for 62% of the escape events compared to 14% prior to 1992. Weather accounted for 59% of earlier escape events compared to 9% beginning in 1992. Predation-related escapes increased in recent years from 7% to 24%.

In summary, farm operations and predation have been the primary factors contributing to salmon escapes in recent years, responsible for 86% of the reported escapes. Weather was a primary factor prior to 1992, primarily due to the major winter storm of 1989.

E. RECOVERIES OF FARMED ATLANTIC SALMON IN THE WILD

Marine Waters

In 1991, a joint federal/provincial program, Atlantic Salmon Watch (ASW), was initiated by MAFF and Canadian Department of Fisheries and Oceans (CDFO) to monitor the presence of Atlantic salmon in B.C. coastal streams. This program was expanded in 1992 to include Atlantic salmon catches and sightings in all B.C. waters, obtain specimens for biological sampling, develop a repository for data and information about Atlantic salmon, and increase public awareness of the program.

The following information was obtained primarily from a recent review of data collected during the first four years (1991-1995) of the ASW program (McKinnell *et al*. 1997) and from ASW annual reports (Burt *et al*. 1992, Thomson and McKinnell 1993, 1994, 1995, 1996, 1997). The reader should note that the program is based on an opportunistic sampling plan that is likely to underestimate total abundance of Atlantic salmon in the wild. Most captured Atlantic salmon are believed to be reported by commercial fishermen and processors, but an unknown percentage of Atlantic salmon may go unreported. In a recent year, one of the largest processors in B.C. reported unusually few Atlantic salmon compared to other processors, suggesting that reporting by company varied (A. Thomson, DFO, pers. comm.). Atlantic salmon in streams are reported by sport fishermen and by biologists conducting surveys of Pacific salmon. Obviously only a small percentage of stream areas potentially occupied by Atlantic salmon are observed by fishermen and biologists. During 1994 and 1996, Ministry of Environment, Lands and Parks (MELP) staff conducted field surveys to recover juvenile and adult Atlantic salmon in selected streams and lakes believed to have relatively numerous Atlantic salmon compared to other streams (Lough and Law 1995, Lough *et al*. 1997).

The first documented catch of Atlantic salmon in B.C. fisheries was in 1987. During 1987 to 1996, 7,394 Atlantic salmon were caught and reported in coastal marine waters of B.C. This estimate represents approximately 5% of the reported escape of Atlantic salmon during this same period. Catches peaked in 1993 (4,543 fish), declining to approximately 1,000 fish or fewer in recent years. Most catches (86%) have occurred in the Johnstone Strait region (Figure 10), including the largest single day harvest of 4,067 Atlantic salmon during a sockeye salmon fishery in early August 1993. This fishery occurred shortly after approximately 10,000 Atlantic salmon escaped from two sites in the Johnstone Strait region. Since 1987, a total of 70 Atlantic salmon have been recovered in the Strait of Georgia, 546 fish along the west coast of Vancouver Island, and 367 fish along the north coast, including the Queen Charlotte Islands (Table 6). Most Atlantic salmon are caught in summer salmon fisheries, although some are caught later during fall chum salmon fisheries.

Figure 10. Catches of Atlantic salmon (numbers) in coastal waters of British Columbia, 1987-1995.
Source: McKinnell et al. 1997.

In 1996, 669 Atlantic salmon were caught in B.C. marine fisheries, primarily along the west coast of Vancouver Island (73% of 1996 total). The percentage of Atlantic salmon harvested on the west coast compared to the total harvest in B.C. was unusually high in 1996, but according to CDFO (1997) this may reflect low fishing effort in the Johnstone Strait area in 1996. However, the commercial fishing effort throughout B.C. was low in 1996 due to conservation efforts, and recovery of Atlantic salmon in marine waters would have been higher in 1996 had the effort been comparable to earlier years. In light of the absence of significant escapes from the west coast of Vancouver Island, the recoveries along outer Vancouver Island may in part reflect the high number of escapes in Puget Sound during July 1996 (101,000 Atlantic salmon).

Table 6. Recoveries of Atlantic salmon in marine waters of British Columbia, Washington and Alaska, 1987-1996.

Note: One fish from Alaska with unknown year not shown. Numbers are current through March 17, 1997.Source: A. Thomson and S. McKinnell, DFO, pers. comm.

In Washington State, 2,363 Atlantic salmon were caught in commercial and tribal fisheries and reported during 1988 to 1996. Most fish were recovered in central and lower Puget Sound (Figure 11). Catches peaked in 1991 (970 fish), declining to 125 fish in 1995 (Table 6). Although the harvest effort in Washington during 1996 was one of the lowest during the past 20 years, an estimated 90 Atlantic salmon were recovered from south Puget Sound and the San Juan Island areas.

Atlantic salmon were first reported in Alaska in 1990 (Wing *et al*. 1992). A total of 223 fish, mainly from the net fisheries in southern southeastern Alaska, were reported during 1990 to 1996. However, the largest annual catch occurred in 1996 (135 fish). A single Atlantic salmon was recovered in the Shumagin Islands near the Alaska Peninsula, approximately 1,100 km from B.C. and Washington (Figure 12), indicating that Atlantic salmon can travel long distances from the area of escape. Atlantic salmon are not farmed in Alaska.

In summary, a total of 9,980 Atlantic salmon have been recovered in marine waters of British Columbia, Washington, and Alaska since 1987. In British Columbia, 7,394 fish have been recovered. Recoveries per year are highly variable and a trend over time is not apparent. Most recoveries had been made in Johnstone Strait, but in 1996 an unusually large number of Atlantic salmon were recovered along the west coast of Vancouver Island, an area where no escapes had been reported. Although no Atlantic salmon are farmed in Alaska, the recovery of Atlantic salmon in Alaska in 1996 was a record. The origin of the large recoveries along outer Vancouver Island and Alaska in 1996 is unknown.

Figure 11. Catches of Atlantic salmon (numbers) in coastal waters of Washington State, 1988-1995.

Source: McKinnell et al 1997.

Figure 12. Catches of Atlantic salmon (numbers) in coastal waters of the State of Alaska, 1989-1995.

Source: McKinnell et al. 1997.

Fresh Waters

Between 1990 and 1996, 399 adult Atlantic salmon were caught or sighted and reported in 49 freshwater systems in B.C. (Table 7, Figure 13). The frequency of Atlantic salmon observations in each region generally reflects effort, which has been greatest along the west coast of Vancouver Island. Most fish have been reported from the west coast of Vancouver Island (249 fish) and Johnstone Strait (115 fish) regions (Table 7). Systems having the largest reported observations are Zeballos (67 fish), Bedwell (40 fish), Salmon (40 fish) and Kokish rivers (27 fish). The presence of numerous Atlantic salmon in the Salmon and Kokish rivers could be related to the Atlantic salmon hatcheries located in these river drainages. Annual observations of Atlantic salmon have increased since 1990. Observations of Atlantic salmon in 1996 (210 fish) were more than triple the previous annual estimate (57 in 1995).

In 1991, vandals released approximately 70,000 chinook salmon (2.5 kg) from a farm near Sooke River on the west coast of Vancouver Island. Over the next two breeding seasons 50 chinook salmon were collected from spawning runs in the river and analyzed for carotenoid content because farm salmon have different levels of this pigment compared to wild fish. From this analysis only two fish (4% of 50 fish sampled) were of farm origin, suggesting that the contribution of farm chinook salmon into this river was low compared to the potential contribution if most of the large escape from a nearby farm had entered the river (Black 1995). The average spawning population of chinook salmon in this river during 1984-1991 was 350 fish. Although this study indicates few escaped chinook salmon returned to the Sooke River, we do not know whether some of the escaped salmon were attracted to other streams in the region. More investigations of this type are needed.

During October to January 1995 and April to December 1996, MELP personnel made a special effort to snorkel streams with the following characteristics: (1) streams where Atlantic salmon had been previously reported, (2) streams in the vicinity of reported escapes, and (3) streams with Atlantic salmon hatcheries.

Table 7. Recoveries of Atlantic salmon in freshwater systems of British Columbia and Washington as of March 17, 1997.

Note: Washington data in 1996 are incomplete. Atlantic salmon hatcheries indicated by (H).
Source: A. Thomson and S. McKinnell, DFO, pers. comm.

Figure 13. Catches and sightings of Atlantic salmon (numbers) in British Columbia rivers and streams, 1990 to 1995.

Source: McKinnell et al. 1997.

In late 1994, two Atlantic salmon adults were sighted during 41 snorkel surveys covering 160 stream kilometers during a 4 month period (Lough and Law 1995). On average, only 29% of potential habitat was surveyed within the surveyed streams. Low visibility, high water, and high densities of Pacific salmon in some deep pools reduced chances for detecting escaped salmon.

During early 1996, MELP personnel snorkeled the Salmon River (Johnstone Strait), where numerous Atlantic salmon were captured by sport fishermen during January to March. Thirty Atlantic salmon captures or sightings were reported to the ASW program during this period (Lough *et al*. 1997). Preliminary inspection of carcasses by ASW indicated the fish were large (2.2-8.1 kg), lacked spawning characteristics such as kypes, contained undeveloped gonads, and were reported to contain aquatic insects and detritus. The snorkel survey revealed only two Atlantic salmon during February, but further surveys were hampered by freshets and poor visibility. No Atlantic salmon were observed when surveys resumed in April and May. Lough *et al*. concluded that most fish had been captured and killed by sport anglers during February and March.

MELP also snorkeled the lower Zeballos River during June 1996 to January 1997 (Lough *et al*. 1997). Adult Atlantic salmon were present in the river from June to January. The peak count of 31 Atlantic salmon occurred in September, but more than 20 fish per survey were recorded during July to mid-October. The Atlantic Salmon Watch reported 40 adults sighted or captured in the Zeballos River during 1996.

In Washington, 319 adult Atlantic salmon were captured or sighted in rivers during 1990-1995. Numerous sightings occurred in 1996, including 30 fish (2.3-4.1 kg) in the Dungeness River and 50-100 fish in the Elwha River (near Port Angeles) during August by Washington Department of Fish and Wildlife personnel (D. Seiler, WDFW, pers. comm.). Approximately 20 of these fish were captured for biological evaluation, but only nine fish have been examined to date. No fish were feeding and the gonads suggested that the fish were not ready to spawn this year. In 1996, Atlantic salmon were also captured or angled in the Nooksack, Skagit, Snohomish, and Green rivers, in north Puget Sound near Oak Harbor and Coupeville on Whidbey Island, and in south Puget Sound. One Atlantic salmon was sighted in Lake Washington. These reports have not been verified.

Juvenile Atlantic salmon were first reported in B.C. streams in 1994 when three separate observations were made (Thomson and McKinnell 1995). The largest occurrence was in Morstrom Creek near the Campbell River after a hatchery transport truck accidentally spilled an estimated 20,000 pre-smolts (30 g fish). Industry personnel visually approximated that 13,000-15,000 fish were recovered as mortalities. A total of 860 live parr were electrofished from the stream. In order to contain the fish, a wire fence was constructed at the outlet of Morstrom Lake, and no Atlantic salmon were captured downstream of the fence. An estimated 3,745 to 5,745 juvenile Atlantic salmon could not be accounted for and were considered possible survivors. Cutthroat trout were found with Atlantic salmon in their stomachs, indicating that some fish reaching the lake were killed by predators. Subsequent sampling during spring 1995 produced approximately 50 Atlantic salmon in the lake and fewer than five fish in the outlet trap, indicating that numerous Atlantic salmon survived over winter (P. Law, MELP, pers. comm.). Sampling at the outlet during the peak migration period in 1996 (1 April to 15 June) did not produce any Atlantic salmon.

Three screens are required below commercial salmon hatcheries to prevent escapes (March 11, 1997 memo from R. Cox, MELP, to the EAO). However, two sightings of juvenile Atlantic salmon were made in 1994 following a survey of eight hatcheries and a broodstock facility (Lough and Law 1995). Two dead juveniles were observed in the Stamp River and four live fish were observed in the Kokish River. Containment screens below Boot Lagoon and Kokish hatcheries associated with these streams were reported to be inadequate. The screen below Seasprings Hatchery was also reported to be inadequate, but no juveniles were found downstream. The facilities were notified by MELP and actions were reportedly taken to repair the screens. Both of these leakage incidents were unknown until the survey by MELP.

In April 1996, an estimated 40,000 Atlantic salmon fry escaped from a net pen site on Georgie Lake (Lough *et al*. 1997). The fry averaged approximately 0.25 g and many still contained yolk. During an assessment survey of Georgie and Songees lakes, MELP personnel recovered a total of 33 Atlantic salmon from Georgie Lake, including fry, parr, pre-smolts, and smolts. Atlantic salmon represented 11% of the total fish sample. The presence of parr, pre-smolts and smolts suggests that earlier escapes of Atlantic salmon into Georgie Lake were not reported. One Atlantic salmon smolt was captured approximately 1 km downstream of the Georgie Lake outlet. Stomach contents of 40 cutthroat trout and 34 Dolly Varden char (*Salvelinus malma*) did not reveal predation on Atlantic salmon. Limited sampling of Songees Lake and Songees River did not reveal Atlantic salmon, but sampling conditions in the river were unfavorable.

Lois Lake near Powell River was examined by Lough *et al*. (1997) in May 1996 following an escape of 941 parr and pre-smolts from net pens in November 1995. A total of 13 Atlantic salmon were recovered by trap nets. However, 211 coho smolt and 261 adult coho were also captured even though anadromous salmon are blocked by the dam on the outlet river. Atlantic salmon and non-local coho represented 78% of the fish sample. Coho have been raised in Lois Lake, but no coho have been reported lost. Some coho may have escaped prior to 1991 when MAFF first required farms to report salmon escapes (C. Backman, MAFF, pers. comm.). It is not known whether the juvenile coho observed in 1996 originated from recent unreported escapes or from spawning of residual coho salmon.

In August 1996, MELP personnel snorkeled, trapped and/or electrofished 11 streams in the Broughton Archipelago because of their proximity to farms and the prior history of Atlantic salmon escapes in the area (Lough *et al*. 1997). Additional surveys were conducted on nine streams in the Broughton Archipelago and Vancouver Island during April to October, 1996. The purpose of these surveys was to find juvenile Atlantic salmon in an effort to determine successful reproduction by adults. Although no juvenile Atlantic salmon were found, difficult sampling conditions in some streams reduced Lough's confidence in the results. Numerous native juvenile salmonids were observed in some of the streams.

In summary, a total of 718 adult Atlantic salmon, including 399 fish in British Columbia, have been recovered and reported in freshwater since 1990. This total is low compared to the actual numbers of adult Atlantic salmon entering freshwater because significant areas have not been sampled. In B.C. most salmon recoveries in freshwater have been along west Vancouver Island (249 fish) and Johnstone Strait (115 fish). Two rivers with relatively high numbers of observed adult Atlantic salmon also have Atlantic salmon hatcheries, raising the question of whether salmon may be attracted to odors produced in these rivers or whether fish may have returned from hatchery escapes. No spawning Atlantic salmon have been observed, but observations were made during brief periods in difficult water conditions. A few juvenile salmon were observed below two Atlantic salmon hatcheries, and containment screens have reportedly been repaired. Efforts to document reported escapes of juvenile Atlantic salmon also discovered fish from at least two earlier unreported escapes: in Georgie Lake older juvenile Atlantic salmon were recovered, and in Lois Lake juvenile and adult coho were recovered.

F. ACCURACY OF REPORTED ESCAPE ESTIMATES

Salmon farms are required to report fish escapes, but typically only those escapes of economic importance are reported to MAFF (C. Backman, MAFF, pers. comm.). Escaped fish claims are reported to insurance companies in order to recover costs; presumably, these escape claims are also those reported to MAFF. Discussions by MAFF and MELP personnel regarding requirements to report small escapes, e.g., ten fish, are presently underway. Field inspections by MAFF are used to verify some, but not all, reported escapes. Typically, field inspections are made when the escape is unusually large or if the industry report is unclear. During field visits, Backman requests information on reported and unreported escapes; this approach led to information on two or three unreported escapes in past years. Backman suggested that the escape estimates are reasonable (in terms of reporting requirements) after considering the accuracy of fish counts coming into the pens and the various techniques used to estimate escaped fish.

Nevertheless, frequency of escapes by size supports the belief that small escapes or "leakage" are rarely reported. Among 60 reported salmon escapes since 1988, <2% involved 100 or fewer fish and <7% involved 101-1,000 fish. Most reports involved 1,000-10,000 lost fish (65%), followed by reports of 10,000-50,000 fish (22%). Small escapes of farm salmon can go unnoticed or unreported. Leakage can occur during handling or transfer of fish to another cage and from small holes in the nets. Typically, small holes in nets would be identified and repaired during twice weekly dives. No estimates of leakage have been quantified, but estimates of 0.5% to 1.0% of the net pen population per year have been suggested (B. Ludwig, cited in Lough and Law 1995; J. Forster, formerly with Sea Farms of Washington, pers. comm. (see Parametrix 1990). This approximation of leakage translates to approximately 35,000 to 70,000 additional escaping salmon, assuming an average harvest of approximately 25,000 mt and an average weight of 3.5 kg. We emphasize, however, that this estimate of leakage is unreported in the formal literature, but implies that total escaping salmon in B.C. could be up to twice the level reported in recent years.

It is important to note that the majority of mortalities at farms typically occurs when fish are small and usually shortly after their introduction to the pens. Because fish decompose rapidly they are often not seen by divers. Mortalities of small fish are often associated with bird predation, which is typically not observed by farmers. Thus, these types of mortalities may be a significant source of error associated with inventoried discrepancies. Unaccounted losses of salmon during pen rearing are widely acknowledged among farmers, but the extent of such losses is rarely documented. Educated guesses of unaccounted losses have ranged from 10% to 30% of the caged population (Moring 1989). In the early 1970s, Moring (1989) conducted a study in Puget Sound to quantify unaccounted losses of salmon from net pens which were similar to commercial pens used at that time. Chinook salmon were hand-counted and stocked into 23 net pens located at four sites. After 214-260 days, the fish were recounted by hand. Chinook salmon disappeared from every cage even though daily diving to retrieve mortalities revealed no tears in the cages. Unaccounted losses during the 214-260 day tests ranged from 8.4% to 37.9% of the caged population, averaging approximately 22%. Decomposition of dead fish, which reportedly could occur in less than one day, was suggested as a significant factor in the unexplained losses. Predators, such as spiny dogfish (*Squalus acanthias*), are known to feed on dead fish through cage netting and were suggested as an additional source of losses. Unaccounted salmon losses tended to be higher in cages that experienced outbreaks of Vibrio (r=0.52), suggesting that unaccounted fish could be related to mortality rather than escape; documented mortality related to Vibrio ranged from 1% to 19%. Predation by birds was another source of unaccounted loss, especially in two cages where scars from bird attacks were found on 13%-51% of the surviving fish. However, scars from birds were observed on only 0.2% of all surviving salmon. In commercial pens, sea lions are known to chew on the netting to feed on salmon (C. Mahnken, NMFS, pers. comm.). Moring concluded that escape of small fishes through net meshes and intra-species cannibalism were unlikely sources of unaccounted losses in this experiment.

In commercial net pens, inaccurate enumeration of salmon transferred from hatcheries to net pens represents another potential source for discrepancy in fish accounting (Backman, pers. comm.; J. Forster, formerly with Sea

Farms of Washington, pers. comm.). Forster noted that the largest accounting error typically occurs between the smolt count during transfer from hatchery to pen and the first count in the pen approximately six months later. Both Forster and B. Harrower (MAFF, Interoffice Memorandum, 23 Sept. 1996) noted that hatcheries likely over-estimate numbers of smolts transferred to net pens, leading to high estimates of reported escapes during subsequent inventories. Harrower also noted that some juvenile salmon die upon transfer because they have not physiologically adapted to sea water at the time of transfer; these fish may decompose or slip through the nets, thereby contributing to possible escape counts during subsequent inventories.

Escapes of Atlantic salmon in Georgie Lake and coho salmon in Lois Lake were unknown until discovered by MELP surveys related to reported escapes of more recent year classes of Atlantic salmon. Farmed salmon are presently permitted in only these two lakes. These data demonstrate the occurrence of two unreported escapes from freshwater net pens.

The sharp decline in escaped salmon in recent years has been viewed by some concerned groups to have resulted from incomplete reporting of escaped salmon. Accounting of fish numbers in cages is poorly documented and salmon farms could deceive government officials, even though reporting of escaped salmon is required. Many concerned groups believe the Salmon Aquaculture Review process may have encouraged some farms not to report salmon escapes. However, we have no evidence of such negligence.

Interviews with biologists from the National Marine Fisheries Service (NMFS) and MAFF who are familiar with salmon farms and industry personnel are in agreement that the downward trend in escaped salmon is expected. Clearly, the farm industry has an economic incentive to reduce salmon escapes and to report escapes in order to make insurance claims. Improved net pen technology, handling methods, and greater experience have likely contributed to reduced escapes in recent years. Farm siting has reportedly improved following the experience gained by farms and the regulatory agencies, e.g., unfavorable siting of farms contributed to the largest escape in B.C. history during the 1989 winter storm. Methods such as predator nets, noise-making devices and shark guards have been used to reduce escapes caused by predators such as pinnepeds and dogfish. Escapes may also be lower because fish mortalities, which attract dogfish, are apparently lower following the transition from chinook to Atlantic salmon (C. Mahnken, NMFS, pers. comm.). Lower mortality of Atlantic salmon may be related to docile behavior and to higher resistance to Bacterial Kidney Disease (BKD).

Questions have been raised over the presence of escaped Atlantic salmon along the west coast of Vancouver Island, an area where few escapes have been reported. Two escapes, totaling 8,154 fish, were reported in 1992 and 1994 (Table 5). However, similar numbers of Atlantic salmon were reported in streams and commercial/sport harvests during 1993 (45 fish) and 1995 (31 fish) when no escapes were reported, compared to 1992 (51 fish) and 1994 (48 fish) when escapes were reported. Most unusual is the 1996 recovery of 125 Atlantic salmon on spawning grounds and 487 fish in the commercial/sport harvests along the west coast of Vancouver Island. Southeast Alaska fishermen harvested a record number of Atlantic salmon in 1996 (135 fish). Did these fish originate from the large escape in Puget Sound (101,000 fish) during early July 1996, or did these fish originate from an unknown or unreported escape along west coast Vancouver Island? This question remains unanswered.

McKinnell *et al*. (1997) reported no statistically significant correlations between annual escapes of farm Atlantic salmon and annual farm production and annual commercial harvests in fisheries through 1995. Our re-analysis of the data for the years 1991-1996 also showed that annual reported numbers of escaped Atlantic salmon in B.C. were not correlated with annual production (mt) of Atlantic salmon ($r = 0.50$, $p = 0.308$), recovery on streams ($r = -0.07$, $p = 0.89$), and harvest ($r = -0.14$, $p = 0.78$). Furthermore, harvest of Atlantic salmon in marine waters ($r = 0.18$, $p = 0.74$) was not correlated with farm production in B.C., but recovery on streams was weakly correlated with production ($r = 0.66$, $p = 0.155$). However, if escaped salmon from Puget Sound (101,000 fish in 1996) are included in the total escape estimate, then recovery of Atlantic salmon on B.C. streams was correlated with reported escapes ($r = 0.90$, $p = 0.016$).

Expansion of the reported commercial harvest of Atlantic salmon was attempted by the ASW program. However, the results were highly unreasonable, possibly a result of nonrandom distribution of the fish and the low total abundance of Atlantic salmon captured. The ASW program has considered requesting a population estimate based on the expansion of Atlantic salmon recovered by the Mark Recapture Program (MRP), which is designed to expand recoveries of coded-wire tags. However, funding for this project has not been available.

In summary, reported escapes of salmon appear to be reasonably accurate estimates of large escape events, especially those involving large, valuable fish where insurance claims may be made. Unaccounted losses are expected because many dead fish decompose or are eaten before divers can retrieve them, according to a controlled experiment in Washington State. Small escapes, or leakage, may go undetected or unreported. Unverified estimates of leakage are 0.5%-1.0%. If these estimates of leakage are accurate and are added to the reported escape estimates, then up to approximately 65,500 Atlantic salmon, 38,000 chinook and 5,000 coho salmon may have escaped per year during 1992-1996, or approximately twice the reported number for this time period. These estimates likely mark the upper bound of escaped salmon.

G. REDUCING THE LEVEL OF ESCAPES

The prevention of escapes constitutes a major activity of fish farmers in that the economic consequence of loss can be catastrophic when large numbers are involved. The reduction in escapes since the early inception of aquaculture farming has resulted from a number of technological developments, experience and probably change in target farm species. As most current losses result from tears in the webbing or damage to cages, these problems have been addressed by the use of stronger cage materials, better net design including the use of double bottoms, and improved training of staff handling logistics to and from the farms.

Losses involving storms are reported to have been addressed by improved anchoring designs, better cage technology, greater experience of farm operators and agency personnel in siting farms, and insurance demands which require having a farm inspected and certified by an aquatic engineer prior to start-up. For many farms the addition of guard nets has served to reduce losses due to predation by seals or dogfish. Also, the use of deeper net pens allows the contained stock more room to avoid predators. Finally, inspection of nets by underwater observations, including divers and cameras, has helped to detect net damage and minimize losses.

Some opportunity exists for recapture of escaped farm animals through employment of seine boats and harvest in the commercial and recreational fisheries. The effectiveness of recapture is dependent, however, on many factors, including the availability of commercial fishing vessels, weather, tides and size of fish (BCSFA 1996).

H. BIOLOGICAL INFORMATION ON ESCAPED SALMON

Since 1991, biological data have been obtained on 478 Atlantic salmon caught in B.C. Most fish recovered in marine waters of B.C. were immature and most recovered in freshwater were maturing. Of 20 fish recovered in freshwater between 1991 and 1995, 17 had gonadal development and external coloration associated with sexual maturation. The most mature female was recovered from Glen Lyon Creek, near Port Hardy, when local hatchery staff were seining for ripe Pacific salmon. The eggs were loose within the ovaries, and many discharged when the fish was killed.

MELP radio-tagged a ripe, male Atlantic salmon in the Kokish River in October 1994 (Lough and Law 1995). The fish migrated 5 km upstream where it remained for at least five days before returning to the estuary. Total stay in the Kokish River was at least 33 days. Spawning behavior was not documented, but as a result of a series of floods only one observation was made.

Approximately 15 adult Atlantic salmon were observed in Mikey Creek on Flores Island, west Vancouver Island (A. Keitlah, Nuu-chah-nulth Tribal biologist, pers. comm.). The fish appeared to be ready to spawn; one fish was captured and transferred to the ASW program. In order to evaluate whether the salmon had successfully spawned, Keitlah electroshocked the entire stream area having access to anadromous salmon below the impassable falls. No juvenile Atlantic salmon were captured and Keitlah concluded that none were in the creek.

Atlantic salmon in the Zeballos River were examined in October to December 1996 for spawning condition and behavior (Lough *et al*. 1997). Up to six fish were examined for spawning condition on each survey, although up to 31 Atlantic salmon were observed in the river during a single survey in early September. Prior to early December, the fish did not show behavior that might indicate spawning activity, such as holding in the tail of a pool or pairing. In mid-December, the spawning condition of a female salmon was observed to be ripe and running. However, no spawning activity was observed and flooding during late December inhibited further observations. Only one Atlantic salmon was observed in Zeballos River during early January, 1997. Lough *et al*. suggested that the fish may have moved back to marine waters or migrated above the formidable falls in the lower river.

A total of 90 adult Atlantic salmon recovered from B.C. and Alaska have been examined by the Fish Pathology Lab, Pacific Biological Station, between 1991 and 1995 (Burt *et al*. 1992, Thomson and McKinnell 1994, 1995, 1996, 1997). Two fish were infected with *Aeromonas salmonicida*, the causative agent of furunculosis. Three fish were marginally positive for Bacterial Kidney Disease (BKD). None contained unusual parasite infestations. Of 56 fish tested for common viral infections, none were infected. Sixty parr taken from Morstrom Creek after the November 24, 1994, spill were analysed, but all were free of internal parasites and infectious disease agents known to occur in cultured salmonids in B.C.

Approximately 20 of 46 large Atlantic salmon (2.3 kg-4.1 kg) captured by the Washington Department of Fish and Wildlife (WDFW) in the Dungeness and Elwha rivers during August 1996 have been preserved for biological evaluation (D. Seiler, WDFW, pers. comm.). To date, nine fish have been examined. No fish contained food, and swollen gall bladders indicated little or no recent food intake. The immature gonads suggested the fish were not ready to spawn this year. Presumably, these large fish originated from the reported escape of 101,000 Atlantic salmon near Anacortes in early July, 1996.

In summary, no spawning or successful reproduction of Atlantic salmon has been documented in B.C. streams, but difficult field conditions have limited attempts to observe spawning fish. Ripe female Atlantic salmon have been observed in streams. Some Atlantic salmon adults have been observed with furunculosis or low levels of Bacterial Kidney Disease.

III. POTENTIAL IMPACTS OF FARMED SALMON ESCAPES ON NATIVE SALMON STOCKS

A variety of concerns is frequently noted regarding the potential consequences of escaped cage-cultured salmon on local/wild population. Most important among these concerns include: (1) interbreeding of farm and wild Pacific salmon causing genetic dilution or alteration of the gene pool that leaves the wild stock less competitive in its own habitat, (2) hybridization between Atlantic and Pacific salmon and trout, (3) colonization of Atlantic salmon and associated impacts on native populations, (4) predation on wild salmon by escaped salmon, (5) competition between escaped salmon and wild salmon, and (6) disease transmission. A key component when evaluating the potential effects of each concern is the abundance or status of the wild salmon populations.

A. STATUS OF WILD SALMON AND TROUT STOCKS IN BRITISH COLUMBIA

An important aspect in the evaluation of potential effects of interaction between escaped farm salmon and wild populations is the status of the wild populations that might interact with farm salmon.

A review of stock status of wild salmon in B.C. was completed in 1996 (Slaney *et al*. 1996b, in press; K. Hyatt, DFO, pers. comm.). This review examined historical spawner abundance (escapement) records in order to classify stocks in the following categories: high or moderate risk of extinction, extinct, special concern, unthreatened, or unknown. These classifications were defined as follows:

Extinct: stocks known to exist for several decades but no returns have been observed in more than a decade.

At high risk of extinction: mean population in the current decade was less than 20% of long-term mean and fewer than 200 fish.

Moderate risk of extinction: large populations exhibiting declines to 200-1,000 fish from more than 5,000 fish or small populations reduced to less than 20% of long-term mean of 1,000-5,000 fish.

Special concern: stocks that could be threatened by minor disturbances, or stocks having insufficient data on population trends but available information suggests depletion, or stocks that may breed with introduced, non-native fish, or stocks that are not currently at risk but require attention because of unique characteristics.

Unthreatened: Stocks averaging more than 1,000 fish or greater than 20% of their long-term mean. This category included many stocks that were depressed far below their maximum yield from a harvest perspective but not at risk of extinction.

Stocks in this review were defined in terms of management stocks, which generally include several or many genetically distinct spawning populations. Because historical fishery data of this type is subject to many sources of error, the authors were careful to describe the quality of data. This report represents an important step toward the evaluation of salmon stock conditions in B.C.

The status of salmon stocks by region and species is shown in Table 8. Of 5,448 stocks where status could be evaluated,1 2% were classified as extinct, 11% as high risk, 1% moderate risk, 4% as special concern, and 81% as unthreatened. Georgia Strait (33% of 651 known stocks) had the highest percentage of stocks in the special concern to extinct categories, followed by Johnstone Strait (24% of 454 stocks), west Vancouver Island (22% of 653 stocks), areas north of Vancouver Island including transboundary stocks (16% of 2,982 stocks), and Fraser River (14% of 708 stocks).

West Vancouver Island had the greatest percentage of stocks at high risk of extinction (15%), followed by Johnstone Strait (14%), north of Vancouver Island (12%), Georgia Strait (11%), and Fraser River (5%).

Stock status by species indicated that coho salmon had the highest percentage of stocks in the high risk category (16%), followed by cutthroat trout (13%), chinook (12%), chum (12%), sockeye (11%), pink (9%), and steelhead (2%). However, when stocks in the special concern to extinct categories are combined, 55% of cutthroat trout stocks were of concern, followed by steelhead trout (37%), coho (22%), chinook (19%), chum (16%), sockeye (14%), and pink salmon (13%).

Regions of special interest to the Aquaculture Review are those areas having the greatest activity of salmon farms, including Johnstone Strait, west Vancouver Island, and Georgia Strait. In the Johnstone Strait region, which includes the Broughton Archipelago, 29% of chinook stocks, 35% of coho stocks, 33% of sockeye stocks, and < 30% of other species stocks were classified in the special concern to extinct categories. Along west Vancouver Island, 50% of cutthroat trout stocks were classified in the special concern to extinct categories, followed by 49% of steelhead stocks, 38% of pink stocks, 35% of chinook stocks, and 2%-21% of other species stocks. Twenty-two chinook salmon stocks along west Vancouver Island were classified as high risk of extinction. In Georgia Strait, 69% of cutthroat trout stocks were classified in the special concern to extinct categories, followed by 46% of steelhead stocks, 30% of coho stocks, 28% of chinook and pink stocks, and 10%-24% of sockeye and chum stocks.

Table 8. Number of Pacific salmon and trout stocks in British Columbia by status (i.e. risk of extinction) and region.

Note: Yukon, Laird and Columbia River stocks were excluded. Source: K. Hyatt, DFO, pers. comm.

The status of salmon stocks described in these reports is sensitive to the criteria used to define the status categories. At a recent fisheries conference in B.C., Dr. Don Hall (Nuu-chah-nulth Tribal Council, pers. comm.) presented a re-analysis of the west coast of Vancouver Island stock data presented by Slaney *et al*. Hall noted that the criteria used by Slaney *et al*. tended to understate the weak status of salmon stocks, especially those on outer Vancouver Island, with which Hall is most familiar. For example, the long-term average abundance of Jacklah River chinook salmon was 34 fish and the mean for the most recent decade (1983-1992) was 7 fish, yet using Slaney's criteria this stock was classified as unthreatened. The long-term average of Kennedy Creek chum was 143 fish, the recent decade average was 0 fish and Slaney's classification was "unknown." Hall re-analysed west coast Vancouver Island stock status using additional criteria: stocks were classified as high risk if the decadal mean was less than 10 fish, moderate risk if the mean was 10-25 fish, and special concern if the mean was 25-50 fish. This re-analysis resulted in a significant increase in the percentage of stocks classified as special concern or worse. For example, chinook stocks of special concern or worse increased from 35% to 81% and coho stocks increased from 21% to 67%. Hall noted that local government biologists were in general agreement with this reclassification of stock status.

Slaney *et al*. briefly reviewed factors contributing to depressed stock status in B.C., including habitat destruction by human activities, overutilization, and natural factors. Of interest to the Salmon Aquaculture Review, they noted that "little risk of stock loss through introgression with non-native hatchery fish appears to exist, although some stocks may be modified as a result of hatchery operations." Salmon hatcheries (i.e., ocean ranching) began in British Columbia in 1884 and were accompanied by widespread transplants, especially of sockeye eggs. Low survival led to the cancellation of the program in 1937 and little introgression was thought to have occurred. When salmon hatchery operations resumed in the 1960s, federal/provincial guidelines were introduced prohibiting transfers of non-native stock between watersheds unless the native stock was extinct. Two examples of hatchery effects on local B.C. stocks are described in the Genetic Effects section of this report.

B. GENETIC EFFECTS

Local Adaptation

Salmon show a pronounced tendency to form local populations distinct from each other in a variety of traits. These unique traits are thought to represent adaptations by natural selection to local environmental conditions. A primary factor that enables locally adaptive traits to evolve is the ability of salmon to home back to natal streams (Scheer 1939, Quinn 1993). Homing to natal streams reduces interbreeding between salmon populations, thereby allowing potential divergence in genetic population structure. Furthermore, local adaptations are the basis of the stock concept in salmon management, that is, the principle that populations are unique and should be managed as discrete entities.

Local adaptation may be defined as a process that increases the frequency of traits within a population that enhance the survival or reproductive success of individuals expressing such traits (Taylor 1991). At least three conditions probably should be met to demonstrate local adaptation: (1) the trait must have a genetic basis, (2) differential expression of the trait must be associated with differential survival or reproductive success among individuals in a common environment, and (3) a mechanism selection for the trait should be demonstrated. Compliance with all three conditions in order to demonstrate local adaptation unequivocally is a difficult task. Some differences between populations may be responses to different environmental conditions, but such responses can be genetically controlled. Nevertheless, a considerable body of circumstantial evidence exists that supports the idea that local adaptation is responsible for much of the observed variation among salmon populations.

Many traits have been shown to be directly or indirectly influenced by genetic factors and are examples of local adaptation in salmon. The following list presents examples of local adaptation observed in a variety of field investigations (see Ricker (1972), Taylor (1991) and Allendorf and Waples (1995) for review of studies):

- body and fin morphology
- egg number and size
- survival to various life stages
- growth rate
- precocious male maturity
- age and size at smoltification
- age and size at sexual maturity
- migratory behavior at sea and in freshwater
- agonistic behavior of juvenile salmon
- migratory timing of adults
- spawn timing
- development rate of incubating eggs in response to water temperature
- homing precision
- swimming performance
- resistance to bacterial diseases and parasites
- resistance to low pH

Local adaptation in salmon may be evident from comparison of traits among populations over a broad geographic area. However, evidence for local adaptation has been reported for populations within the same watershed and separated by a few kilometers or less (Taylor 1991).

Although local adaptation appears to be important to population success, Larkin (1981) suggested the idea that successful populations must be finely tuned to an optimal phenotype by natural selection is unwarranted in some cases. For example, successful introductions of kokanee (nonanadromous sockeye salmon) and rainbow trout have been made to many non-native lakes in British Columbia and elsewhere. Also, chinook salmon in New Zealand and pink salmon in the Great Lakes have established naturalized populations. However, the apparent flexibility of such introduced populations might result from adaptations in highly variable environments through selection for phenotypic plasticity (Taylor 1991).

Genetic Effects of Interbreeding between Conspecific Salmon Populations

Before reviewing results of studies examining genetic effects of interbreeding between native and cultured salmon, we present a brief review of key terminology and concepts that are critical to this evaluation. Much of the following discussion was extracted from the 1995 workshop, "Genetic effects of straying of non-native hatchery fish into natural populations," held by the National Marine Fisheries Service (Waples 1995), and review articles by Utter *et al*. (1993) and Hindar *et al*. (1991).

Definitions

The factors influencing genetic change in a population are natural selection, random genetic drift, inter-population migration (straying), and mutation. Mutation rates are typically low for most genes and are likely to have little effect in short time periods (<100 years). Thus, mutation likely plays little role in interbreeding of salmon and it will not be discussed further. A few definitions of key concepts and terminology are presented below.

Natural selection is a process that increases the frequency of traits within a population through enhanced survival or reproductive success of individuals expressing such traits. The traits must have a genetic basis and a mechanism (biotic and/or abiotic factors) must influence differential survival of individuals.

Random genetic drift is the random change in **allele** (the various forms of a gene) frequencies that occurs in all finite populations. The effects of drift are unpredictable and can be substantial in small populations.

Stray rate is the proportion of non-native fish spawning in the target population. However, stray fish may not reproduce, or if they do reproduce, they may have lower reproductive success.

A key factor in evaluating potential effects of interbreeding is **gene flow**, which is the proportion of non-local spawners that actually contribute genes to a native population. Since gene flow occurs only to the extent that genes from stray fish become integrated into local natural populations, the stray rate is generally an upper limit to the level of gene flow, which can be considered the "genetically effective" rate of straying. If local salmon prefer to spawn with other local salmon, or stray salmon are less able to spawn successfully, or spawn timing of stray and native salmon is markedly different, then gene flow can be less than stray rate.

The genetic consequences of straying depend on the **effective population size**, which is influenced by unequal numbers of successfully spawning males and females, nonrandom distribution of family size, and unequal number of breeders in successive generations (Gall 1987). Effective population size is typically much less than the total population size and it is difficult to measure in natural populations. Waples *et al*. (1995) note that for a variety of organisms the ratio of effective population size to total size is typically about 0.1 to 0.3. For example, the effective population size of two males spawning with 50 females is about 8 fish (Gall 1987). Introductions of non-local salmon can also reduce effective population size. For example, assume an effective population size of 200 wild parents is supplemented with fry produced from an effective population of 20 parents. If the introduced fry represent 40% of the total number of offspring in the stream, then the total effective size of the wild population is reduced from 200 to about 100 fish (Ryman 1991).

Isolated populations with an effective population of 50 or less will lose substantial genetic variability through random genetic drift (Waples 1995). Natural selection resulting in local adaptations might play a lesser role in small populations as a result of random genetic drift. Populations with effective populations of 1,000 or more tend to act like an infinite population in which genetic diversity is not lost through random drift.

Inbreeding is the mating of related individuals. In small populations, the level of inbreeding increases because most or all individuals are closely related. Inbreeding results in an increase in homozygosity (same gene in the two corresponding loci of a chromosome pair). **Homozygosity** for recessive alleles can cause a reduction in fitness known as **inbreeding depression.**

Outbreeding is the mating of genetically divergent individuals, such as domesticated farm salmon and wild salmon. If the genetic differences are large enough, the result can be a reduction in fitness known as outbreeding depression. **Outbreeding depression** can be caused by either or both of two factors: (1) loss of local adaptation, and (2) breakdown of favorable combinations among gene loci. Outbreeding depression due to loss of local adaptation may occur in the first generation after hybridization. Reductions in fitness due to breakdown of gene complexes may not be apparent until the F2 (second) or later generations.

Hybrid vigor (or heterosis) may occur in the first generation in cross breeding between two distinct inbred lines when highly heterozygous progeny outperform either parent line. This concept primarily pertains to captive inbred populations and it generally does not apply to native anadromous salmonids where hybridization might destroy highly specific local adaptations for migration and habitat (Gall 1987, F. Utter, University of Washington, pers. comm.).

Genetics, Life History Traits, Straying and Impacts

This section presents information on genetic concepts related to interbreeding of conspecific salmon populations. It is important to note that these concepts may be unsubstantiated by experimental evidence involving interbreeding salmon populations, rather they were developed from genetic investigations involving many species. The reader is encouraged to review Waples (1995), Ryman *et al*. (1995), Utter *et al*. (1993), and Hindar *et al*. (1991) for additional information related to the conservation of salmon.

Genetic and life history differences between cultured and native populations are important in the evaluation of interbreeding effects. In general, larger genetic differences between native and cultured populations may increase the effects of interbreeding, but the dynamics of any particular situation can be complex. If differences are large and important, then substantial reductions in survival may occur in the short term because of outbreeding depression. However, reduced survival of intraspecific hybrids may help to limit the extent of introgression into the native population. In contrast, more modest genetic differences may not result in large, short-term reductions in survival, but persistent gene flow would probably cause replacement of local genes with non-native genes. One problem when attempting to apply this concept to interbreeding between cultured and native salmon populations is that scientists typically do not know whether measured genetic differences between cultured and native populations are large or important. Thus, the extent of outbreeding depression is difficult to quantify or predict.

Swamping of genes under selection depends on the magnitude of straying and strength of selection on genes that are the basis of local adaptation. Persistent straying of genetically different cultured salmon into a native population may eventually lead to the loss of selectively neutral genes, regardless of the stray rate. If the rate of gene flow from cultured salmon to the native population is greater than the selection coefficient acting on local adaptations, then straying will swamp genes related to local adaptations. Even low rates of gene flow will eventually lead to the loss of genes with small selective advantage. Natural selection, however, is expected to maintain genes with large fitness values in a local population in spite of gene flow. From an empirical perspective, selection coefficient values of adaptive traits are not well known.

The time in which a specific amount of genetic diversity will be lost can be calculated from the rate of gene flow and a constant related to the specific amount of lost variability. For example, the number of generations to reach 50% loss of variability for neutral or slightly adaptive genes (i.e., selection coefficient < gene flow) has been calculated for the following levels of gene flow per year (Waples 1995):

69 generations @ 1.0% gene flow25 generations @ 2.5% gene flow12 generations @ 5.0% gene flow

It is important to note that as gene flow increases, the time to 50% loss decreases and the fraction of all genes subject to replacement increases. Thus, small levels of continuous gene flow introduced by stray salmon can lead to rapid alteration of genetic diversity, especially among neutral or slightly adaptive genes.

Greater reduction in diversity among populations will occur if stray, non-local cultured fish affect multiple populations, rather than a single population. If flow of cultured strays is only into a single population of a metapopulation with some level of natural straying among subpopulations, the strays will ultimately affect a wider range of populations, but they will do so at a much slower rate. Thus, local adaptations for the metapopulation as a whole are less likely to be washed out if straying is only into a single subpopulation.

Short-term versus long-term straying of non-local salmon into a native population can have different outcomes. A short-term infusion of non-native genes may be offset by selection due to outbreeding depression, i.e., intraspecific hybrids may experience higher mortality and be rapidly removed from the population. Long-term effective straying will eventually replace neutral genes in the local population with non-native genes. Genes with small adaptive effects (selection < gene flow) will also be flushed out of the local population. Outbreeding depression in a local population may not be apparent for some time after a straying event.

The genetic effects of straying are permanent. If straying stops, wild populations may recover lost fitness over time, but it is unlikely that the original genetic composition of the population will return.

Straying may be beneficial under certain circumstances. For example, foreign genes introduced by strays may mask the effects of deleterious recessive alleles in inbred populations. Furthermore, during the initial stages of straying, genetic diversity will generally increase in the local population. However, there is a tradeoff between increases in genetic diversity and loss of adaptive fitness within populations (due to outbreeding depression), and the effect of continued straying may be a reduction in population diversity.

Can some level of effective straying occur that is consistent with conservation of natural populations? Safe levels of straying depend on the strength of selection for local genes. Maladaptive genes introduced by strays may be filtered out by local selection, but productivity of the spawning population may suffer during this time period. For neutral genes or genes with small adaptive effects, any continuous straying will erode genetic diversity.

The genetic consequences of straying are difficult to predict with certainty because the amount of gene flow resulting from a given level of straying is difficult to predict. However, the effects of continued gene flow on neutral, weak, or moderately adaptive alleles are predictable, i.e., diversity may be reduced. The consequences of gene flow on fitness or productivity of the population are typically unpredictable.

In 1994, the NMFS established an interim standard to limit the proportion of stray, non-local hatchery fish to no more than 5% of the natural spawning population. The purpose of this standard was to protect native salmon listed as threatened under the U.S. Endangered Species Act. A key point here is that the standard refers to release of non-local populations rather than supplementation using local populations propagated in hatcheries and released in the wild. Pacific salmon escaping from farms in B.C. would be considered non-local stocks, even though they are derived from one of several salmon stocks in B.C., because selective breeding and domestication likely would alter the genetic composition of the farm stock.

The NMFS workshop presented conclusions regarding the 5% interim stray rate standard. As noted above, the genetic effects of straying at any given level cannot be reliably predicted, but some effects of gene flow are possible. Based on estimates of gene flow from allozyme (allele protein) frequencies in natural populations, a value of 5% gene flow is much higher than that generally occurring between non-local, wild populations. Based on what is known about the strength of selection in other animals, this amount of gene flow could quickly lead to the replacement of both neutral genes and locally adapted genes, if genetic differences between the populations were large and important. Most genes in natural populations probably have selection coefficients <5% and would thus be subject to loss if gene flow from non-local salmon occurred at this level. The workshop concluded that there is no genetic justification for allowing gene flow from non-local fish at levels as high as 5%.

In a recent manuscript on conservation strategies, Ryman *et al*. (1995) suggest that only minor levels of introgression can be tolerable when conservation aims at preserving the characteristics of a genetically distinct recipient population. They suggest that permissible levels of introgression should be related to that occurring naturally. For conspecific populations that are somewhat distinct (i.e., fixation index FST = 0.10), the permissable number of successfully interbreeding strays, according to Ryman *et al*., is only two individuals per generation. Interbreeding between two highly similar populations (e.g., FST = 0.01) would correspond to a permissable migration of only 25 effective strays per generation. Based on this approach, greater gene flow would be acceptable between genetically similar compared to distinct populations. Furthermore, they suggest that the number of successful strays rather than the percentage of strays in the recipient population is the critical parameter. This counterintuitive effect is the result of the balancing effect of migration and genetic drift.

Empirical Observations

Genetic Changes within Cultured Populations. Changes within cultured populations can be intentional or unintentional. Demonstrated intentional changes include characteristics such as growth rate, disease resistance, spawning time, age of maturity, etc. (Utter *et al*. 1993). Unintentional changes, resulting primarily from inbreeding and loss of genetic variability, are typically inevitable in any selective breeding programme. Inbreeding may result in reduced performance, including reduced viability, growth, and fertility. Thus, domestication of cultured salmon will lead to intentional and unintentional results. Cultured populations must adapt to conditions of growth, maintenance, and reproduction that are not encountered in nature, and genetic changes from wild ancestral populations are inevitable. Some changes result in desirable effects, such as fish that are more docile and manageable in culture conditions. Domestication will likely be greater in farm salmon compared to salmon raised in a hatchery for release into the wild.

Genetic Changes from interbreeding of Cultured and Wild Populations. Table 9 shows results of a variety of studies involving interbreeding of non-local populations. Although some studies to date suggest negative effects of interbreeding on genetic structure, reproductive success, juvenile survival, survival to adult, physical fitness of juvenile salmon, territorial behavior, concealment behavior, competitive ability, and disease resistance, some studies found either no effect or hybrid vigor in the first generation.

A number of studies have shown only differences between cultured and wild salmon without comparison to crosses of cultured and wild fish. Although one may infer negative effects of interbreeding from studies showing cultured salmon to have reduced genetic variability or lower performance in the wild, studies examining performance of cultured/wild hybrids would provide more direct information. In general, additional carefully designed and controlled experiments are needed in order to evaluate thoroughly the effects of interbreeding between cultured and wild salmon. A few examples of studies examining interbreeding of cultured and wild salmon are discussed below.

Table 9. Observations bearing on the effects cultured salmon may have on indigenous populations.

Note: See source for specific references to studies. Source: Utter et al. 1993

Although federal/provincial guidelines for operations of salmon hatcheries in British Columbia limit potential introgression by prohibiting transfer of non-local stocks between watersheds, a few documented examples of introgression still exist (Slaney *et al*. 1996a). In the Chilliwack River, hatchery chum and coho salmon are derived from native stock. However, it is no longer possible to distinguish between wild and hatchery stocks in this river. Numerous stocks, including Capilano River chinook, do not represent the native stock, but a more recent introduction.

Interbreeding of cultured and wild salmon is generally believed to result in reduced gene diversity between populations that receive strays, which can limit the evolutionary potential of the species as a whole (Waples 1991). Reisenbichler and Phelps (1989) provided circumstantial evidence for the homogenizing effects of interbreeding in some steelhead populations. They suggest that electrophoretic differences among steelhead streams in the Olympic Peninsula, where substantial introductions of hatchery fish had occurred, were much smaller than those in British Columbia, where no artificial propagation had occurred. In Northern Ireland, analysis of allele frequencies of wild Atlantic salmon in a stream identified the presence of cultured salmon after an escape from a nearby farm (Crozier 1993). Subsequent analysis of offspring revealed that allele frequencies in the wild population had shifted in the direction of those in the nearby farm salmon, contributing to lower overall heterogeneity between the two types. Nevertheless, the two populations remained genetically distinct.

Bams (1976) provided evidence for the significance of local adaptation, including lower success potential of local/non-local hybrids. Bams studied returns of local, donor (wild stock 100 miles away), and hybrid pink salmon to Tsolum River, B.C., where the stocks had been fertilized, reared and released. Survival to coastal fisheries was apparently similar in all three stocks, but the local stock was markedly superior to hybrids and donor fish in locating the native tributary (83%:46%:22%). Bams concluded that hybrids as well as local fish may return to the native river region, but that high accuracy of return to the home tributary requires both male and female locally adapted gene complements. Bams also cited an unpublished study in Washington that yielded similar results involving chinook salmon, that is, homing ability was strongly associated with inherited local genes.

In a series of experiments, Brannon (1972) demonstrated population-specific traits involving the migratory behavior of juvenile sockeye salmon. Although environmental conditions influenced sockeye behavior, hybridization between sockeye populations produced fry that behaved intermediate to parent populations. This result established the genetic basis for the observed migratory behaviors, including directional responses to water flow (rheotaxis), and it is an example of how locally adapted traits can be altered by interbreeding on non-local stocks.

In the Sakhalin-Kuril region of Russia, a chum salmon population appeared to be displaced after introduction of non-local chum salmon (Utter *et al*. 1993). During 1964-1972, approximately 19-70 million non-local chum salmon eggs per year (>350 million total) were transferred from Kalininka to the Naiba River (Altukhov 1981). In some years, the donor stock exceeded egg takes at the Naiba Hatchery. Gene frequencies typical of the donor population were present in the run during the first generation after the first transfer. In subsequent generations, no trace of the donor population was found. The chum return rate declined by over 50% and total returns declined from >600,000 chum prior to the transfers to <15,000 chum in recent years. In contrast, runs to the donor river did not decline. Altukhov concluded that the sharp decline was caused by disturbance of the genetic structure of Naiba River chum salmon through introductions of non-local salmon. Unfortunately, Altukhov did not discuss or exclude other potential mechanisms that may have led to the collapse.

Some experiments involving crosses of hatchery/wild salmon and wild/wild salmon show that survival of hatchery/wild crosses is reduced. Reisenbichler and McIntyre (1977) reported lower survival in a stream by offspring of hatchery/wild trout hybrids and hatchery-reared steelhead compared to wild offspring. Hatchery/wild trout hybrids displayed greater growth in streams, but this effect was believed to be an effect of hybrid vigor, which would be lost in subsequent generations. In the hatchery pond, hatchery trout experienced the greatest survival. All steelhead in this experiment originated from the test stream, although the hatchery fish were two generations removed, thereby controlling for local adaptation of different stocks.

In a predation risk experiment, Johnsson and Abrahams (1991) crossed wild steelhead with trout that had been domesticated in a farm for over 20 years. In a laboratory tank, juvenile cultured/wild trout hybrids exposed themselves to a predator (adult rainbow trout) more than wild fish, even though the hybrid and wild trout were equally vulnerable to predation. The authors suggested that interbreeding of cultured and wild steelhead can lead to greater predation loss of hybrids. However, the predation history of the original cultured trout population was not discussed; therefore we cannot be certain that the increased vulnerability to predators was related to culture. Furthermore, a cultured trout might be expected to be less vigilant when confronted by a larger member of its own species.

In the Skagit River, Washington, returning steelhead trout were initially believed to be sustained by natural reproduction of both straying hatchery and wild steelhead, but gene frequencies of naturally produced juveniles indicated a predominance of wild parentage (reported in Hindar *et al*. 1991, Utter *et al*. 1993). Apparently, the fitness of cultured steelhead spawning in the streams was especially low. This result surprised fishery managers because only a portion of the total spawning escapement actually contributed to subsequent returns, apparently because hatchery salmon spawn timing was different from wild salmon.

Factors Influencing Gene Flow. As noted in the conceptual section, gene flow rather than stray rate is the critical factor when evaluating effects of cultured salmon straying into streams. Several studies indicate that strays from hatcheries have lower reproductive success compared to individuals from the local population, indicating that gene flow associated with strays is reduced. Fleming and Gross (1992, 1993) reported that hatchery coho salmon, particularly males, were competitively inferior to wild fish, being less aggressive and more submissive. Hatchery male salmon attained only an estimated 62% of the breeding success of wild males. In contrast, hatchery females averaged an estimated 82% of the breeding success of wild females. Hatchery females experienced delayed spawning and increased egg loss through retention and nest superimposition. Furthermore, the breeding success of hatchery coho salmon declined with increasing density.

Tallman and Healey (1994) demonstrated that the rate of straying among three native populations of chum salmon on Vancouver Island was significantly higher than gene flow, as determined by electrophoretic analysis. This study suggests that nonlocal salmon may have lower reproductive success compared to local salmon.

Preliminary results from an ongoing study in Hood Canal, Washington, further support the hypothesis that hatchery-reared salmon have lower reproductive success. Coho fry captured in streams but raised to adults in captivity were allowed to spawn with wild coho salmon in a stream. Although equal numbers of wild and captive-reared salmon were present, preliminary results indicate that wild males produced 85% of all emerging fry, based on a DNA fingerprinting technique (B. Berejikian, NMFS, pers. comm.). Results involving female salmon were less conclusive, but wild females tended to produce more progeny than did captive-reared parents. Observations of spawning fish indicated that female aggression (both wild and captive-reared) was much higher against captive-reared males than wild males. External characteristics of captive-reared salmon were markedly different from wild fish: they were heavier at given length, had different coloration, and other secondary sexual characteristics were not as pronounced. Nevertheless, the study demonstrated that captive-reared salmon were reproductively competent. No difference was discovered in viability of eggs to hatching. This study is consistent with that by Fleming and Gross in that selection was most intense on male salmon.

Another factor that may limit gene flow between cultured and wild salmon on the spawning ground is spawn timing. Several studies have indicated that spawn timing of stray cultured salmon was different from the local population to which they strayed (Nickelson *et al*. 1986, Lura and Saegrov 1993, Webb *et al*. 1991, 1993). For example, Nickelson *et al*. (1986) reported that the early spawn timing of returning presmolt coho salmon stocked into Oregon streams led to reduced densities of offspring in subsequent years when compared to unstocked, control streams. Presumably, the early spawn timing of surviving cultured salmon led to greater mortality of progeny. In Norway, farm Atlantic salmon were found to spawn earlier than the local population (Lura and Saegrov 1993). The authors hypothesized that early emergence in spring probably reduces survival of cultured salmon offspring. Other studies have reported farm salmon to spawn later than wild fish (Webb *et al*. 1991, Gudjonsson 1991). Earlier spawning salmon, whether cultured or wild, may be more vulnerable to redd superimposition (uncovering of nests) and destruction of redds by fall storms.

Distribution of spawning wild and cultured salmon within the same drainage could influence gene flow between populations. Webb *et al*. (1991) reported that Atlantic salmon escaped from a farm and observed in a Scottish river tended to spawn in lower reaches, whereas wild Atlantic salmon spawned in the upper reaches. More than 330 farm salmon were observed in the river. Farmed salmon tended to spawn later than wild salmon, although there was considerable overlap. Farmed fish of both sexes were observed to spawn freely with wild fish, although no confirmation of hybridization was presented. While this study appears to provide evidence that farm salmon might spawn in different locations from wild conspecifics, it was confounded by the possible imprinting of approximately 23% of the farm salmon at a river located in the lower river (origin of the escaped salmon was suggested but not confirmed).

Summary of Interbreeding Effects

- Many traits of Pacific salmon appear to be population-specific, important to the survival of local stocks, and genetically based, especially in larger populations (>1,000 fish) where random genetic drift is minimal.
- Genetic effects of interbreeding of nonlocal and local salmon are difficult to predict because gene flow between populations and selection coefficients of locally adapted traits are typically unknown.
- Field studies show that wild salmon discriminate against cultured salmon, especially male cultured salmon. Thus gene flow is likely less than that indicated by the stray rate (i.e., proportion of spawning fish represented by cultured salmon).

- Low levels of continuous gene flow between nonlocal populations (e.g., 5% per year) can lead to 50% loss of genetic variability within 12 generations.
- A genetic workshop involving international experts concluded, in reference to an interim NMFS standard, that there is no genetic justification for allowing continuous gene flow from non-local fish at levels as high as 5% per year.
- A variety of empirical studies suggests that population characteristics can be altered by interbreeding with nonlocal salmon, suggesting that survival can be reduced.

C. INTERSPECIFIC HYBRIDIZATION

The primary concern involving interspecific hybridization is mating between Atlantic salmon and species of salmon and trout native to the Pacific coast (i.e., *Oncorhynchus* spp.). The following discussion describes results of studies involving laboratory crosses of Atlantic salmon and Pacific salmon and trout.

One of the most comprehensive investigations of hybridization between Atlantic salmon and Pacific salmon and trout is being conducted by Dr. Robert Devlin, West Vancouver Laboratory, Department Fisheries and Oceans. Logistics of this study were complicated by different spawn timing of the seven test species. In order to conduct the experiment properly, the researchers needed to collect eggs and milt from ripe individuals of all species within a few days. Spawn timing of pink salmon, steelhead trout and cutthroat trout were dissimilar to Atlantic salmon; steelhead and cutthroat crosses were performed using cryopreserved milt. A fall spawning stock of rainbow trout was used rather than typical spring spawning populations. All fish employed in the study originated from farms and hatcheries.

The initial pilot study involved two adults of each sex of each species. For each cross, approximately 500 eggs were fertilized from two females of each species. Hybridization was unsuccessful (0% survival) between Atlantic salmon and coho, chum, chinook, sockeye salmon, and rainbow trout (Table 10a). The only successful cross to the hatching stage involved female Atlantic salmon and male pink salmon; survival was 5.5%. Survival of interspecific crosses among Pacific salmon ranged from 0% to 93.2%. Pink salmon tended to hybridize more successfully with other species than did other salmonids. In comparison, survival to the hatching stage of conspecific crosses (e.g., chum x chum) ranged from 54.6% for rainbow trout to 94.9% for chum salmon; survival of Atlantic salmon eggs was 64.1% (Table 10a).

The second series of hybridization tests by Dr. Devlin involved much higher sample sizes (2,325 to 81,254 eggs per cross), plus the addition of cutthroat trout. This series of tests demonstrated minimal survival between Atlantic salmon and each species of *Oncorhynchus.* Among successful crosses, survival to hatch ranged from 0.0012% for male steelhead crosses to 6.07% for female steelhead crosses (Table 10b). Survival of crosses with Pacific salmon was <0.5%. No cutthroat trout hybrids survived to hatch.

Atlantic salmon hybrids surviving to hatch have been maintained in aquaria at the West Vancouver Laboratory for approximately three years. Preliminary results indicate survival from hatch to near maturing adult is approximately 4.5% for steelhead hybrids and 6% for pink salmon hybrids; some coho and chum salmon hybrids are still alive. Thus, survival from egg to near maturing adult under hatchery rearing conditions is approximately 0.14% for steelhead hybrids and 0.01% for pink salmon hybrids. Although Dr. Devlin would like to complete this experiment by spawning successful hybrids, the Aquaculture Division at the West Vancouver Laboratory was scheduled to be terminated at the end of 1996.

Survival of some eggs and fish in hybridization experiments can be potentially explained by gynogensis, a mechanism where the egg becomes fertilized without genetic contribution from male salmon or where a triploid (sterile) fish is produced having two doses of female genes plus the male genes. However, subsequent electrophoretic analyses by Dr. Devlin on fish that have died have identified few, if any, fish produced by gynogensis.

Table 10a. Percent survival to hatch of F1 progeny from small-scale (approx. 500 eggs/cross) interspecific salmonid crosses.

Note: male fish are listed on vertical axis. Source: R. Devlin, DFO, pers. comm.

Table 10b. Percent survival to hatch of F1 progeny from interspecific crosses between Atlantic and Pacific salmon.

Note: steelhead and cutthroat crosses were performed using cryopreserved milt.Source: R. Devlin, DFO, pers. comm.

Hybrid studies such as this have several shortcomings. First, the hybridization success rates presented here are approximations because hybridization success will likely vary with stock and year (Devlin, pers. comm.). Second, survival studies in controlled aquaria environments likely enhance the chance for survival of eggs and fish. For example, 99% dead eggs in a nest located in a river might attract fungus or other pathogens that cause additional mortality. This mechanism was proposed by Ricker (1954) as one that led to overcompensation in the spawner-recruitment relationship of Pacific salmon. Third, Atlantic and Pacific salmon and trout in the wild might have less probability of mating because mating behavior, physical appearance and spawn timing may be inappropriate. Nevertheless, the laboratory hybridization experiment provides valuable information showing the low potential for hybridization.

Other investigators have examined hybridization success of Atlantic salmon and other salmonids. Blanc and Chevassus (1979) reported 100% mortality of Atlantic salmon/coho salmon crosses at the eyed egg stage. Atlantic salmon/rainbow trout crosses were only 3.2% as successful as rainbow trout/rainbow trout crosses to the 15th day after hatching. No Atlantic salmon/rainbow trout crosses survived to age four months (Blanc and Chevassus 1982). Although 76% of Atlantic salmon/brown trout (S. trutta) crosses survived to the eyed stage, survival declined to 5.2% of normal crosses on the 15th day after hatching. Atlantic salmon/brown trout crosses in this study survived only four months, but other investigators have shown offspring from this cross to survive longer. Brown trout are not native to the Pacific Coast, but they have established at least three self-sustaining populations on Vancouver Island (CDFO 1997). This suggests the possible opportunity for hybridization between these species, but only one Atlantic salmon to date has been observed in streams known to contain brown trout.

D. TRANSGENIC SALMON

“Transgenic” fish are defined as fish having within their genetic makeup (chromosomal DNA) copies of novel genetic constructs introduced through molecular genetics techniques (Kapuscinski and Hallerman 1990). Transgenic animals are usually the result of microinjection of DNA into newly fertilized eggs. The result is an individual who has newly integrated DNA within its genetic composition. Although the techniques frequently fail, fish geneticists have been able to engineer new attributes into experimental lots genetically.

Transgenic fish may be descendants of engineered transgenic parents, i.e., the introduced DNA may be inherited by the transgenic fishes’ offspring. The genetic injection may be derived from conspecifics, unrelated species, or from combinations of inter- and intraspecific sources. According to Kapuscinski and Hallerman (1990), 13 species of fish involving successful transgenic experiments were reported as of the onset of the 1990s, including transgenic Atlantic salmon. Since then, successful transgenic experiments have been conducted with chinook salmon, coho salmon, rainbow trout and cutthroat trout (Devlin *et al*. 1994, 1995). The purpose of these genetic experiments has been to produce favorable altered characteristics among transgenic fish, e.g., increased growth rate and feed conversion efficiencies, altered behavior, maturation rate, disease resistance, reproduction rates, etc. The laboratory results of some experiments have been quite impressive. For example, Devlin *et al*. (1994, 1995) developed transgenic salmon in the laboratory that were, on average, approximately ten times heavier than non-transgenic control salmon after 14 months.

Escape of transgenic fish into natural environments introduces the possibility that their descendants could adapt to the release environment and produce fertile offspring as a result of mating with other transgenic or, if sterilization failed, local wild stocks. A result could be a variety of offspring having transgenic genotype with varying adaptive values. Changes that might be expected by the introduction of transgenic fish might be comparable to the introduction of closely related non-native species. However, given the tremendous growth potential of transgenic salmon shown in the laboratory, transgenic fish could out-compete wild salmon for resources.

The development of fast-growing transgenic salmon and the concern to maintain healthy native populations has led countries such as Canada to develop draft policies and guidelines for transgenic aquatic organisms. These policies describe the need for both physical and biological (reproductive) containment of transgenic organisms (Hallerman and Kapusinski 1990, CDFO 1994).

The salmon farming industry in B.C. presently does not raise transgenic salmon and they have no plans in the future to do so (G. D'Avignon, BCSFA, pers. comm.). In general, the international salmon farm community is opposed to the use of such genetically engineered salmon because the public perception of transgenic salmon could harm salmon sales. On 13 September 1996, the International Salmon Farmers Association (ISFA) issued a statement that they disapproved of transgenic salmon production (ISFA memo provided by G. D'Avignon, BCSFA).

E. COLONIZATION OF ATLANTIC SALMON

The potential for colonization will depend on the suitability of the environment into which the exotic species is introduced, interspecific competition and other ecological interactions. In terms of Atlantic salmon considerable experience exists with attempts to introduce this species into Pacific waters and other regions outside the native range of this species.

Global Attempts to Introduce Atlantic Salmon

Due to their popularity as game fish in the United Kingdom, efforts have been made to introduce Atlantic salmon into several regions of the world. In the Southern Hemisphere, introduction attempts were made in Tasmania beginning in 1864, New Zealand from 1868 to 1911 (Gibbs 1981), the Falkland Islands from 1959 to 1964 (Stewart 1977), Argentina from 1904 to present (MacCrimmon and Gots 1979), and Chile from 1905 to 1935 (Lindbergh 1984). In Europe, attempts were made to introduce Atlantic salmon to Italy and the Mediterranean Sea (Sommani 1976).

All of these attempts failed to establish sea-run populations. Some Atlantic salmon in Chile returned to two rivers and successful spawning was suggested; however, the run eventually failed by 1940. Stewart (1977) theorized that the lack of success in introducing anadromous populations in South America was due to the fact that oceanographic gyres in the Southern Hemisphere circulate in the opposite direction, which could have swept migrating salmon away and thus prevented their return.

Two landlocked populations were established in New Zealand (Gibbs 1981, Lindbergh 1984). The landlocked populations began declining after 1920 and presently there are few, if any, Atlantic salmon remaining. The demise of Atlantic salmon may have been caused by the introduction of rainbow trout, which have established an abundant population in these lakes.

A number of self-sustaining landlocked Atlantic salmon runs have become established in Argentina (McClane 1965, MacCrimmon and Gots 1979). These populations were established using landlocked stocks in streams and lakes having few fish. Although these streams had access to the ocean, no anadromous salmon have been reported.

Atlantic salmon have also been introduced to non-indigenous systems within their natural range, or reintroduced to systems that have depleted or extinct stocks. In Norway, attempts have been made to enhance native Atlantic salmon stocks through annual releases of fry into streams and rivers which are inaccessible to returning adults (Heggberget and Hesthagen 1981). Repopulation of the River Esva in Spain with Atlantic salmon was undertaken using one stock from Scotland and the other from remaining River Esva fish. Subsequent chromosome pattern testing indicated that the Scottish stock had failed completely, suggesting that exotic stocks compete poorly with native stocks (García-Vázquez *et al*. 1991).

In Canada, attempts were made to reintroduce Atlantic salmon to the Great Lakes, with numerous plantings from 1867 to 1980. Atlantic salmon had historically existed in Lake Ontario. All of these plantings failed to establish a self-sustaining population (Emery 1985).

British Columbia and the Pacific Northwest

Numerous attempts have been made to establish Atlantic salmon runs in British Columbia and Washington. Between 1905 and 1935, more than 7.5 million eggs, fry, fingerlings and yearlings were stocked into 57 different streams in B.C. during the course of 172 reported releases (Table 11; MELP Release Record Database in Burt *et al*. 1992). Many additional Atlantic salmon may have been released because Neave (1949) reported that more than 5.5 million fish were planted into the Cowichan River alone (a number that greatly exceeds the number reported by the MELP Release Record Database. Donor stocks originated from the Canadian Atlantic coast (primarily Miramichi River stock) and Scotland (Thurso River). Most releases were made into selected rivers and lakes on the east coast of Vancouver Island and in the lower Fraser River valley, including the Cowichan River drainage, Weaver Cr., Nixon Cr., Oliver Cr., Robertson Cr., Shaw Cr., and Sutton Cr. (MacCrimmon and Gots 1979, Black 1995).

Table 11. Intentional Atlantic salmon releases in British Columbia streams, 1900-1935.

Note: The above releases were made in 57 different river systems. Source: Burt et al. 1992.

Only a few returning fish were recovered from these early transplants, and Neave (1949) concluded that the attempts to establish Atlantic salmon in B.C. had failed.

Attempts were also made to introduce Atlantic salmon to landlocked waters in Banff and Jasper National Parks between 1915 and 1923; additional attempts were made to introduce Atlantic salmon into streams and lakes in Banff and in Waterton Lakes National Park during 1959 to 1963 (MacCrimmon and Gots 1979, Burt *et al*. 1992). These releases were intended to provide tourists and local sport fisheries with an alternative, highly prized trophy fish. These fish did not appear to reproduce and no further plantings were attempted. There is no record of recoveries over the 1915-1923 time period. No assessment of why the project failed was conducted.

Attempts were also made to introduce Atlantic salmon to Washington, Oregon, California and New Mexico, but none have been successful (MacCrimmon and Gots 1979, Lindbergh 1984). In Washington, 1,000 smolts were released into Chambers Creek, Puget Sound, but no fish returned. In 1980, approximately 8,000-10,000 smolts were released from Minter Creek, Puget Sound. These fish were not considered to be in good condition and no fish returned to the hatchery. Approximately 2,800 Atlantic salmon escaped from a NMFS pen at Manchester in the 1970s, but no there were no confirmed reports of these fish being seen or recaptured. Early unsuccessful introductions were made into Washington lakes and streams during 1904-1910 and in 1935.

The Washington Department of Game released Atlantic salmon fry, smolts and brood fish into various lakes during the early 1960s through 1976 to provide a sport fishery. The fish were moderately successful when planted as the lone species or in combination with brook trout (*Salvelinus fontinalis)*, but did poorly in combination with rainbow trout (Lindbergh 1984). No reproduction of Atlantic salmon was observed in Washington streams. Some fish reportedly migrated downstream, possibly to the ocean, but no returning adults were recovered.

The Oregon Department of Fish and Wildlife released Atlantic salmon fry and yearlings into lakes during 1904-1905 and from 1950 to at least 1984 (MacCrimmon and Gots 1979, Lindbergh 1984). Releases have averaged from 8,000 to 15,000 fish annually. Although some releases had access to the ocean and some were captured in downstream traps, no returning adults were recovered. Spawning behavior was reported in Quinn Creek above Hosmer Lake (Deschutes Basin) and in the upper Metolius River, but no progeny from such spawning have been found in spite of intensive searches.

A variety of attempts were made between 1880 and 1900 to establish self-sustaining populations of Atlantic salmon in lakes in the Sierra Nevada mountains, California. None of the attempts was successful, although a few fish were captured by sport fishermen (Lindbergh 1984).

The authors note that all of these experiments have involved transport of Atlantic salmon eggs or fry. Thus survival potential may be significantly different than those involving the escape of Atlantic salmon from farms adjacent to potential spawning rivers.

Competition Between Pacific and Atlantic Salmon

Several authors examining colonization of Atlantic salmon suggested that competition in freshwater between juvenile Atlantic salmon and Pacific salmon and trout may have been a primary factor leading to unsuccessful colonization (Neave 1949, Lindbergh 1984, Burt *et al*. 1992). They noted that abundance of Atlantic salmon declined after introductions of Pacific salmon or trout. Little or no competition would be expected with juvenile pink and chum salmon, which spend little time in freshwater before emigrating to sea.

A few studies of competition have been conducted, primarily to determine potential impacts on Atlantic salmon of exotic Pacific salmon and trout planted into eastern North American streams. Atlantic salmon and steelhead appear to be most similar in their ecological requirements because both tend to inhabit riffle areas (Gibson 1981). In the study by Gibson, steelhead were more aggressive compared to Atlantic salmon of similar or slightly larger size, but Atlantic salmon were more aggressive compared to coho salmon, which tend to inhabit pools. Beall *et al*. (1989) reported that survival of Atlantic salmon fry declined in the presence of larger coho salmon fry. Fewer Atlantic salmon fry occupied pools in the presence of coho and growth of the Atlantic salmon fry was reduced. Jones and Stanfield (1993) reported that growth and survival of hatchery-reared Atlantic salmon parr were significantly greater in stream reaches after removal of larger coho fry and yearling rainbow and brown trout. The potential for competition between coho and Atlantic salmon may increase with age of Atlantic salmon as they move into pools (Fausch 1988). Hearn and Kynard (1986) found no evidence of competition between underyearling rainbow trout and Atlantic salmon, but habitat use by yearling Atlantic salmon changed in the presence of similar size rainbow trout.

Lindbergh (1984) cited a number of unpublished observations by agency personnel that suggest Atlantic salmon may not compete effectively with rainbow trout and possibly brook trout (*Salvelinus fontinalis*), a species introduced from the east coast of North America. In Chopaka Lake, Washington, Atlantic salmon yearlings (25-36 cm) were observed only in shallow areas of the lake (within 6 m of shore), presumably a response to the large rainbow trout population (length and weight of trout not reported). The condition factor of the yearling Atlantic salmon (weight in relation to length) was very low compared to the rainbow trout. In another study, Atlantic salmon and rainbow trout were raised concurrently in a 1.8 m diameter tank (0.6 m deep); the rainbow trout continuously "harassed" the Atlantic salmon and reportedly "forced" them into the outer 15 cm of the tank. In Hosmer Lake, Oregon, Atlantic salmon reportedly did not compete effectively with either rainbow or brook trout. In New Zealand and Chile, Atlantic salmon introductions either failed or established minimal land-locked populations, whereas introduced rainbow trout flourished in the same lakes and rivers.

In contrast to the studies presented by Lindbergh (1984), Lough *et al*. (1997) reported that the condition factor of juvenile Atlantic salmon (parr to smolt stage) captured after multiple escapes in Georgie Lake was not statistically different from Atlantic salmon sampled in net pens. The Atlantic salmon were present in the lake for an unknown period after escape. Stomach content analysis indicated that 52% of the Atlantic salmon contained prey (primarily insect larvae and amphipods) compared to 65% of the native cutthroat trout and Dolly Varden char. Lough *et al*. suggested that , in contrast to rainbow trout, native cutthroat trout and Dolly Varden char populations in Georgie Lake may not adversely affect growth of Atlantic salmon.

Size of fish can be an important factor influencing dominance during competitive interactions. In order to compare size of Atlantic salmon and steelhead at the time of emergence in a B.C. stream, Brian Ludwig (MELP, Fisheries Branch, pers. comm.) calculated the date of emergence of Atlantic salmon and compared this to the observed date for steelhead at the Quatse hatchery. The calculation used the relatively slow development rate of Atlantic salmon (800 temperature units to reach swim-up). Assuming equal size at emergence (0.2 g) and equal growth rates thereafter, Ludwig estimated size of the two species on 1 July. Assuming Atlantic salmon spawned on 15 December, Atlantic salmon fry would be twice the size of steelhead on 1 July (1.4 g vs 0.6 g). Although studies have shown that steelhead can displace Atlantic salmon fry of equal or slightly larger size (Gibson 1981), this calculation by Ludwig suggests that dominance by steelhead might be reduced if Atlantic salmon fry emerge at an earlier date compared to steelhead and if sufficient food is available to the early emerging Atlantic salmon. In contrast, Harache (1992) suggested that coho fry would be large compared to Atlantic salmon fry because coho typically spawn and emerge from gravel earlier than Atlantic salmon and because coho are larger at emergence. In B.C., the relative size of juvenile Atlantic salmon compared to Pacific salmon would likely depend on time of spawning, which could range from approximately October to January.

After reviewing studies of competition between native and introduced juvenile salmonids in streams, Fausch (1988) suggested that most studies were not rigorous and that mechanisms leading to competition were often not identified. Competition among salmonids in streams is dynamic and dependent on many factors, including availability of resources, population densities and relative size of fishes. This complexity makes generalizations about competition between two species difficult.

Few, if any, observations have been made of interactions between adult Pacific and Atlantic salmon on spawning grounds. Both Pacific and Atlantic salmon typically spawn in gravel-bottom riffles above or below pools. Spawn timing of Atlantic and Pacific salmon varies with species and stock, but generally occurs during fall to winter. Harache (1992) noted that Atlantic salmon typically spawn later than Pacific salmon, but suggested that behavioral interactions between the species are possible given overlap in timing and preferred spawning habitat. The outcome of behavioral interactions has not been observed in streams, but one can expect that a female salmon (Atlantic or Pacific) would protect her redd (egg nest) until death against subsequent spawners, regardless of species. Disruption of Pacific salmon redds by late spawning Atlantic salmon is possible, but adverse impacts would require significant density of Atlantic salmon on the spawning ground and overlap in habitat preference. In most B.C. streams during recent years, adult Atlantic salmon likely represent a small percentage of total spawning salmon (<1%, e.g., Lough *et al*. 1997).

The North Atlantic Experience with Farmed and Wild Salmon

Farming of Atlantic salmon by North Atlantic rim countries began around 1970 and has subsequently grown dramatically. By 1989, the total production was 170,000 tonnes, with about 115,000 tonnes from Norway, 30,000 from Scotland, and the remainder from the Faeroe Islands, Ireland, Canada, and Iceland (Hansen 1991).

The potential effects of escaped farm Atlantic salmon on wild Atlantic salmon populations is a major issue in these countries. The main concerns are: (1) the dilution or elimination of the genetic integrity of wild Atlantic salmon through interbreeding with, or displacement by, escaped Atlantic salmon, and (2) the transfer of diseases from farm to wild fish or vice versa (Hansen 1991). This has led to numerous studies, many of which were presented at an international symposium held in Norway in 1990, and published in a special edition of *Aquaculture* (Volume 98, 1991).

The threat to wild Atlantic salmon stocks in the North Atlantic is considered serious because of the large numbers of this species that are being cultured relative to the numbers of wild fish. For example, the 1989 production of farm Atlantic salmon in Norway was 115,000 tonnes, compared with a wild catch varying from 1,000 to 2,000 tonnes in recent years. The number of Atlantic salmon escaping from fish farms during that same year was estimated at two million fish. In comparison, about half of the 400 Atlantic salmon rivers in Norway have fewer than 100 spawners (Bergen *et al*. 1991). Heen *et al*. (1993) note that in Norway the proportion of escaped farm salmon on the spawning grounds of a number of rivers has increased in relation to the number of wild fish there. A graphic illustration of the increasing number of escaped farm salmon on Norwegian spawning grounds is shown in Figure 14. In some rivers it is apparent that the number of farm fish dwarfs wild spawners.

Migration of escaped Atlantic salmon into spawning rivers is well documented in North Atlantic rim countries (Gudjonsson 1991; Lura and Saegrov 1991; Lund *et al*. 1991; Webb *et al*. 1991). In some rivers the ratio of cultured to wild fish has reached alarming proportions. For example, an inventory of 30 rivers in Norway indicated that escaped Atlantic salmon comprised on average 13% of mature salmon in 1987 and 28% in 1988. The highest frequency was 77% in the River Os in 1988 (Lura and Saegrov 1991). In Iceland, surveys of the angling catch from four rivers during 1989 showed that the proportion of escaped salmon varied from 5.4% to 39.3% (Gudjonsson 1991). In northern Scotland, roughly half the fish returning to the River Polla in 1989 were of farm origin following a marine accident the previous winter (Webb at al. 1991).

Although escaped Atlantic salmon were documented in rivers of the North Atlantic, it was questioned whether they would be able to spawn. Carotenoid analysis on alevins and fertilized eggs from naturally produced redds confirmed successful spawning of escaped Atlantic salmon in both Norwegian (Lura and Saegrov 1991) and Scottish rivers (Webb *et al*. 1991). The rate of spawning success relative to wild Atlantic salmon remains unresolved. For example, observations on the spawning behavior of sea-ranched and wild salmon in the River Imsa, Norway, showed that ranched fish moved about more, sustained more injuries during spawning, stayed in the river for a shorter period, and had a larger proportion return to sea unspawned.

Figure 14. Proportions of wild and escaped net-pen Atlantic salmon on spawning grounds of six rivers in southern Norway, 1987-91.
Note: The empty circle indicates no data available. Source: Utter et al. 1993.

This suggests that farm Atlantic salmon have a lower spawning success rate than wild fish (Jonsson *et al*. 1991). In contrast, in the Etne and Os rivers in Norway, the ratio of spawners to redds was similar for both wild and farm fish, suggesting a comparable spawning success rate between farm and wild Atlantic salmon, although the fertility may have been lower for eggs of farm origin (Lura and Saegrov 1991).

Interbreeding of escaped and wild Atlantic salmon has also been documented. In the River Polla of Northern Scotland, wild and cultured Atlantic salmon of both sexes were observed spawning together (Webb *et al*. 1991). Thus gene-flow from farm to wild stocks is a valid concern; however, the consequences to the genetic structure and survival of wild populations awaits further study.

A recent study involving the reproductive behavior and success of fifth generation farmed Atlantic salmon and wild Atlantic salmon indicates farmed salmon are less successful. Farmed females displayed less breeding behavior, constructed fewer nests, retained a greater weight of eggs unspawned, were less efficient at nest covering, incurred more nest destruction and suffered greater egg mortality than wild females. As a result, farmed females had less than one-third of the reproductive success of wild females (Fleming *et al*. 1996). Farmed males were much less successful than the farmed females in competition with wild fish; farmed males experienced only 3% of the reproductive success of wild males. Farmed males exhibited inappropriate mating behavior that led to poor fertilization success even in the absence of competition with wild males. Fleming *et al*. concluded that adult farmed salmon are likely to be relatively unsuccessful in the natural environment due to a competitive and reproductive inferiority apparently resulting from domestication.

Observations of spawning by escaped Atlantic salmon suggest that farm salmon tend to spawn later than wild fish (Webb *et al* 1991; Gudjonsson 1991). This has raised concerns that escapees may dig up the redds of wild salmon and thereby lower the reproductive success of wild fish. Indeed, in the River Polla, Scotland, females of cultured origin were observed digging up the redds previously created by wild fish (Webb *et al*. 1991).

Experimental releases of cultured Atlantic salmon have been undertaken to assess their survival, migration and homing abilities in the open ocean. Ocean survival was found to vary with the age of the fish and the time of release. Salmon released as smolts had poorer survival compared to larger, older adults. Fish released during their first year in sea cages had a much greater ocean survival when released in the spring compared with other times in the year (Hansen and Jonsson 1989). Fish released as smolts at the mouth of the River Imsa, Norway, survived about half as well as wild fish, although there was no significant difference in growth rates between the two groups (Jonsson *et al*. 1991).

Experimental releases of farm Atlantic salmon have also indicated that fish released while immature migrate to traditional wild salmon feeding grounds in the North Atlantic (Hansen *et al*. 1987). Upon return to spawning rivers, cultured salmon tended to enter fresh water later than wild fish (Gudjonsson 1991; Gausen and Moen 1991; Jonsson *et al*. 1991; Lund *et al*. 1991).

Studies on the migration of released Atlantic salmon have supported the hypothesis by Harden Jones (1968) that homing in salmon is imprinted sequentially during smolt migration. On the River Imsa in Norway, smolts released directly into the river homed with a high degree of precision back to the river; smolts released from farms tended to return to the area of the farm first and then entered the nearest river; fish released from farms as adults were less discriminate in the rivers they ascended (Hansen *et al*. 1987). The farm releases of smolts and adults migrated back to the point of release, rather than to their natal stream despite being exposed to river water during freshwater rearing. Hansen and Jonsson (1991) released salmon from a farm on a monthly basis during their first year at sea and found that fish released during the winter strayed more and entered rivers further away than fish released during the summer. The straying rate increased from just over 20% for early summer releases to over 60% for winter releases.

In Norway a number of actions have been taken, or are planned, to reduce the potential effects of farm escapees on wild stocks. A detailed description is given in Bergen *et al*. 1991. In summary, these include:

(1) Preventative measures: excluding new farms from within 20 km or more of important salmon rivers, technically improving fish farms, limiting the production per unit of cage volume and introducing strict rules for the transport of live fish.

(2) Recovery of live escaped salmon: acting promptly to recover escapees in the sea as soon as they occur, constructing traps in fish ladders to separate farm and wild salmon, and initiating a fishery in estuaries late in the season when there is a high proportion of farm fish.

F. Predation

Predation by Escaped Salmon on Wild Salmon

Predation on salmon is often most intense in "bottlenecks" where salmon are concentrated, thereby allowing predators to aggregate (Ruggerone 1992). Concentrations of salmon can occur during emergence from spawning gravel, migration of smolts to sea and spawning in rivers. In some freshwater areas over 50% of a population may be consumed by predators (Ruggerone and Rogers 1992). Recently, significant predation on salmon (> 50% of salmon population) was documented in Alberni Inlet and Barkley Sound, Vancouver Island, where predators such as Pacific hake, walleye pollock, and spiny dogfish can be abundant (Hargreaves 1992). Predation by fishes on salmon is typically size selective and smaller salmon are consumed more frequently than larger salmon (Parker 1971; Hargreaves and LeBrasseur 1986; Ruggerone 1989).

Escaped farm salmon can be expected to select prey based on prey size, their own size and availability of prey. Larger escaped salmon will likely consume, on average, larger prey. Although all salmon introduced to sea net pens can consume small salmon, larger farm salmon will likely consume more fish than smaller salmon.

Escaped salmon may not begin feeding on wild prey for some period after escape because they have been domesticated and they have been trained to consume fish pellets rather than live prey. Stomach samples removed from Atlantic salmon captured in marine and freshwaters support this observation. Furthermore, maturing Pacific salmon and Atlantic salmon stop feeding upon re-entry to freshwater for spawning; the same can be expected of maturing farm salmon if they re-enter freshwater.

Nearly 450 stomachs of escaped Atlantic salmon caught in marine fisheries in B.C. have been examined (McKinnell *et al*. 1997). Only 5.8% of these fish contained prey. In contrast, 13.1% of 61 Atlantic salmon recovered in Alaska contained prey. Herring (*Clupea harengus pallasi)* was the dominant prey consumed; no salmon were found in stomachs.

The frequency of escaped Atlantic salmon feeding in B.C. and Alaska is considerably lower than that reported for wild coho and chinook salmon in marine waters of B.C. (range: 61-80%) or that reported for wild Atlantic salmon (up to 35%) in their native range (McKinnell *et al*. 1997).

In Washington, Department of Fish and Wildlife biologists became concerned when approximately 45 large, but immature, Atlantic salmon were discovered in the Dungeness River during August 1996 because the Atlantic salmon might prey upon juvenile spring chinook (D. Seiler, WDFW, pers. comm.). Dungeness spring chinook is considered very depressed (only 14 females returned in 1996) and attempts are underway to rebuild the stock through a captive brood stocking program. WDFW removed 20 Atlantic salmon from the river by hook-and-line. To date, nine fish have been examined; stomachs of all nine fish were empty and a swollen gall bladder suggested they had not consumed food for a while. All fish were robust, as would be expected from a recently escaped farm salmon. Presumably, these fish originated from the large escape near Anacortes, Washington, in early July.

The *Seattle Times* recently published a newspaper article on Atlantic salmon caught by sport fishermen in the Elwha River (12 November 1996). A sport fisherman "biologist" was quoted as saying that one Atlantic salmon "had a bellyful of king salmon eggs, meaning that the fish have the capacity to interfere with already depleted native salmon runs." This statement is misleading because salmon eggs consumed by fishes, such as char or

Atlantic salmon, are eggs that have not been covered by gravel (Hubbs 1940) and are dead as a result of brief (minutes) exposure to light (Leitritz and Lewis 1976). Thus, consumption of eggs by escaped Atlantic salmon would have no impact on the native spawning stocks; however, some reduction in food (eggs) for small salmonids may result.

Predation by Caged Salmon

Juvenile herring, salmon and other species have been seen in or around salmon net pens. Occasionally predation by caged salmon on wild fish is witnessed on farms. Because of concern over numbers of wild fish consumed by caged salmon, MAFF initiated three studies to evaluate predation and food consumption in net pens.

In the 1989-1990 study, stomachs of 2,059 chinook salmon and 60 coho salmon were sampled from ten farms near the Queen Charlotte Islands and Georgia Strait during mid-April to mid-June (Black *et al*. 1992). This time period corresponded to the migratory period of juvenile salmon in the area. Observations and sampling by purse seine confirmed that juvenile salmon were present near the farms. On ten occasions, large schools of chum and pink salmon fry (up to 10,000 fish each) were observed immediately outside the cages, but none were observed inside the cages.

Fewer than 1% of the sampled farm salmon contained fish remains. Juvenile herring (~0.7 g) was the only fish identified in stomachs. Coho salmon tended to consume more prey than did chinook salmon. Coho also consumed relatively more fish prey. Invertebrates, especially amphipods associated with fouling nets, were consumed more frequently than fish.

Consumption of woody debris was examined in a separate study by MAFF. The percentage of farm salmon that consumed woody debris ranged from 21% to 80% depending on the test group (Black and Miller 1993). Apparently, farm salmon confused wood debris with food pellets. The authors noted that consumption of wood debris caused up to 90% of mortalities in studied net pens because digestion was impaired or blocked.

In the 1996 study, stomach contents of Atlantic salmon (length: 30-80 cm) were sampled from farm sites with and without night illumination lights. Night illumination is used by some farms in B.C. and Norway to enhance growth through natural hormonal changes influenced by light, especially during the short days of winter. Although growth of such fish is enhanced, food consumption does not necessarily increase. Night lights may be used from approximately November through June. However, public concern has risen in that night lights might attract wild prey, such as salmon, herring and eulachon (*Thaleichthys pacificus*), into net pens, thereby allowing caged salmon to consume them and possibly impact their populations. The study was conducted at four farms near north Vancouver Island during early May to mid-July, a period when juvenile salmon and herring are expected to be abundant in this area (Hay *et al*. 1996; E. Black, MAFF, pers. comm.). Approximately 600 stomachs of farm salmon were examined from the four sites; additionally, 134 stomachs were sampled from a farm site near the Pacific Biological Station. Of the samples from northern Vancouver Island, approximately 180 fish stomachs were taken from one farm site that utilized night illumination.

Preliminary results indicate that only one fish (sandlance, *Ammodytes hexapterus)* was consumed by the sampled salmon in both illuminated and non-illuminated cages. The single wild fish was recovered from a salmon in a non-illuminated cage. Few larval fish were observed in the area and no larval fish were observed in the farm salmon, but the authors indicated that larval fish might have been infrequently consumed. Unidentified wild fish were observed in the net pens and could have been consumed by the salmon, if they chose to feed on them. Very few wild prey, such as small crustaceans associated with fouling nets, were consumed.

In Puget Sound, juveniles of wild fishes, such as clupeids, osmerids and embiotocids, have been observed to seek refuge inside net pens. Many apparently prefer to be inside the cage with farm fish because some have grown too large to exit through the mesh. Net pens, especially those with Atlantic salmon, can contain hundreds or thousands of wild fishes that enter the cages voluntarily but grow too large to exit (B. Waknitz, NMFS, pers. comm.).

In summary, results of the 1996 study are consistent with observations of farm Atlantic salmon recovered in marine waters and the previous study involving caged salmon. Night lights did not appear to increase consumption of fish prey that might enter the cages. In all instances, farm salmon consumed few wild fishes, especially when compared with expectations based on observations of wild salmon in the cage area. It appears that farm salmon have become trained to consume pellets rather than fishes, although they occasionally consume invertebrate prey. The higher frequency of feeding by Atlantic salmon in Alaska compared to British Columbia might be related to the potentially longer period since captivity and greater time to learn how to consume wild prey.

G. Competition

Competitive interactions between individuals within a species and between species is generally believed to be a primary force involved in the structuring of animal communities. In general, competition is potentially greatest among closely related species compared to distantly related species (Schoener 1983). Effects of intraspecific competition are generally greater than interspecific competition. Interspecific competition is often unidirectional, such that one species typically dominates interactions with another species and the subordinate species typically has little impact on the dominant species (G. Orians, University of Washington, pers. comm.). However, relative size of the interacting individuals often plays an important role; larger individuals may dominate smaller individuals. One apparent result of competition in a stable environment is that coevolved species typically reduce competitive interactions by occupying different niches. Competition may occur when species niches overlap. Considerable research has focused on competition, but such studies have met only limited success because of the complicated, synergistic nature of competition in nature. Competitive interactions are generally defined as either exploitative (e.g., sharing a common food source) or interference (e.g., aggressive encounters) competition. Investigations of competition are further complicated by the fact that individuals may compete for many resources (e.g., prey species and sizes, rearing areas, spawning areas) and the availability of these resources is seldom stable over time. Typically, important competitive interactions have been demonstrated only when one or more resources are in short supply (Weins 1977).

Most competitive interactions among salmonids are likely to occur in freshwater or estuaries, although inferences involving competition for food in the ocean have been drawn from observations of density-dependent growth of returning salmon (Rogers and Ruggerone 1993). Competition between juvenile salmonids can result either in the disruption or the displacement of one species by a behaviorally dominant species or in reduced growth and survival (Slaney *et al*. 1985).

Although cultured salmon may have fewer locally adaptive traits compared to local wild salmon, introductions of cultured salmon can negatively affect wild salmon. Some investigators have shown cultured salmonids (coho and cutthroat trout) to be more aggressive than wild fish (Swain and Riddell 1990, Mesa 1991), although aggressive interactions may be a function of recent foraging history (Berejikian 1995). Some investigators have shown that while cultured salmonids often prevailed during agonistic encounters with wild salmonids, survival of the cultured fish was reduced because energy expenditure was greater (Bachman 1984). The large size of cultured salmon introduced into streams likely provides some advantage over wild salmon.

Large introductions can disrupt existing interactions among native fishes in a stream, possibly leading to reduced survival. In 15 Oregon streams, Nickelson *et al*. (1986) demonstrated that density of wild juvenile coho salmon declined approximately 44% in 15 streams stocked with hatchery presmolt coho salmon. The decline of wild coho was believed to result from competition between smaller wild coho and larger hatchery coho. This study is an example of how numerous, large hatchery salmon can influence wild salmon survival. Additional examples of competitive interactions among cultured and wild salmonids are reviewed by Slaney *et al*. (1985).

Late-spawning salmon can disrupt redds of earlier-spawning salmon. Evidence of redd disruption by farm salmon has been observed on Atlantic salmon streams (Webb *et al*. 1991). Although cultured salmon tend to be discriminated against by wild salmon, some cultured salmon are successful in competing for mates (Fleming and Gross 1992; Fleming *et al*. 1996), thereby leading to reduced effective population size of the wild population (Utter *et al*. 1993).

An indirect effect that abundant hatchery salmon can have on wild salmon occurs during commercial fishery harvests. Hatchery salmon can sustain much greater harvest rates compared to wild salmon because fewer eggs are needed to reproduce the population. If harvest management manages a mixed-stock fishery based on hatchery rather than wild salmon abundance, then the wild salmon populations will be overharvested. A prime example of this indirect interaction is the demise of wild coho salmon in the Columbia River (Jonsson *et al*. 1991). This indirect effect should not occur at current levels of escaped salmon from farms.

Competition in the marine environment between escaped salmon and wild stocks is unlikely to be an important factor at present levels of escapes primarily because the numbers of escaped salmon compared to wild populations has been extremely low. Much of the feeding of wild fish throughout a major portion of their life cycle occurs in ocean areas at great distances from farm sites. Furthermore, feeding rates of escaped Atlantic salmon appear to be low compared to local wild stocks or Atlantic salmon within their native habitat. Nevertheless, localized competition of escaped Atlantic salmon in close proximity to farm sites could occur until the fish disperse over broader area.

H. Disease Transmission

The potential transfer of diseases of farm salmon to wild salmon is a key topic of concern. Disease transfer is discussed in the Fish Health discussion paper.

IV. RISK ASSESSMENT

The following assessment of risk associated with salmon escaping from farms and interacting with wild salmon is based on historical numbers of escaped farm salmon in B.C. We have not attempted to evaluate the consequences of increased numbers of farms and salmon production, although, in general, risks would likely increase with greater numbers of escaped farm salmon.

A. Proximity of Salmon Farms Relative to Native Salmon Spawning Grounds

A key component to the evaluation of adverse risk of escaped farm salmon on native salmon populations is the proximity of native salmon spawning areas to clusters of salmon farms. Native populations that are close to salmon farms may have higher risk than those further away simply because the probability for interaction is greater. However, it should be noted that straying tends to increase with age (Quinn 1993) and vary with season at release (Hansen and Jonsson 1991). Thus, escapes of larger, older salmon may disperse more than those that escape shortly after entry to saltwater.

Native salmon populations in watersheds where Atlantic salmon hatcheries operate may experience greater numbers of Atlantic salmon, which may be attracted to water qualities of the watershed.

B. Potential Genetic Effects of Spawning with Native Salmon

Intraspecific Genetic Effects

The genetic consequences of successful breeding between farm and wild chinook and coho salmon in B.C. are difficult to predict with certainty because the amount of gene flow and the degree of natural selection acting on locally adapted traits are typically unknown. Escaped farm salmon may enter streams to spawn, but some discrimination by wild salmon is likely to reduce spawning success of farm salmon (Fleming and Gross 1992, 1993; Berejikian, NMFS, pers. comm.). The effects of continued gene flow on neutral, weak or moderately adaptive alleles will likely result in reduced genetic diversity. However, the consequences of interbreeding of farm and wild chinook and coho salmon on fitness or productivity of the wild population are somewhat unpredictable.

A primary conclusion from a genetics workshop involving an international group of experts was that there is no genetic justification for allowing continuous gene flow from non-local fish at levels as high as 5% (Waples 1995). This conclusion was in response to an interim standard established by the NMFS to protect salmon stocks listed under the U.S. Endangered Species Act from straying of non-local cultured salmon. This conclusion was based on continuous gene flow rather than intermittent gene flow or straying.

A number of empirical and experimental studies have suggested negative effects associated with interbreeding of cultured and wild salmon, although some studies found no apparent effects. Studies involving intraspecific hybrids are difficult to conduct, and large numbers of well-controlled studies are not available for review. More studies of this type are likely to be published over the next decade, leading to more informed estimates of interbreeding effects. Nevertheless, current knowledge about genetics, coupled with empirical observations, suggests that wild populations can be negatively affected by interbreeding with cultured salmon. Key components to this evaluation are the level of successful interbreeding that actually occurs on the spawning grounds, the genetic characteristics of the stocks and the population status and current abundance of the wild stocks.

Wild stocks at greatest potential risk include those stocks whose numbers are depressed relative to historic numbers and which are located near farms producing conspecific salmon, assuming that escaped salmon enter streams near the farm site (homing accuracy will likely decrease among fish that escape at an older age). Twenty-two percent of chinook salmon stocks on the west coast of Vancouver Island, the area of greatest farm chinook production, are presently considered to be of high risk of extinction (K. Hyatt, CDFO, pers. comm.). Farmed coho production is greatest in the Strait of Georgia and west coast of Vancouver Island where 27 stocks and 30 stocks, respectively, are considered to be at risk of extinction.

A complicating factor in evaluating effects of interbreeding is the fact that the effective population size of many chinook and coho salmon populations in B.C. is small, indicating that random genetic drift might overshadow all but the most highly selected locally adaptive traits. The effects of interbreeding among populations having fewer and weaker locally adapted traits might be less than if the population had numerous highly adapted traits.

We conclude that the genetic risk of escaped Pacific salmon to wild stocks is potentially high if large numbers of farmed Pacific salmon, e.g., escapes during 1989-1991 (165,000 to 390,000 fish), successfully spawn with wild conspecific stocks over a number of years. However, at the levels of observed escaped salmon during 1993-1996 (1,825 chinook and 3,278 coho salmon per year, excluding undocumented escapes from leakage), we judge the genetic risk from commercial farming of salmon to most populations to be low. Many of these escaped salmon will not survive to enter freshwater streams, while others will not successfully interbreed with wild salmon. Nevertheless, some stocks, especially those near farms raising Pacific salmon, may have somewhat higher risk if the number of farm salmon successfully spawning with wild salmon year after year approaches 5% of the wild population. The actual outcome of interbreeding on productivity of these smaller populations cannot be accurately predicted. The implication of government hatchery and stocking policies regarding genetic risk to wild stocks has not been considered in this evaluation.

Hybridization between Atlantic and Pacific Salmon and Trout

We believe that hybridization between farm Atlantic salmon and Pacific salmon and trout in B.C. streams followed by self-sustained reproduction and population expansion of the hybrid salmon is highly improbable. Thus, the risk of interspecific hybridization in B.C. is judged to be exceptionally low. Justification of this evaluation is described below.

Laboratory experiments demonstrated that survival of hybrids between Atlantic salmon and Pacific salmon and trout under ideal laboratory conditions is possible, but it is very low (<0.14% survival from egg to near adult). Survival of these hybrids in nature would undoubtedly be much less than that experienced in the laboratory. Lower survival in the wild is expected because some locally adapted traits contributing to the survival of the native species would likely be lost in the hybrids. Traits related to the domestication of Atlantic salmon in the farms might also contribute to lower survival of hybrids.

Successful hybridization also depends on concurrent maturation of two species in the same area of a stream and appropriate behavioral interactions leading to mating. Most Atlantic salmon spawn from October to January; therefore crosses with steelhead trout, which spawn during spring and have the highest potential viability of crosses with Atlantic salmon, would be unlikely. Spawn timing of Pacific salmon can overlap with Atlantic salmon, but timing will vary from stock to stock and appropriate timing of both specific stocks of Pacific salmon and escaped Atlantic salmon into these specific streams appears to be less probable.

As discussed previously, several investigators (Fleming and Gross 1992, 1993; Fleming *et al*. 1996; Berejikian, NMFS, pers. comm.) demonstrated on spawning grounds that cultured salmon are often discriminated against by wild salmon of the same species. Appropriate interplay between potential spawning pairs should be present before mating can proceed, otherwise aggression will dominate the interaction. Appropriate interplay depends on fish behavior, breeding coloration of body and mouth, body shape and odor. Similar discrimination between wild Pacific salmon and Atlantic salmon is likely (see Fleming 1997).

In the absence of a conspecific mate, male salmon may attempt to court a female of a closely related species and the female may, in some instances, accept the early stages of courting from an inappropriate male (C. Groot, cited in Black 1995). However, in all cases witnessed, the female eventually rejected a male which was not a conspecific. Groot concluded that it would be unlikely that a female Pacific salmon would accept an Atlantic salmon as a mate.

Male salmon that are unacceptable to female salmon can indirectly mate by sneaking between spawning actions of a mating pair. This is generally a rare event among conspecific salmon. Sneaking male salmon are typically much smaller and less conspicuous relative to males selected by females. However, between closely related species, such as rainbow and cutthroat trout, this behavior may explain the occurrence of occasional hybrid fish in feral populations.

Transgenic Salmon

The salmon farming industry in B.C. presently does not raise transgenic salmon and they have no plans in the future to do so (G. D'Avignon, BCSFA, pers. comm.). In general, the international salmon farm community is opposed to the use of such genetically engineered salmon because the public perception of transgenic salmon could harm salmon sales.

We presently do not know how genetically engineered salmon might interact with wild populations. Until further information is provided about genetically engineered salmon, which may display enhanced performance traits, we must assume that escapes could constitute an unknown risk to native populations.

C. Colonization of Atlantic Salmon in B.C.

Although Atlantic salmon have been extensively introduced throughout the world over the past century, no self-sustaining populations of sea-run salmon have become established outside the endemic range of the species, including British Columbia and the Pacific Northwest after substantial effort (MacCrimmon and Gots 1979; Lindbergh 1984). Furthermore, few self-sustaining populations of sea-run Atlantic salmon have become established within the native range of the species even though considerable effort has been made to establish new runs or reintroduce salmon into previously inhabited streams. The results of continual entry of escaped farm salmon into Norwegian and other European salmon rivers, in terms of establishing self-sustaining populations, have not yet been verified.

Slightly greater "success" has been achieved for introductions into landlocked waters. Self-sustaining populations have been established in New Zealand (marginal population) and Argentina (McClane 1965; MacCrimmon and Gots 1979). No landlocked populations have become established in British Columbia and the Pacific Northwest. However, many lakes in B.C. are somewhat similar to those within the native range of Atlantic salmon where landlocked populations exist, indicating the potential for successful landlocked populations (K. Hyatt, CDFO, pers. comm.). Presumably, landlocked populations might be more easily established than anadromous forms because local adaptations that enable migration to and from the ocean are not necessary and because competition might be less in communities without anadromous forms.

The low success rate of Atlantic salmon introductions suggests that the probability of establishing self-sustaining anadromous populations is low. However, considering the importance of this issue and the need to maintain healthy native populations of Pacific salmon and trout, we emphasize the need to view this evidence carefully. Unexpected introductions of salmonids have happened in the past. For example, pink salmon established reproducing populations in the Great Lakes after 21,000 excess fry were discarded into the hatchery sewer (Withler 1982). No previous attempts were made to establish pink salmon in the Great Lakes, presumably because pink salmon were not known to form landlocked populations within their native range. In contrast, pink salmon did not establish self-sustaining anadromous populations in Maine and Newfoundland where introductions were planned. Today, pink salmon produce abundant runs throughout the Great Lakes and have established both odd and even year runs derived from this one-time seeding of odd year fish.

Competition in B.C. streams and lakes might be less today compared to years when numerous introductions of Atlantic salmon were made. Competition by Pacific salmon and trout has been suggested as a significant factor influencing the failure of Atlantic salmon in British Columbia and elsewhere (Burt *et al*. 1992). Lindbergh (1984) noted that introduced runs of Atlantic salmon declined substantially after successful introductions of rainbow and brown trout in New Zealand and Chile. Several studies suggest that juvenile Atlantic salmon tend to be subordinate to steelhead and coho salmon of similar size (Gibson 1981; Hearn and Kynard 1986; Beall *et al*. 1989; Jones and Stanfield 1993), although Atlantic salmon might overcome competitive disadvantages if they obtain greater size compared to other salmonids. Because many salmon and trout populations in B.C. are presently below historical levels of abundance (Slaney *et al*. 1996a), competition may be less today than when Atlantic salmon were introduced in the early 1900s. However, colonization of Atlantic salmon would likely be adversely impacted to the extent that present Pacific salmon populations are reduced by habitat destruction. Competition and predation is likely considerably less in lakes where Atlantic salmon cages are presently allowed because they do not contain anadromous fishes.

A cautionary note is further supported by a review of fish introductions in North America. Moyle (1986) reported that 22% of 67 species of freshwater and anadromous fishes inhabiting the Pacific drainages of Canada are non-native; in Washington State 39% of 76 fish species are non-native. In North America, successful invasions of fishes are much more common west of the Rocky Mountains (30%-60% of species are non-native) compared to those east of the mountains (10% non-native), presumably because the number of fish species is much greater in the east and because many of the eastern fauna already contained fishes with characteristics prized by Americans. Moyle suggests that most local fish faunas in the east have adjusted to species enrichment without loss of native populations, whereas complete replacement of native fish faunas by introduced fishes is common in the west. Disturbances to fish habitat, such as dams and water diversions, have produced habitat and niches that favor introduced fishes, especially in the west. Orians (1986) notes that disturbances to animal communities, including disturbances by humans, enhances the opportunity for successful invasions by non-native species. In spite of knowledge gained on the ecology of species in recent decades, scientists still cannot predict whether or not a species will successfully invade new areas (Kareiva 1996).

Although the probability of establishing self-reproducing populations of anadromous Atlantic salmon is low, annual escapes of Atlantic salmon from marine and freshwater net pens essentially introduce an annual recruitment of Atlantic salmon into the environment at all life stages except egg incubation. Atlantic salmon, therefore, constitute an element within the ecological assemblages of species in B.C. and the Northeast Pacific Ocean, in general. The importance and character of competition and predation effects are a function of the number of annual escapes. Effects of competition and predation of escaped Atlantic salmon are discussed in the Competition and Predation risk sections.

In summary, we judge the probability of establishing significant, self-sustaining anadromous Atlantic salmon runs to be low (but a possibility), based on the failure to establish runs through intentional releases in B.C. and much of the world. The probability of establishing self-sustaining landlocked Atlantic salmon runs is slightly higher, based on the colonization of landlocked populations in New Zealand and Argentina, the somewhat similar lake habitat in B.C. compared to that where Atlantic salmon are present, and the lack of anadromous fishes that might compete with and prey upon Atlantic salmon. Presently, only two lakes (three if an accidental spill is included) have received farm Atlantic salmon; thus potential landlocking is presently restricted to these lakes.

In the event that anadromous or landlocked populations did establish self-sustaining runs, it is possible the populations might persist at marginal levels that would have little measurable effect on native species. Thus, the probability of adverse effects of self-sustained anadromous and landlocked runs of Atlantic salmon is somewhat less than the probability of simply establishing runs. Homing migration of anadromous Atlantic salmon and competition and predation during freshwater residence would play key roles in determining success of reproducing populations and the impacts they might have on native fishes. As stated previously, past performance of Atlantic salmon introductions does not guarantee similar results in the future, especially when considering ongoing changes to the environment. Thus, caution should be exercised when viewing these estimates of risk.

D. Competition

The risk of competition by farm salmon will depend on the availability of resources and abundances of wild and farm salmon that interact. In general, greater adverse competitive interactions will occur in areas where farm salmon represent a sizable percentage of the overall population, thereby either reducing available resources for wild salmon or interfering with utilization of the resources.

Most escapes of farm salmon occur in marine waters. Body size of escaped salmon vary, depending on the time of escape after introduction to sea cages. Considering the relatively small numbers of escaped salmon compared to wild salmon in marine waters of B.C. and the dispersal of these fish over a broad region, we conclude that competition between farm salmon and wild salmon in the marine environment is typically negligible; however, competition may occur during brief periods within localized areas but this is unlikely to produce measurable population effects among native salmon. This observation does not suggest that the same conclusion can be applied to the extensive culture and release of salmon cultured in government hatcheries.

Competition on the spawning grounds can occur if Atlantic salmon or farmed Pacific salmon uncover redds of wild salmon. Spawning ground surveys for Atlantic salmon, though very incomplete relative to total spawning areas available, indicate that the abundance of Atlantic salmon on the spawning grounds is low, especially when compared to native Pacific salmon (e.g., typically <1% of total; Lough and Law 1995, Lough *et al*. 1996). No spawning by Atlantic salmon has been observed in B.C. streams. Superimposition of native salmon redds by Atlantic salmon may occur occasionally, but the random and infrequent occurrence of redd superimposition at current levels of escaped salmon is unlikely to measurably affect native salmon populations.

Farmed chinook and coho salmon may compete for wild salmon for mates. The primary effect of this competition, if farm salmon successfully spawn wild salmon, is that the effective population size of the wild population will be reduced. Furthermore, progeny of farm/wild hybrids may have lower survival, if genes related to locally adaptive traits are replaced (see discussion on interbreeding). In general, the risk of mate competition is likely small for most native populations in B.C. given recent low levels of escapes and the relatively low competitive ability of cultured salmon, especially males, on the spawning grounds (Fleming and Gross 1992, 1993; Fleming *et al*. 1996; Berejikian, NMFS, pers. comm.). However, some populations of chinook and coho salmon, including those near farms or those in streams that attract farm salmon, could experience a somewhat higher risk if significant numbers of farm salmon stray into these streams.

Most documented observations of competition among salmon have been made in freshwater. However, farm salmon are presently allowed in only two lakes that do not support anadromous forms. Several thousand Atlantic salmon were accidentally spilled into another lake. Competitive interactions in a lake such as Lois Lake could be high, given the potentially large numbers of escaped salmon relative to native populations. Although risks of adverse competitive interactions in these lakes is potentially high, adverse effects would likely be limited to the freshwater system where rearing occurred. Levels of adverse competitive interactions would likely be similar to those experienced by native salmonids in lakes and streams that have been planted with non-local species or stocks by local, provincial and federal fisheries agencies.

E. Predation

Predation is generally believed to be a major, if not the most significant, source of mortality of wild salmon, especially after release from spawning gravel.

Feeding frequency of escaped Atlantic salmon captured in marine waters of B.C. and Alaska was low compared to wild salmon, indicating that the foraging efficiency of farm salmon in the wild is low for a considerable time after escape. Salmon in Alaska had a lower condition factor but somewhat higher frequency of foraging than farm fish recovered in B.C. (McKinnell *et al*. 1997). Presumably, fish in Alaska had been freely swimming in the wild for a longer period. If so, then the observation of greater foraging frequency in salmon caught in Alaska might indicate a slow learning response when switching from farm pellets to wild prey that evade predators. The low feeding frequency of these farm salmon in B.C. and Alaska and the lack of salmon in examined stomachs indicates that predation on wild salmonids by escaped farm salmon is negligible.

Predation by caged salmon indicated that few fishes (sandlance and herring) are consumed during the spring migration period when salmon would be most abundant near pens. No salmon were consumed during the spring study period. The use of night illumination lights by some farms does not appear to increase predation on salmon and herring, based on a recent study in B.C. (Hay *et al*. 1996). In contrast, woody debris was consumed by caged salmon and was reported to be a significant source of mortality of farm salmon.

The risk of predation to wild salmon by escaped and caged farm salmon is judged to be very low.

F. Disease Transmission

The potential transfer of diseases of farm salmon to wild salmon is a key topic of concern. Disease transfer is discussed in the Fish Health discussion paper.

V. ESCAPES AND IMPACTS IN THE BROUGHTON ARCHIPELAGO REGION

The Broughton Archipelago (our study area has been defined by the EAO as essentially that used by the Coastal Resources Interest Study (CRIS) with a few modifications. The case study area is defined as follows: from Aylmer Point the boundary follows due south (along approximately 127°12'W longitude) until it intersects the line demarking 50°30'N latitude. From this point the boundary follows due east until it intersects the Johnstone Strait mid-passage line. From here the line follows the mid-passage line due south to a point due south of Domville Point, after which the boundary heads due north to Domville Point. All other boundaries are the same as defined in the CRIS.

The area includes about 31 salmon farm sites all concerned with the production of Atlantic salmon. The BCSFA estimates there are 270 to 290 pen cages in the Broughton Area. In addition to the farms, the region includes two commercial hatcheries which produce salmon smolt for the industry (the Beaver Cove site east of the Kokish River and the Thiemus Creek site). The Beaver Cove site produces Atlantic, coho and chinook salmon and the Thiemus Creek site produces Atlantic and coho salmon.

A. Number of Escapes

Although the boundaries of the Broughton Archipelago do not correspond to defined federal fish statistical regions, a review of the information on escapees indicates that since the inception of salmon farming in the Broughton area (1991), approximately 69,993 salmon have escaped from farms in the region. Of this total, 67,993 were Atlantic salmon and 2,000 were chinook. Further, an additional 22,660 Atlantic salmon are reported to have escaped from farms in the adjacent areas of Johnstone Strait defined to be outside the Broughton area. All of these escapes have occurred since 1990 and the build-up of salmon farming in the more northern regions. Records maintained by the BCSFA, which are perhaps more specific to the Broughton area, indicate losses of about 87,567 fish between 1992 and 1996. These escapes occurred in the following years: 6,771 fish in 1992, 10,000 fish in 1993, 34,406 fish in 1994, 23,708 fish in 1995 and 12,682 fish in 1996.

B. Recoveries of Atlantic Salmon

As might be expected, there have been erratic increases in the number of recoveries of Atlantic salmon from marine waters of the Johnstone Strait region since the first individuals were captured in 1989. In 1993, over 4,000 Atlantic salmon were recorded taken in the commercial salmon fisheries within Johnstone Strait; most of these fish were taken in a fishery shortly after they escaped from two farm sites. However, the number has declined in recent years and only 109 Atlantic salmon were recaptured in 1996 because commercial fishing effort in the area has declined (DFO 1997).

The first reported sightings of Atlantic salmon in freshwater streams of the Broughton Archipelago (Johnstone Strait) were noted in 1991 where four fish were recovered from Kokish and one from the Quatse rivers. A significant increase in freshwater recoveries of the region occurred in 1995 and 1996 when a total of 29 and 73 Atlantic salmon, respectively, were recovered from rivers entering Johnstone Strait. During these years, the largest number of sightings was reported from the Kokish and Salmon rivers, which also have Atlantic salmon hatcheries located near them. In 1996, a total of 39 Atlantic salmon was recovered from the Salmon River.
Although the largest number of saltwater recoveries has been reported from Johnstone Strait, the most important freshwater recovery area has been along the west coast of Vancouver Island where between 1990 and 1996 approximately 249 recoveries have been reported.

As previously noted, recoveries of Atlantic salmon in the marine and freshwater environments may in general reflect distribution of Atlantic salmon in the B.C. ocean and river environments, but they also reflect opportunity for captures and sightings.

Residents of the Broughton Archipelago provided information on escaped salmon to the Salmon Aquaculture Review through an interview process. Responses by individuals are presented in "Broughton Local Information Report." Of 138 individual comments, 31 were related to escaped salmon. Most of the observations referred to catching or seeing Atlantic salmon, sometimes during commercial fishing. Although some fish were delivered to the ASW, most fish apparently were not. Most people appeared concerned about the growing number of Atlantic salmon in the area.

C. Risk Assessment

Although the Broughton Archipelago has been chosen as a case study area, the potential risks for genetic and environmental impacts are similar for those previously described for the B.C. region as a whole. However, the concentration in farm Atlantic salmon and accessibility of escaped salmon to local rivers of the region increases the risk (although it probably remains low) of genetic and ecological damage vis-a-vis regions where the number of escaped salmon is significantly less. Further, an increased number of farms in the region and corresponding increases in escapes will increase risk. The potential genetic impacts must also be weighted against the poor condition of chinook and coho stocks in the Broughton region. Presently, very little farming of chinook and coho salmon occurs in the Broughton Archipelago; therefore the present risk of genetic damage caused by interbreeding of farm and wild conspecific salmon is low.

An examination of the percentage of stocks considered at high and moderate risk plus those stocks of salmon that are considered of special concern or extinct is presented below.

AREA

Species	**Johnstone St.**		**Georgia St.**		**Fraser**	**W. Vancouver Is.**	**N of Vancouver Is.**
Chinook	13%	25%	9%	22%	23%		
Coho	17%	22%	8%	11%	10%		
Pink	14%	21%	9%	12%	8%		
Chum	14%	23%	3%	11%	12%		
Sockeye	20%	8%	8%	2%	17%		

Georgia Strait and Johnstone Strait have a larger number of stocks in these categories than do other regions. They involve regions where intense salmon culture has occurred, but also regions where habitat degradation and fishing may have played major roles in the historical status of salmon runs. Salmon run status should be considered in the farm siting process because a number of coho and chinook runs in the Broughton are at risk.

VI. MITIGATION APPROACHES

A key component of this paper is the evaluation of current and proposed approaches to prevent or mitigate adverse effects of escaped farm salmon, including those approaches described in the farm licensing process. The following sections describe current government regulations, government agency interactions with farms to minimize and monitor impacts of escaped salmon, and our assessment of these government regulations and operations.

A. Governmental Regulations

A detailed description of federal and provincial regulations regarding salmon farm licensing and operations in B.C. is presented by Hillyer (1997). Most regulations related to escaped salmon are described in the provincial Aquaculture Regulation and the Fishery (General) Regulations adopted under the federal Fisheries Act. Key regulations and requirements related to the escape of farm salmon are as follows:

- No person shall release fish to fresh or tidal waters from an aquaculture facility unless authorized to do so by the terms or conditions of an aquaculture licence.
- A licence holder shall take reasonable precautions to prevent the escape of fish from the holder's facility, including the period of transportation from one facility to another.
- The licence holder or associate who discovers an escape or evidence suggesting an escape of fish from a farm facility shall report the escape or evidence to the manager: (a) verbally, within 24 hours of discovery, and (b) in writing, if requested by the provincial Aquaculture Manager.
- A licence holder who recaptures or attempts to recapture fish that have escaped shall report in writing the results of the recapture to the manager within one week of the recapture attempt.
- A licence to transport fish may be issued only if the transfer will not have an adverse effect on the stock size of fish or the genetic characteristics of fish or fish stocks.

In addition to these regulations, B.C. Lands describes farm siting guidelines in its Aquaculture Policy that are relevant to salmon escaping from farms. The guidelines include the following requirements related to escaped salmon:

- All marine finfish lease and licence applications will be at least 1 km from the mouth of a salmonid stream.
- The spacing distance between a marine finfish lease or licence and a salmonid stream may be increased upon the joint recommendation of MAFF, MELP and DFO.

B. Application of Regulations and Guidelines

Before receiving a licence to operate a salmon farm, an applicant must complete an Aquaculture Fish Farm Development Plan. This plan involves a series of standard questions regarding the physical location and layout (scaled drawings) of the proposed farm, water quality of the site area, site-specific predator abundance and predator control information, bottom profile, proposed anchoring methods, exposure to wind and waves, and proximity to salmon streams, Native Reserves, Ecological Reserves, etc.

The applicant's plan is reviewed by agency personnel as part of the referral process, which is required by the B.C. Lands Aquaculture Policy. MAFF personnel are responsible for reviewing the technical feasibility of the proposed operation and the biophysical capability of the site to support the proposed operation. DFO personnel comment on the farm's potential impact on wild fish stocks and fish habitat. MELP personnel comment on monitoring requirements and effects of the farm on recreational fisheries, wildlife and environment. The review process can lead to changes in the proposed farm design, including changes in location or materials utilized that would reduce the probability of escaped salmon. Improvements have been suggested and acted upon that would reduce escapes of salmon caused by weather and predator attacks, but the referral process typically has little effect on escapes related to accidents.

Although specific guidelines to minimize escaped salmon and their impact on wild stocks have not been developed, the referral process can be a powerful management tool, according to some personnel, because agency personnel have the opportunity to require site-specific actions in order to minimize escapes or reduce their impact. The effectiveness of the referral process would seem to depend on the knowledge and experience of the agency personnel reviewing the applicant's plan.

Once a farm becomes operational, the farm is required to report escapes of salmon to government agencies, as required by the farm's operation licence. Although the regulations do not specify a minimum escape size before reporting is required, in practice small escapes typically are not reported. These small escapes are typically not economically important to the farm and would not be verifiable if one were to attempt to estimate the escape number. MAFF personnel are presently discussing with salmon farmers the need to have farms report small, economically insignificant escapes, e.g., ten fish (C. Backman, pers. comm.). Many farms are presently maintaining records of suspected but unconfirmed losses.

Salmon farms typically report escapes of salmon to MAFF within 48 hours of the event, although reporting can be delayed somewhat by detailed recounting of fish, storms and holidays (C. Backman, pers. comm.). MAFF personnel will visit the site, if a major escape is reported or if questions arise from the report. In earlier years, escaped salmon on occasion were reported only after a visit to the farm site and questioning by MAFF personnel.

In response to the growing concern about Atlantic salmon escaping from salmon farms, a joint federal/provincial program was initiated in 1991 by MAFF and DFO to monitor the presence of Atlantic salmon in B.C. streams. In 1992, an expanded program, the ASW, was launched to monitor commercial and sport catches and observations of Atlantic salmon.

The DFO is presently conducting research into sterilization (triploidy) and monosex (all-female Atlantic salmon) techniques that might be used to reduce the risk of colonization by Atlantic salmon and the risk of introgression by farmed Pacific salmon. Although initial research shows promise (I. Solar and E. Donaldson in Black 1995, E. Donaldson and I. Solar, pers. comm.), the techniques are not sufficiently developed at this time to warrant immediate wide-scale application to salmon farms. This research is considered by the TAT to be an important step to minimizing potential impacts of escaped farm salmon.

C. Assessment of Current Approaches

The referral process is good in that it allows a variety of government agencies to comment on the proposed salmon farm. However, the referral process has few guidelines for the evaluation and the process appears to rely on the expertise of the government personnel assigned to the review. If the government reviewer is highly experienced, then the referral process is more likely to work well than if the government personnel is less experienced with salmon farm operations and their potential impacts.

One guideline that has been required is that farms must be located at least 1 km from a salmon stream. While the intent of this guideline is good, it may not be adequate, especially if the stream supports an important but weak stock of salmon. Furthermore, we believe the genetic effect of escaped Pacific salmon on local populations is potentially greater than that of Atlantic salmon. Thus, more thorough guidelines should be developed for siting the farm. These guidelines should discuss the species of wild salmon in the region of the farm, their stock size, population status and likelihood that escaped salmon might interbreed with the wild stock.

The regulation requiring salmon farms to report escaped salmon is good, but in practice some farms may not report losses even though it is a requirement of their licence. Without some indication of an escape event, government personnel would have a difficult time determining whether one actually occurred. Thus, the escape reporting system is, in a sense, a voluntary reporting system in which farmers can easily deceive government officials, if they choose. Some farms may be encouraged to forgo reporting of a salmon escape because salmon farms have received negative publicity in recent years. However, we have no evidence of this type of negligence. Enforcement of escape reporting is difficult. Better tracking of escape events might be achieved if the government required accounting of salmon at each stage, including smolts received into the farm, mortalities, escapes and harvests. Accounting of fish production would undoubtedly result in many unaccounted fish (8%-40%) according to Moring (1989), but review of such records might enable government personnel to ask questions if the records appeared unusual. Presently, records are maintained only on escaped salmon, salmon harvests and, to a limited extent, mortalities.

We believe that the ASW is a worthwhile program to monitor the presence of Atlantic salmon in B.C. However, in addition to the opportunistic discovery of Atlantic salmon in streams, the program should develop a long-term plan for monitoring streams. This plan might include standardized surveys of key streams likely to receive Atlantic salmon or streams deemed desirable to prevent colonization. Experiments in controlled streams to determine success rates of spawning Atlantic salmon and offspring could be beneficial in determining the probability of colonization, assuming reproductive containment through all-female production is not underway. Although the ASW program encourages the public to report sightings of Atlantic salmon, the reporting of escaped salmon is currently a process limited to farmers and governmental agencies. Local First Nations people and the public are not generally informed of recent major escapes. The potential for increased recoveries of lost salmon and public trust could be enhanced if the process were made more transparent.

Reproductive containment of farmed Atlantic salmon would greatly reduce concerns regarding colonization, but performance of all-female and sterile (triploid) fish in large scale net pen facilities needs to be evaluated. Ongoing research by Dr. E. Donaldson (retired from DFO) is evaluating performance of all-female Atlantic salmon and all-female triploid Atlantic salmon (sterile) at a salmon farm near Campbell River. Results to date suggest that regular male fish grow faster than females, but some males will mature at a younger age (E. Donaldson, pers. comm.). Growth of all-female fish appears to be similar to that of regular females. Performance of all-female triploid fish will likely be less than other test groups because all-female triploid fish are more susceptible to crowding stress and slower growth, and some exhibit jaw deformities. This experiment will likely be completed in 1998 when the fish reach maturation, but funding for the project is presently inadequate. Preliminary results suggest that production of all-female Atlantic salmon may be a more viable option for the farming industry compared to all-female triploid Atlantic salmon. However, some additional research is needed to enhance the technique of developing all-female Atlantic salmon so that it can be readily applied to all farms in B.C.. Production of all-female salmon through use of monosex sperm produces 100% females (no male salmon produced, E. Donaldson, pers. comm.); therefore there is little risk of successful mating. However, all-female salmon production by other techniques does not lead to 100% females. All-female Atlantic salmon used in the aforementioned experiment and production of all-female chinook salmon in B.C. farms employs the monosex sperm technique. The spawning behavior of all-female Atlantic salmon in streams would likely be similar to that of regular females, but observations of spawning behavior of females in the absence of male salmon are not available.

VII. CONCLUSIONS

Although aquaculture dates well back into history, the evolution of high intensity pen and cage culture has evolved rapidly over the past several decades. The development of B.C. commercial salmon farming dates back to the late 1970s; however, most of its productive growth and technological evolution have occurred since the mid-1980s. Since the inception of marine salmon cage culture in B.C. and other areas of the world, potential ecological, disease, and genetic and health concerns have been identified by growers, scientists, governments and concerned citizens.

Many of these concerns are frequently associated with salmon escaping from marine grow-out cages or during growth and distribution of the smolts. Since the inception of farming in B.C., a total of 1,078,368 Atlantic and Pacific salmon were reported to have escaped into marine waters of B.C. Additional salmon escapes are known to have occurred from salmon farms in the Puget Sound region. The reported numbers of escapes do not include chronic leakages or disappearances of animals from cages that could significantly increase the reported population of Atlantic and Pacific salmon that have escaped.

The reported numbers of escaped salmon constitute a small fraction of the population of Pacific salmon known to occur in waters adjacent to B.C. Nevertheless, the annual escapes have ensured that farm salmon have become viable components of the ecological anadromous fish complex of the region, both in the marine and fresh water environment. Further, although the presence of Atlantic salmon is rare in relation to the abundance of Pacific salmon (DFO 1997), the capture of hundreds to thousands of Atlantic salmon each year since 1993 suggest that their capture in waters from Washington to Alaska has become a relatively common event.

The numbers of reported salmon escapes from B.C. farms has decreased since 1994 despite increases in production. However, the number of Atlantic salmon sightings (observations) in freshwater systems has increased from 48 in 1992 to over 200 in 1996. Additionally, the occurrence in certain rivers has been persistent and increasing in recent years. The number observed in individual B.C. rivers has generally been small in absolute numbers (< 40) and relative to Pacific salmon.

Considering the current level of escapes:

(1) The risk of negative genetic impacts on wild Pacific salmon stocks is generally low, but mating of farm and wild stocks could occur somewhat more frequently in streams where farm hatcheries exist and in regions where farms growout Pacific salmon.

(2) Competition and or predation between wild and escaped Pacific salmon is not currently considered a significant factor impacting wild Pacific stocks.

(3) The potential ecological risk of escapes to wild salmon stocks is generally low, but is likely to be greater in areas in close proximity to farm sites. However, the possibility of broader geographic impacts is supported by the recapture of Atlantic salmon at considerable distances from escape locations.

(4) If the level of farm Pacific salmon escapes was to increase significantly and escape levels reach those of the late 1980s, both genetic and ecological risk to some wild stocks could be significant.

(5) The potential for genetic impacts (hybridization) between escaped Atlantic and Pacific salmon seems remote, based on empirical and experimental evidence.

(6) Ecological impacts of Atlantic salmon on wild salmon stocks will vary with the level of escapes. At present, the levels of escapees' measurable impacts appear negligible. However, escapes, such as occurred in Washington state in 1996 (101,000 fish), could become a dominant portion of adult anadromous fish stocks in a local area and compete for available food. This effect, however, would likely dissipate rapidly as the escaped fish began to disperse.

(7) Ecological impacts of farm salmon escaping from freshwater net pens could adversely impact indigenous freshwater populations because levels of escaped salmon can be significantly greater than local fish populations.

(8) Successful establishment of anadromous Atlantic salmon populations in Pacific rivers and streams as a result of reproductive success and survival of progeny in a series of years is considered unlikely, based on the

historical failure to establish the species in waters outside of its indigenous range and apparent low competitive abilities compared to Pacific salmon. However, biological and ecological factors which have contributed to past failures are largely speculative and opportunity to colonize may have improved in recent years as a result of the following factors. Relatively large numbers of adults which have escaped (50,000 to 100,000 animals) would seem to have a higher probability of surviving to spawning grounds than the release of millions of eggs or fry which occurred in past colonization attempts. The proximity of B.C. Atlantic salmon farms to potential spawning areas provides the possibility for repeated attempts at colonization within the same river system. Because of the reduced population status of many Pacific salmon runs in the region, potential competition and predation by wild salmon (in river) has likely declined. However, if habitat degradation has been a major factor adversely affecting chinook and coho runs in B.C., then habitat degradation would also likely be disadvantageous to survival of Atlantic salmon. Nevertheless, although the risk of colonization may remain low, the opportunity for successful colonization has most likely improved.

9) Colonization of land-locked populations of Atlantic salmon appears to be more likely than colonization of anadromous forms because complex ocean migrations are not needed to complete the life cycle and because competition with other fishes, such as anadromous Pacific salmon, would be less.

(10) Although we do not object to experimental laboratory efforts that create transgenic salmon that have enhanced performance traits, their release or escape into B.C. waters could involve serious risks.

(11) Existing law requires both oral and written reports to be made on escapes, but neither the requirement nor its enforcement seem to include estimates of small numbers of escaped salmon.

(12) Existing farm technology and practices have probably contributed to the recent reduction in the number of reported fish escaping from farms. Nevertheless, a standard process for preventing escapes, recapture of escaped fish, and more comprehensive reporting could lead to further escape reductions.

In summary, we view the risk to wild salmon populations in B.C. to be greater from escaping Pacific salmon than from escaping Atlantic salmon. This view is based on the greater likelihood of adverse genetic effects of interbreeding farm and wild Pacific salmon compared to successful colonization of Atlantic salmon and subsequent competition with Pacific salmon. We know that interbreeding between farm Pacific salmon and wild salmon can occur, leading to permanent adverse genetic effects if genetically controlled adaptive traits are removed from the wild population. Furthermore, colonization by Atlantic salmon can be controlled by use of all-female Atlantic salmon. Production of all-female Atlantic salmon using techniques presently under investigation by DFO would greatly reduce potential reproduction because 100% of the fish are female (E. Donaldson, retired DFO, pers. comm.). Production of all-female Atlantic salmon is a key recommendation of the TAT and is described in a separate document. In contrast, viable sterilization techniques for Pacific salmon are not likely to succeed in farms because performance of these fish appears to be less and because sterilization may not be 100%. Thus, switching from a predominance of Atlantic to Pacific salmon in B.C. net pen culture, as proposed by some members of the Review Committee, would likely increase risk to wild Pacific salmon stocks.

GLOSSARY OF TECHNICAL TERMS

Alevins: Hatched juvenile salmon which still retain a portion of the egg yolk.

Allele: A gene form or component capable of mutation.

Conspecific: Same species but different stock or population.

Gene Flow: Portion of non-local stock, which contribute genes to a given population.

Genetic Dilution: Loss of specific genetic attributes as the result of breeding between stocks having different gene characteristics.

Genetic Diversity: Diversity of the genetic make-up of an individual, stock or species.

Homozygosity: Having the same gene in two corresponding loci of a chromosome pair.

Hybrid Vigor: An increased fitness resulting from outbreeding, which may occur in the first generation particularly if inbreeding is characteristics of one of the parents.

Hybridization: The breeding between closely related, but different species.

Interbreeding: The mating of related animals.

Interbreeding Depression: A reduction in fitness due to interbreeding.

Introgression: The act of non-local stocks breeding with a stock native to a particular river or watershed.

Leakage: Loss of fish from farms that cannot be attributed to specific causes or times.

Mort: Dead farmed salmon.

Natural Selection: A process which selects genetic attributes more likely to survive in a given environment.

Outbreeding: The mating of genetically divergent individuals.

Outbreeding Depression: A reduction of fitness due to the intrusion of less fit genes in conspecific breeding.

Parr: Juvenile salmon that have not gone through smoltification.

Random Genetic Drift: A tendency for the genetic characteristic of a stock in population to drift from its historical genetic make-up. A factor more likely to impact small populations, such as farmed brood stocks.

Smolts: Juvenile salmon that have physiologically adapted and are ready to live in a marine environment.

Stock: Depending on usage may refer to a management unit or a genetic distinct population.

Stray Rate: Portion of a non-native fish spawning in a given population.

Transgenic: Fish having altered genetic structure as a result of the introduction of foreign DNA using molecular genetic techniques.

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SALMON AQUACULTURE REVIEW

FISH HEALTH

DISCUSSION PAPER

PART C

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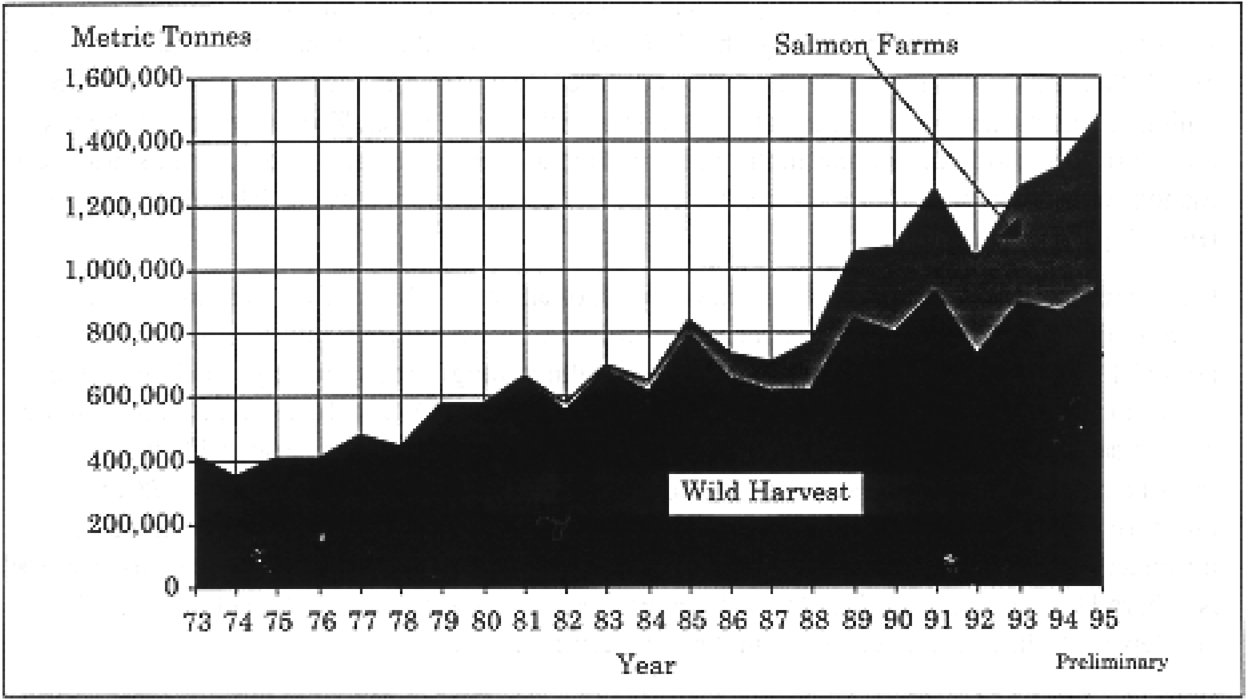

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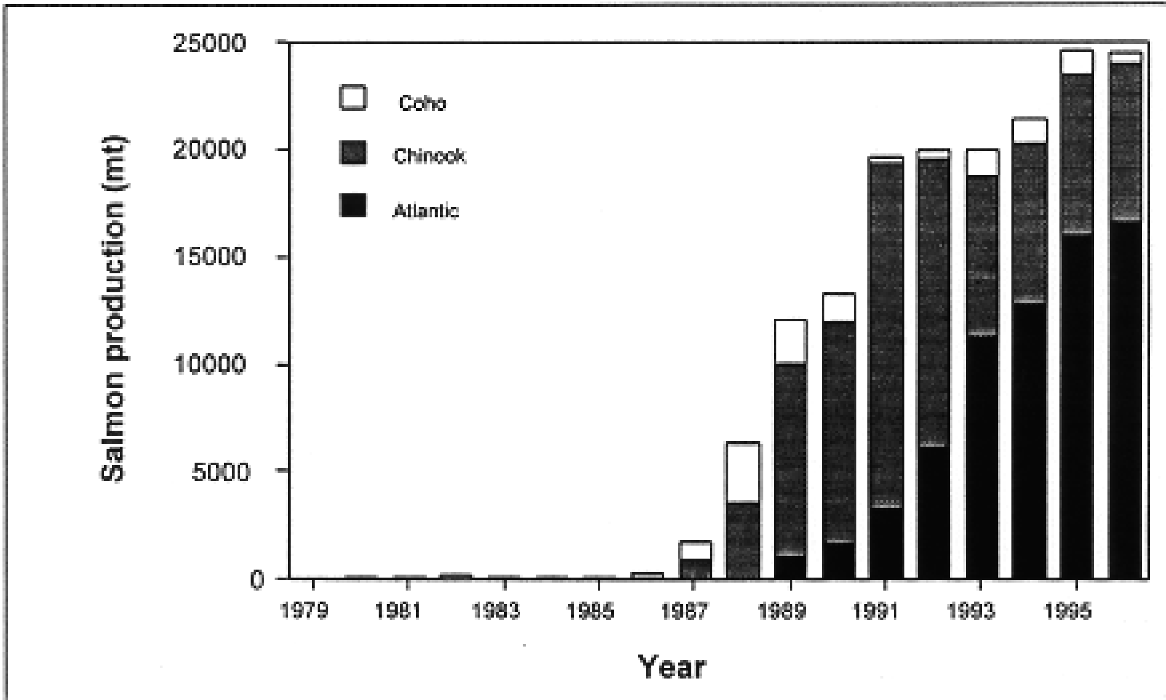

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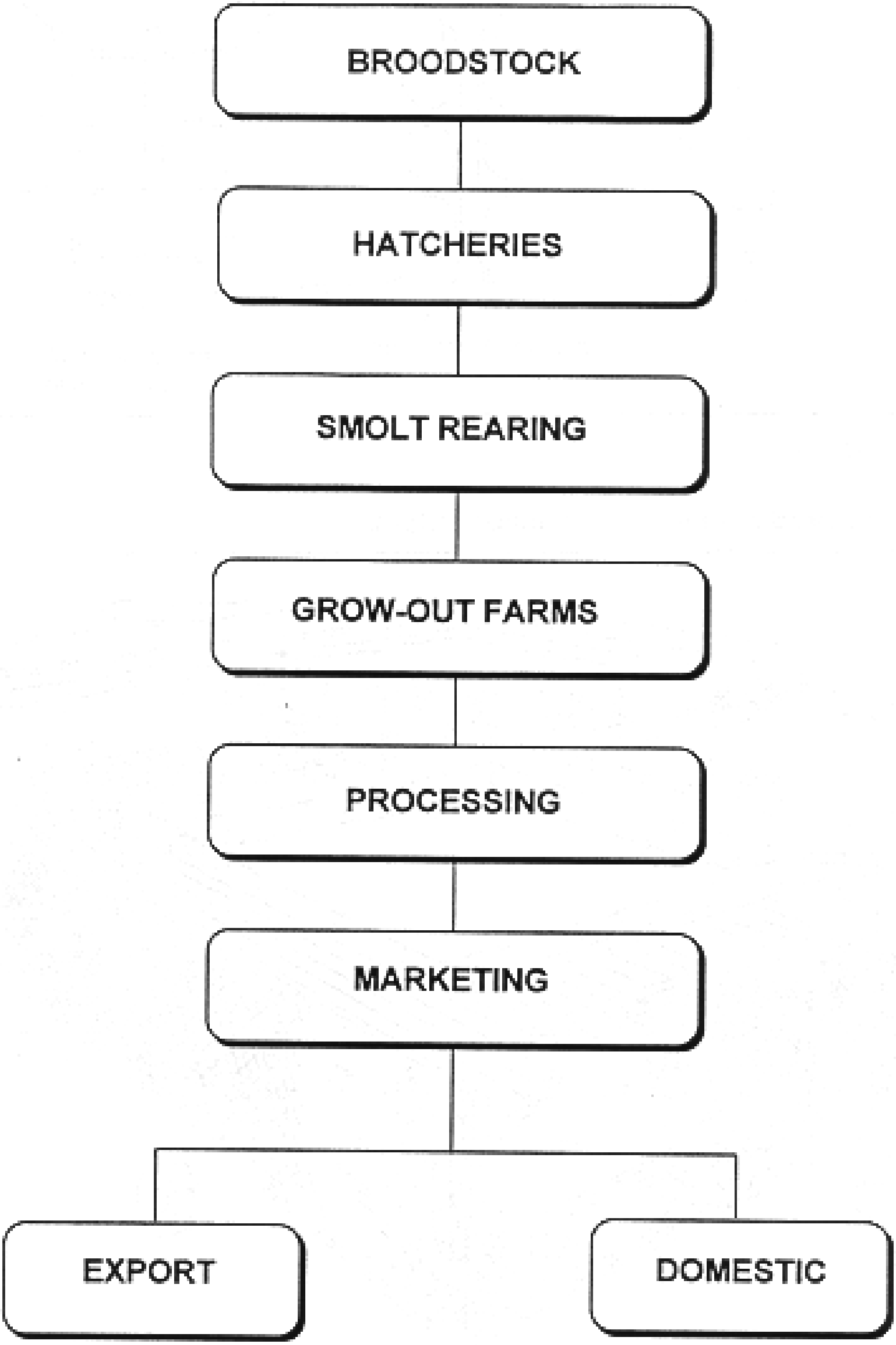

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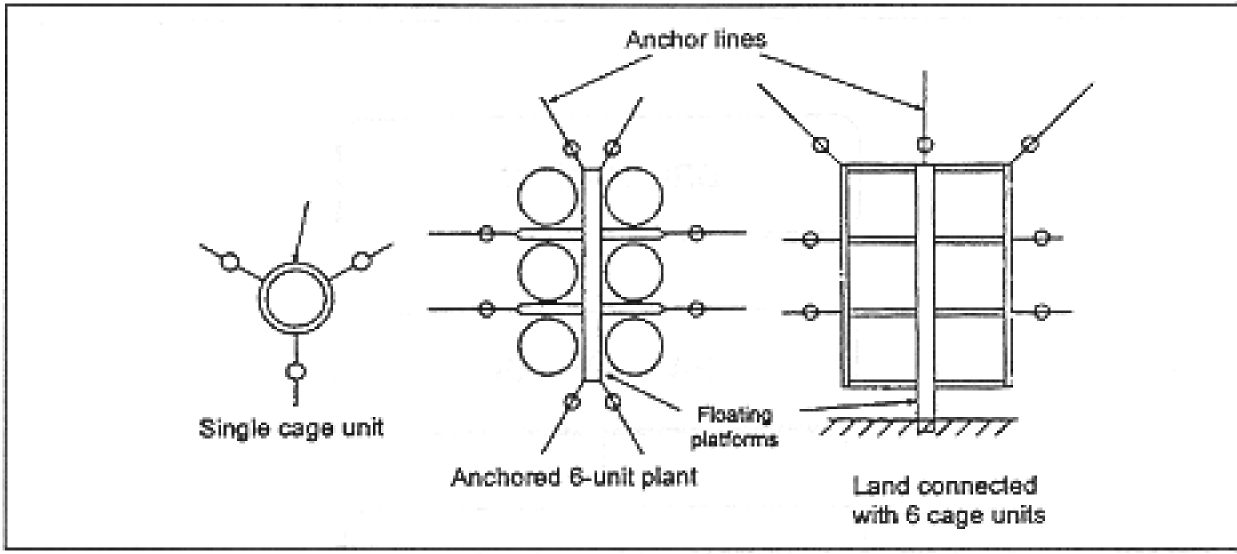

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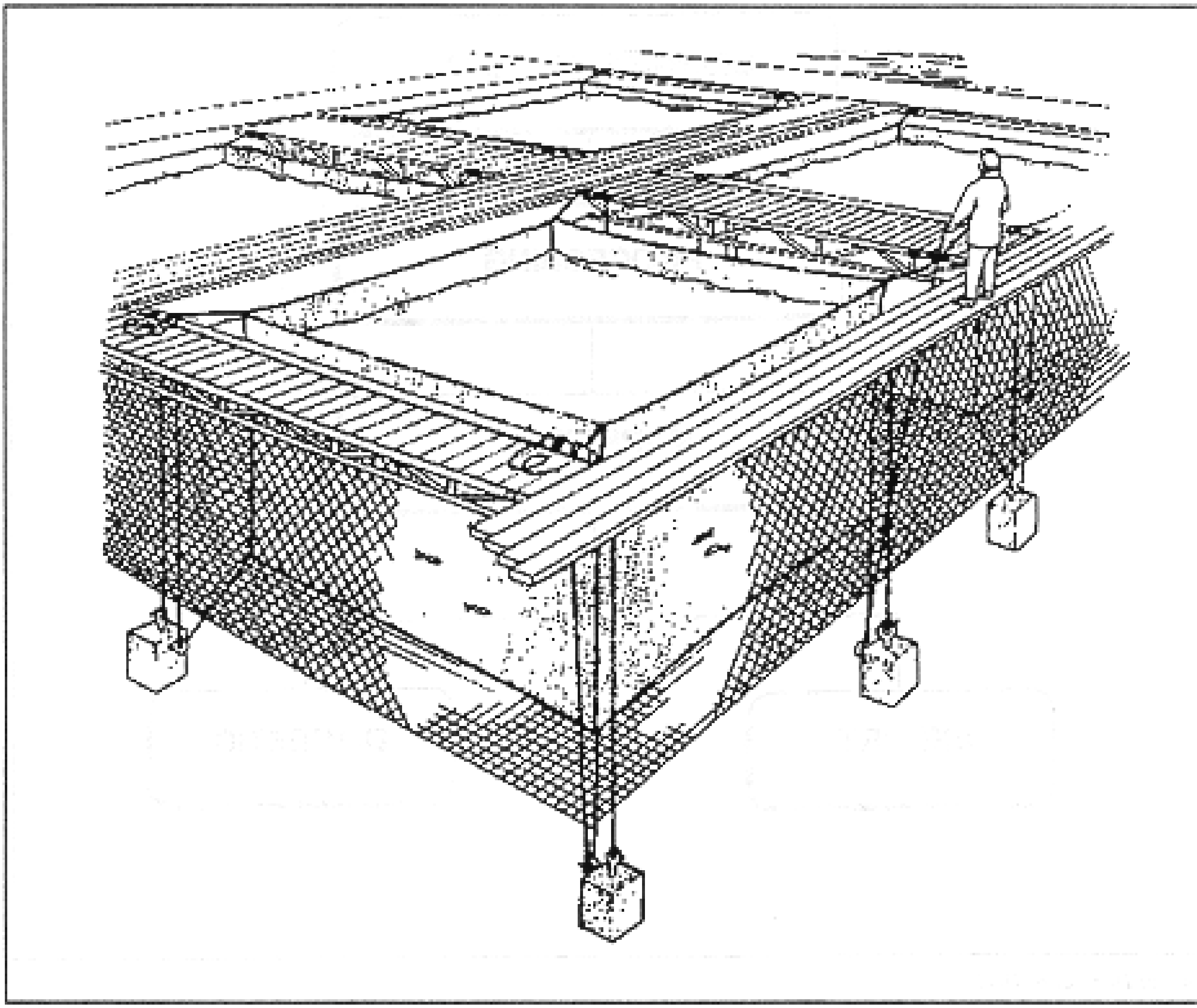

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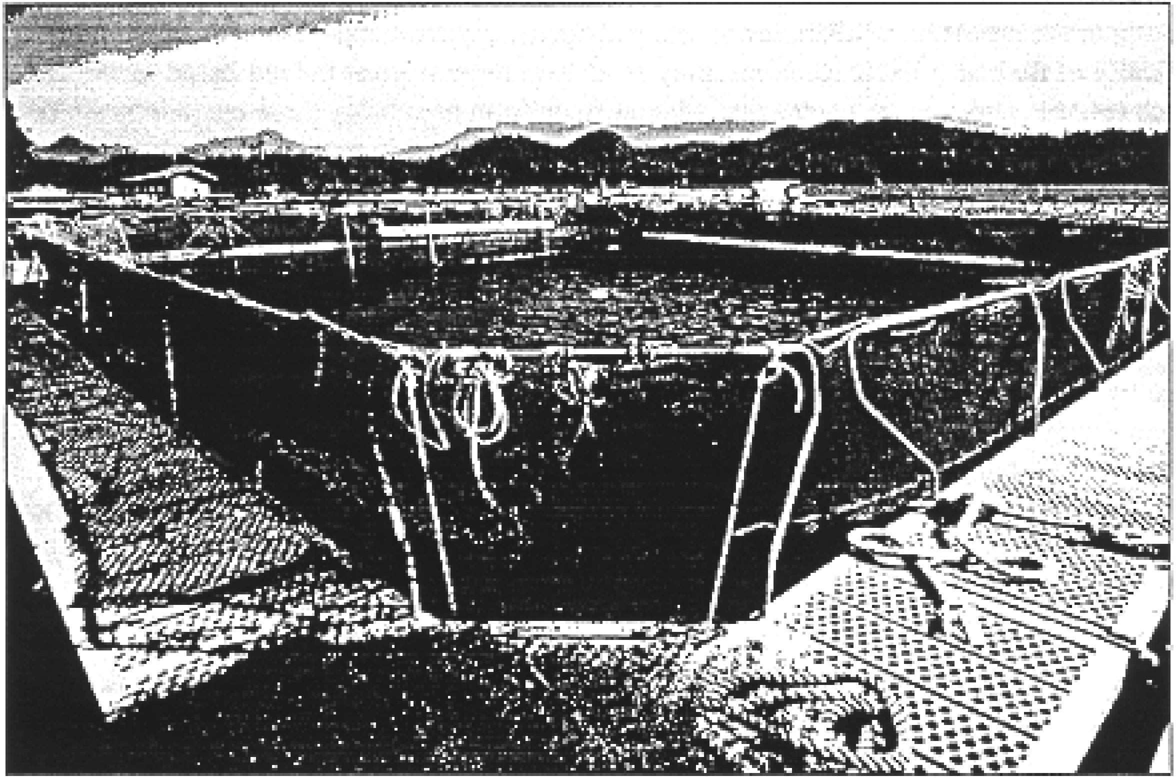

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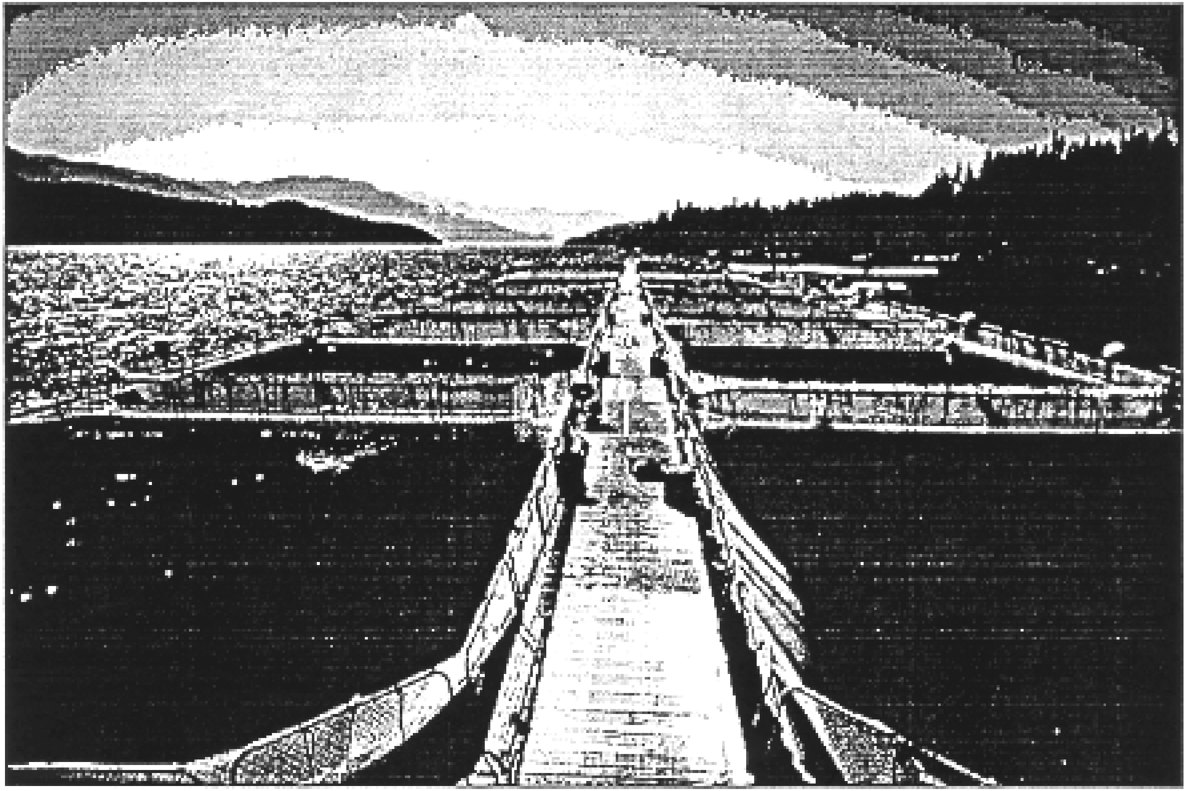

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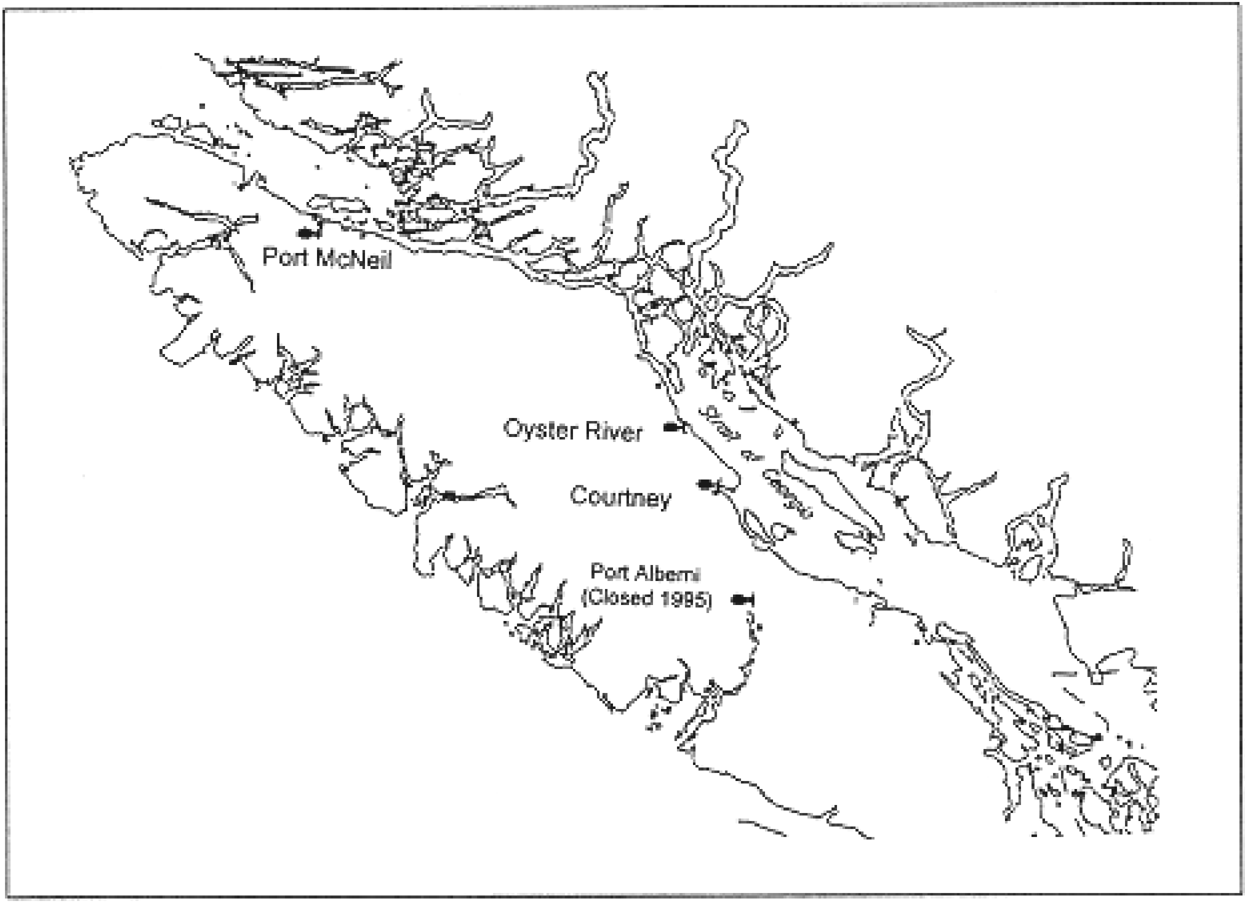

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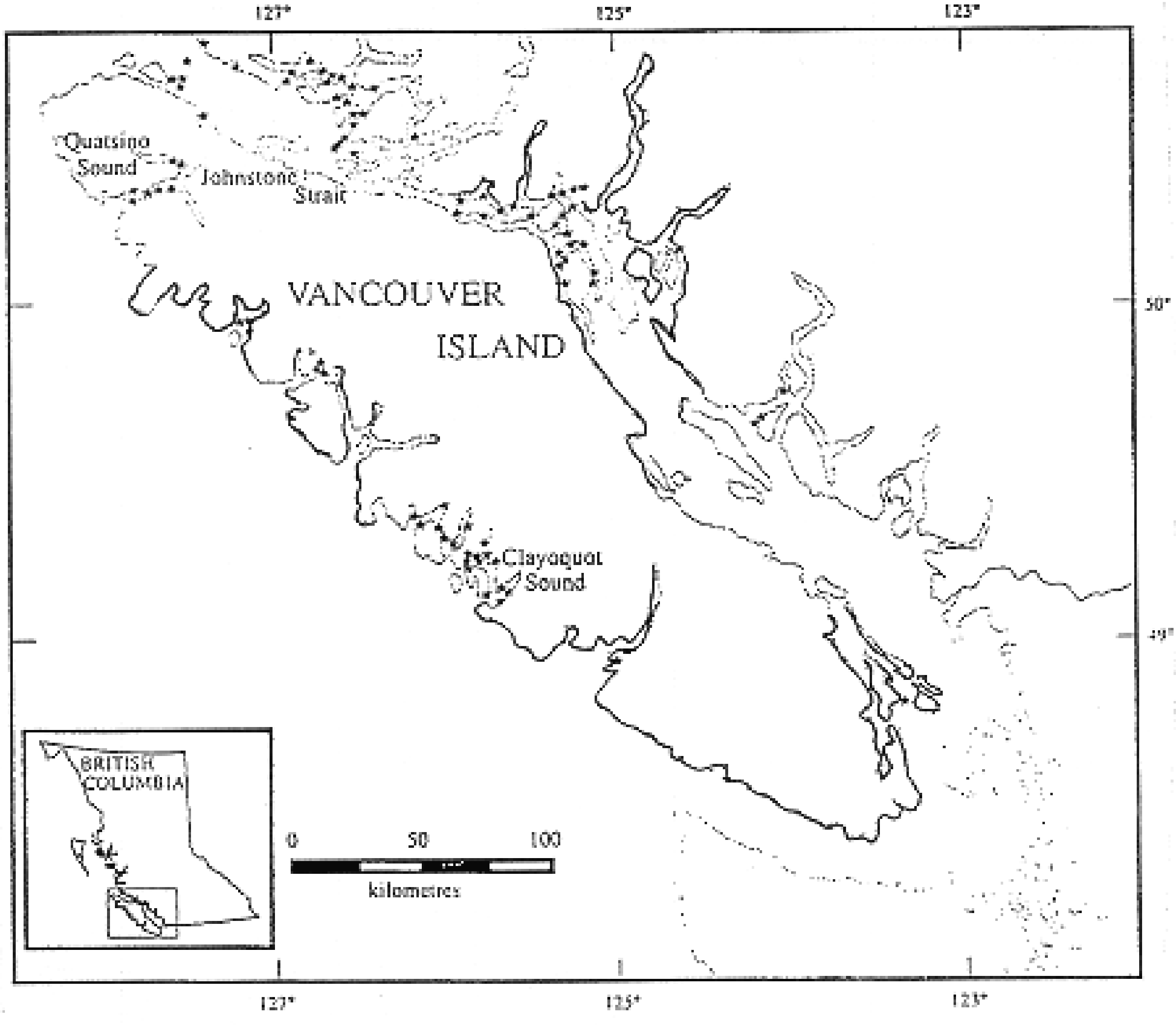

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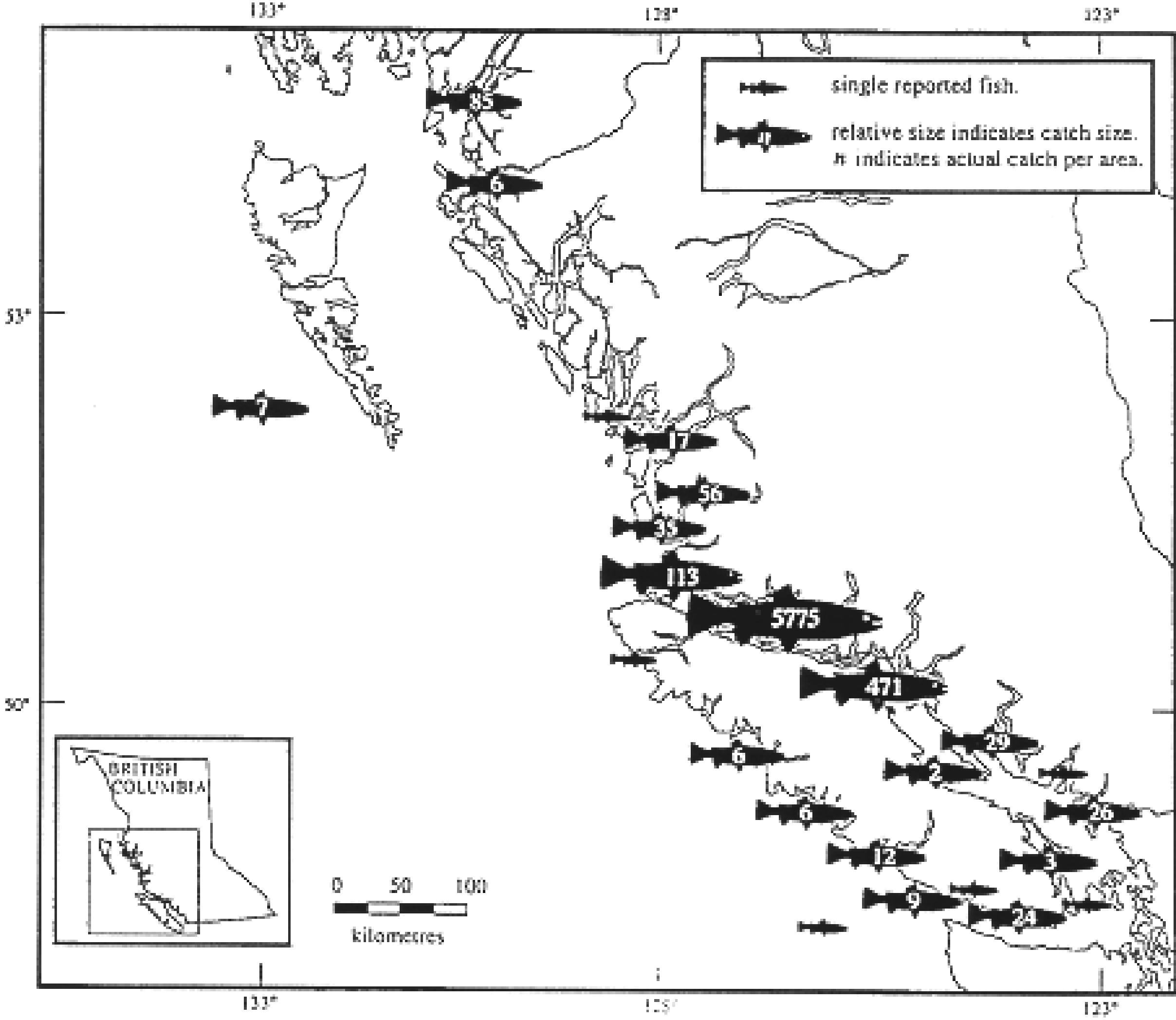

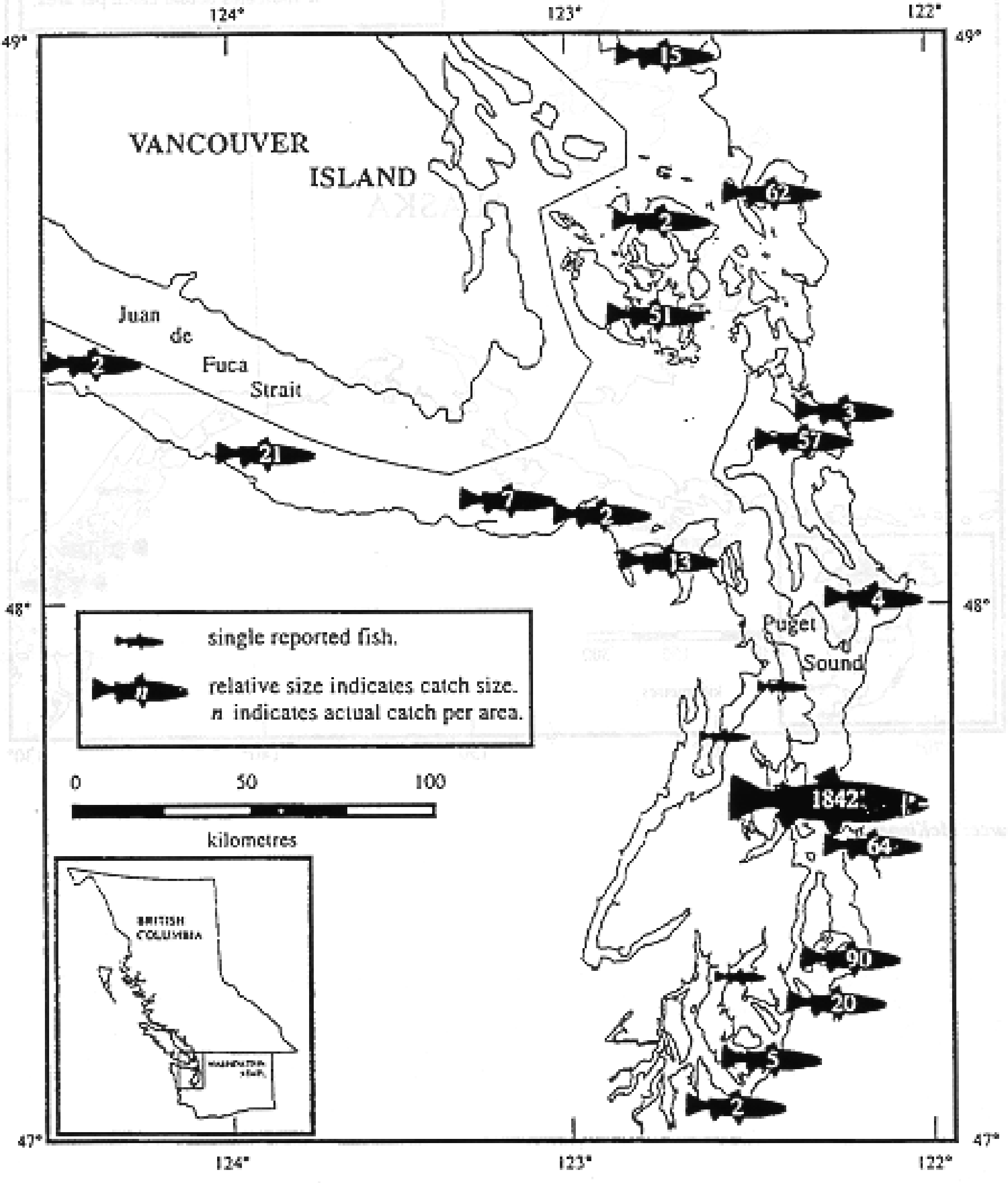

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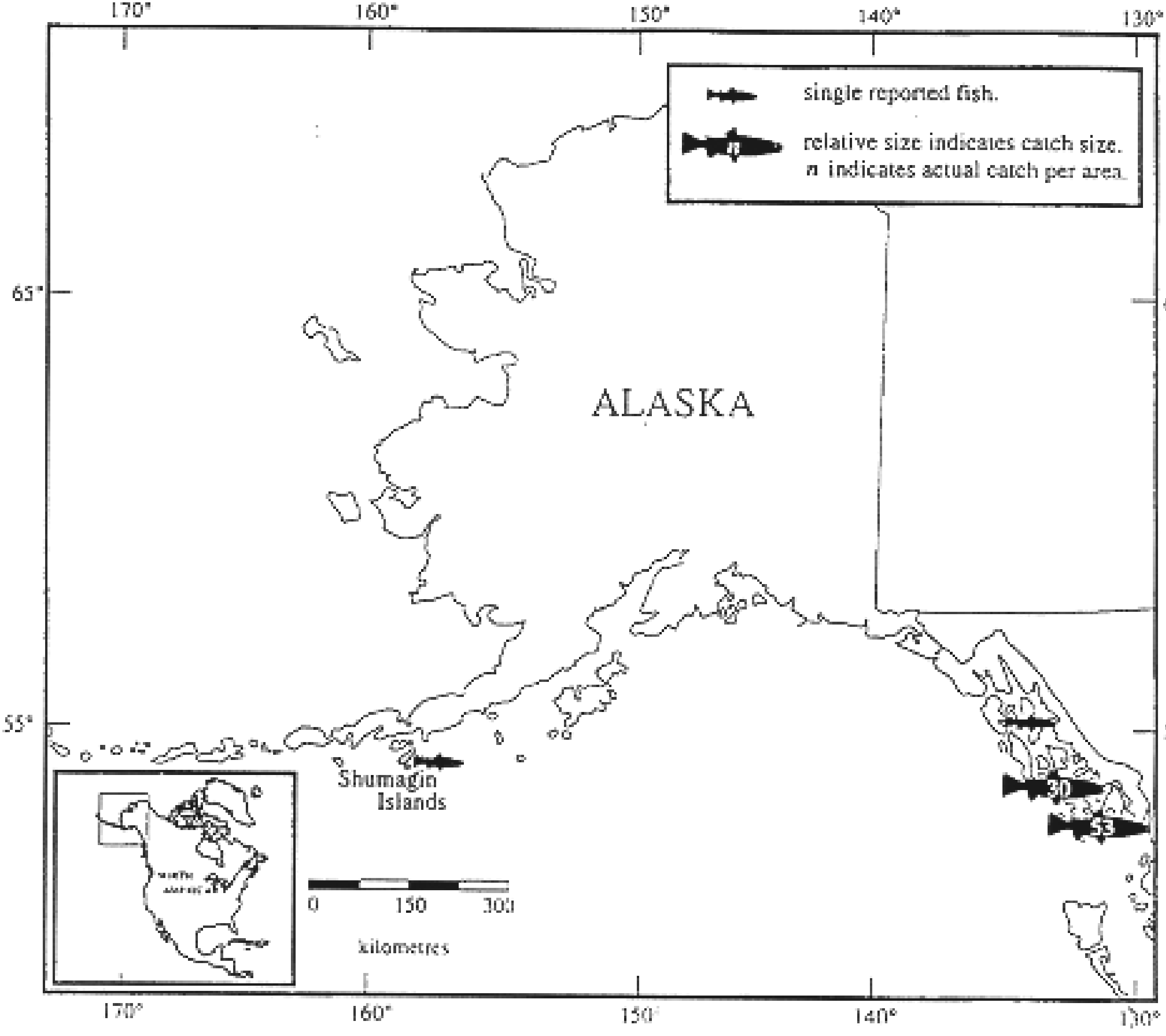

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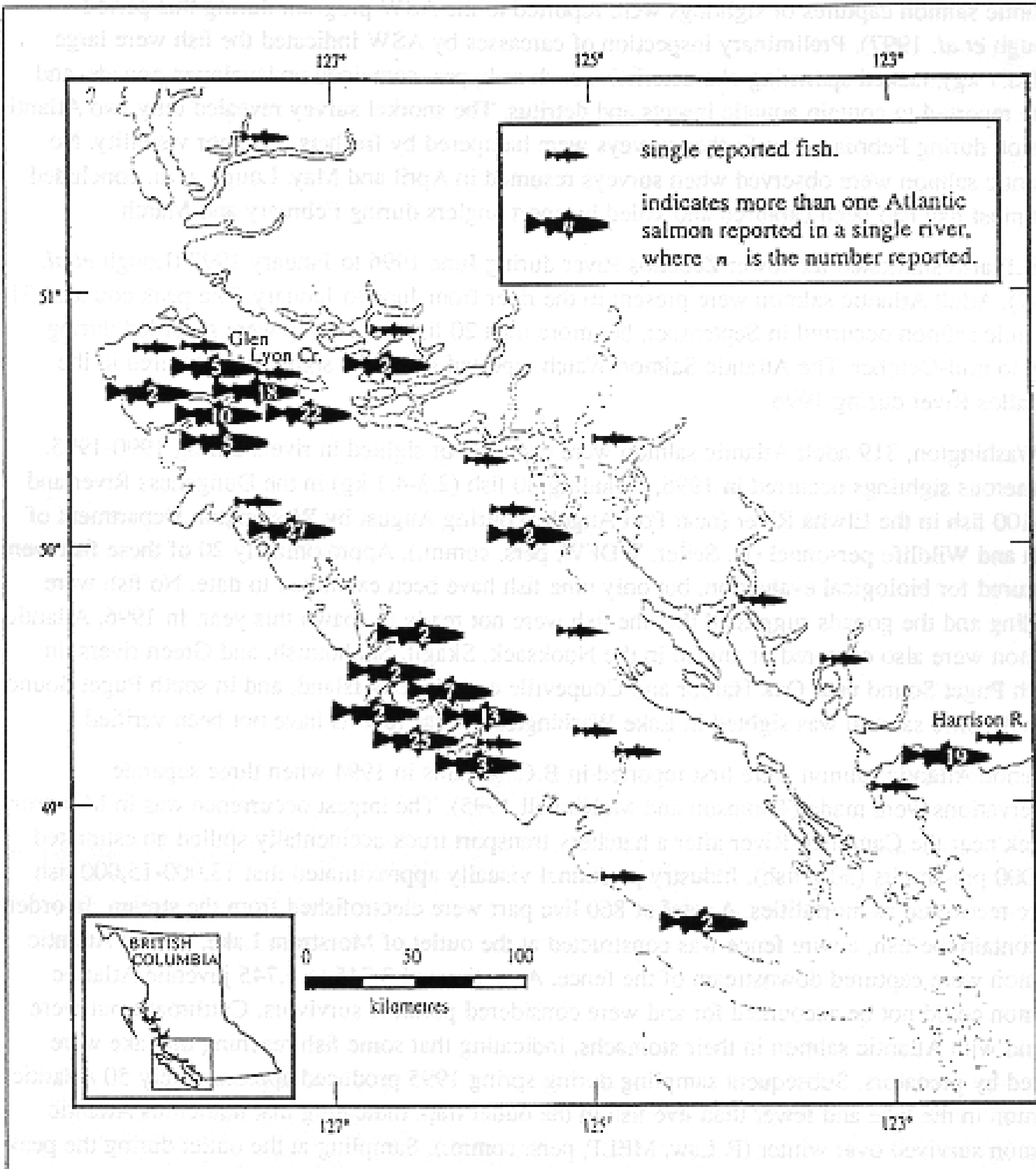

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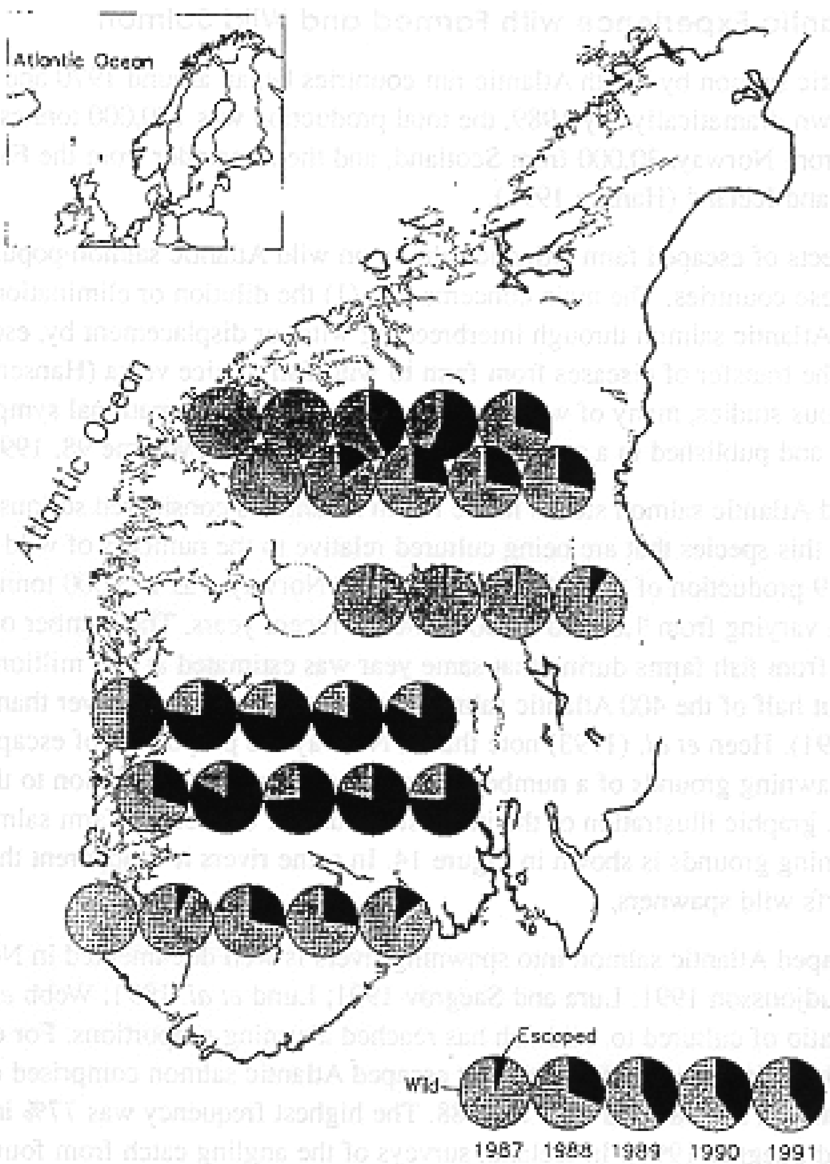

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EXECUTIVE SUMMARY

This paper summarizes the potential health impacts on wild fish and humans arising from the presence and treatment of diseases in commercially cultured salmon in British Columbia. The paper focuses on three main concerns: the risk of importation of pathogens or parasites foreign to the province, the transfer of disease between farmed and wild fishes, and health impacts associated with the use of drugs and pesticides on commercial salmon farms. This paper also reviews existing disease management regulations and strategies, as well as discusses methods for acquiring information on the status of diseases and their treatment in fish in B.C.

Infectious, parasitic and non-infectious diseases have been described in wild and farmed fish in the province. Because of the relative ease with which cultured fish can be monitored compared to wild stocks, disease is more easily and regularly reported for farmed fish. Compared to other areas of veterinary and human medicine, there exists important deficits in our understanding of the epidemiology, ecology and impacts of disease in wild and cultured fish. Much of what we know of fish disease has come from experience gained by culturing fish. Aquaculture has provided significant motivation to investigate fish disease. Compared to natural conditions, culture conditions provide environments in which disease can be more readily observed and studied. In addition, exposure to a variety of pathogens, toxins and parasites in net-cage cultured fish coupled with the stresses created by captive rearing provide an environment that can favor the occurrence of disease in farmed fish, and can allow disease present in wild stocks to become significant causes of mortality in farmed stocks. As in other forms of agriculture, the prevention, and treatment of disease is a constant concern and major activity for fish culturists. Our inability to regularly or readily detect sick wild fish, variations in the pathophysiology of wild species, and the complex interactions of environmental, ecological and microbiological factors in nature are primary sources of uncertainty regarding the role of disease in wild fish, and the interactions between wild and farmed populations. In addition, differences between strains and species complicate efforts to generalize research results. The lack of information on the incidence and prevalence of fish diseases in B.C. together with the lack of information about the ecology of sea cages, limits efforts to assess the magnitude and nature of the risk of pathogen transfer between wild and farmed fish and to identify wild species that are at highest risk of encountering health threats of salmon farm origin.

Importation of pathogens

Internationally, there are several instances where the movement of fish from one region to another has been associated with changes in the occurrence of disease in native fish stocks. There are no confirmed reports of the introduction of exotic pathogens or parasites traceable to the movement of fish or eggs in British Columbia over the past 15 years. The introduction of an exotic pathogen has the potential to result in significant economic losses to industry. Several organizations consider potential importation of exotic pathogens to pose particular risks to wild stocks. However, it is not possible to precisely predict the ecological significance of the introduction of specific pathogens. The enormous numbers of fish moved internationally annually coupled with the relatively small number of reports of outbreaks of exotic diseases suggests the probability of exotic disease outbreaks is low, but not zero. The regional restriction on salmon imports to surface-disinfected eggs greatly reduces the number of pathogens that may be imported and further reduces but does not completely eliminate the risk of pathogen import. Current B.C. policies governing fish importations are among the most rigorous in the world. However, they do not apply risk assessment methods nor standardized protocols for preventing and detecting imported pathogens that are equivalent to those applied to terrestrial species in Canada or fish in some other jurisdictions.

Care must be taken in distinguishing exotic agents from newly described indigenous microbes; the latter being a common occurrence in new forms of fish culture. The disease-causing organisms cultured from farmed fish in B.C. have been previously identified in wild fish or are considered indigenous.

Disease transfer among fish

It is generally held that fish pathogens move from wild to farmed stocks. However, the magnitude and significance of movement of microorganisms from farmed to wild stocks is unknown. It is reasonable to assume that wild and farmed fish are exposed to and can be infected by the same organisms and that some wild fish may be exposed to pathogens originating from fish farms. It is not possible to reach conclusions regarding the ecological significance of such transfers. Local and international experience do not contain sufficient evidence to prove nor disprove that the transfer of pathogens or parasites from farmed to wild fish increases the rate of disease in wild stocks. This reflects difficulties in monitoring diseases and establishing the source of indigenous pathogens. Existing records of disease surveillance of wild and farmed fish are inadequate to confidently detect changes in the level of disease in either population.

The survival of a sick fish is generally low. Thus the likelihood of escaped sick fish transmitting pathogens to wild stocks is also low. However, the role of sub-clinically ill or carrier fish in pathogen transmission is unclear. Pathogens or parasites of farmed salmon can be shed into the water column or sediments below the pens. The survival time of shed organisms will vary with microbe species and environmental conditions. Information is lacking regarding the adequacy of the infectious doses around sea-cages and the likelihood of wild fish exposure. Variability in research methods used to examine these factors complicate efforts to extrapolate results to B.C. farms. Some investigators have suggested that the presence of active fish culture facilities results in an increased risk of wild stocks acquiring disease causing agents. Others conclude that physical and behavioural obstacles, and the dilution of concentration of microorganisms in open water reduce the probability of transmission of organisms between wild and farmed stocks.

Infection with a pathogenic microbe is generally an insufficient condition to result in disease. However, if fish are compromised by other factors, they will be more likely to develop disease after infection. Many of the husbandry conditions of salmon farming can increase the susceptibility of farmed fish to infectious diseases. The impact of these stressors will vary with age, species, and environmental conditions. No evidence was found to show that culture conditions in B.C. result in immunosuppressive stressors in wild fish. Because wild fish are most susceptible to disease at spawning and smoltification, and concentrations of these fish increase at spawning and outmigration, interactions in estuarine zones or spawning streams may be a more plausible location for disease interactions.

There are few pathogens man can acquire from fish. Salmon associated food-borne diseases have generally been associated with the consumption of wild fish or inadequate handling or preparation of fish products. There is no information to suggest any greater likelihood of human food-borne infectious disease from farmed salmon than from wild salmon. Studies of coliform bacterial contamination around sea-cages have been contradictory.

There exists a risk of movements of pathogens or parasites within the provincial boundaries because live fish can be moved and regulations suffer from deficits similar to those governing fish importation. This risk is reduced by the concept of zoning and by restricting the movement of unhealthy fish. However, government-sponsored programs for disease surveillance, control and prevention are inadequate to the task and limit governments ability to identify, prevent or mitigate potential fish health concerns.

Use of drugs and pesticides

The use of chemical compounds and vaccines to prevent and control infectious disease is standard practice in agriculture and aquaculture. With the advent of better vaccines and improved husbandry, antimicrobial use has decreased. There can be notable variation of drug use from farm-to-farm.

Routes of drug and pesticide delivery used by salmon farmers allow these compounds to enter the environment. However, their distribution is generally restricted to the areas in the immediate vicinity of the cages. While some compounds can be detected by chemical means for weeks to months after their use, their biological activity is restricted to a shorter time frame. The tremendous variation in research methods used to explore the environmental fate and impact of drugs and pesticides in aquatic environments and the predominance of research from outside B.C. complicates efforts to generalize findings to B.C.

Pesticides have not been used on salmon farms in B.C. However, experience elsewhere does show non-target toxic effects of their use. The drug ivermectin is used to control parasites in B.C. Evidence regarding its ecological effects are contradictory and inconclusive. Lack of data prevented an assessment of the degree to which this drug is used in B.C.

European studies indicate that wild fish and invertebrates can take up through feed or environmental sources drugs used on salmon farms. Tissue residues in these species tend to be restricted to a period of days to weeks after completion of drug use on the farm and do not represent a threat to the health of wild species. Humans could be exposed to aquaculture drugs by consuming marine species with tissue residues. Adverse effects of human exposure to tissue residues of drugs are rarely reported and generally mild for the drugs commonly used in aquaculture. The relatively low frequency of drug use and salmon farm siting restrictions reduce the probability of human exposure. There exists the possibility of mobile wild species such as crustaceans or escaped farmed fish with violative tissue residues to move out of the immediate vicinity of the farm, and for shellfish from beds sited near treated salmon farms to develop tissue residues.

There exists concerns regarding the potential for antimicrobial use in aquaculture to select for antimicrobial resistant strains of bacteria and that such resistance can be transferred to pathogens of other species, particularly humans. The results of previous reviews of the association of use of antimicrobials in food animals coupled with difference between salmon and human pathogen ecology suggest that this remains a hypothetical, yet unproved risk which is less likely to be realized in aquaculture than in other forms of agriculture. The postulated increase in resistance in human pathogens attributed to drug use in salmon farming would be very small in comparison to alternative sources of resistant organisms.

Timely and regular review by government agencies of drug and pesticide use is hampered by inadequate resources and insufficient data collection, storage and retrieval systems. The use of drugs and pesticides is subjected to a large number of federal and provincial regulations. The restricted number of compounds available and suitable for use in fish, the high level of veterinary involvement and lack of use of medications as growth promotants allow for better control of drug use in aquaculture compared to terrestrial agriculture.

I. INTRODUCTION

A. FISH DISEASE: AN OVERVIEW

Historical aspects

Our understanding of fish disease, compared to other areas of veterinary and human medicine, is still in its infancy. Although some of the first recorded descriptions of sick fish date back to the 1600s, it was not until the turn of the 20th century that the field of fish pathology developed. The majority of efforts in the early to mid-1900s were focused on either (1) the description of fish parasites, (2) the identification of microorganisms, such as bacteria, fungi and viruses, which were capable of causing fish disease, and (3) the description of fish tumours (Moller and Anders, 1986). In the late 1950s, two factors resulted in an intensification of research efforts to understand fish disease: the desire to use fish as bioindicators of marine and aquatic pollution, and the increased use and importance of intensive fish culture for farming and stock enhancement.

Much of what we know of fish diseases has come from experience gained from culturing fish. While the economic values associated with stock enhancement programs and commercial fish farming have provided the motivation to understand and control fish disease, the accessibility of large numbers of confined fish has provided the opportunity to observe disease conditions that would go unnoticed in wild fish. Despite the remarkable growth of our understanding of how disease develops in a fish, there still exist important deficits in our knowledge of the epidemiology, ecology and impacts of diseases of wild and cultured salmon.

Disease in wild fish

The role disease plays in regulating wild salmonids or other wild fishes is largely unknown. The distribution and size of fish populations are largely determined by their interaction with other organisms and their environment. Predation, competition, habitat availability, climate and restriction of movement are some of the key factors that determine the characteristics of a population (Krebs, 1994) . A population can grow by increasing its immigration or birth rate and can decrease by increasing its emigration or death rate (Scott and Smith, 1994). It is difficult for many ecologists to accept that disease plays a predominant role in affecting the long-term stability of naturally occurring populations (Croze, 1981). Disease can, however, have a negative effect on populations. By increasing the death rate or decreasing the birth rate, disease can reduce a species abundance and influence its distribution. Disease can also act as a density-dependent factor that regulates and restricts the number and type of organisms that can thrive in a given environment (Croze, 1981).

For commercially exploited species such as salmon, harvesting pressures coupled with a reduced habitat for spawning and rearing of young stock have been implicated as significant population regulating factors (Krebs, 1994). In an exploited stock such as Pacific salmon, diseased fish may be caught more readily than their healthy cohorts. Thus, fishing pressures may “replace” losses due to disease. Where there is not harvesting pressure, the stressors associated with competition and the increased density of fish may facilitate the spread and importance of disease. Some authors have suggested that epidemics of disease tend not to play an important ecological role in populations below a certain optimum density, but may limit excessive population growth (Scott and Smith, 1994; Moller and Anders, 1986).

In general, scientists have been unable to quantify the contribution of disease or pathogens in individuals or populations of wild fish. Generally, significant diseases problems in wild stocks go largely unnoticed or unrecorded (Traxler, 1986; Moller and Anders, 1986). This is particularly true for chronic parasitic infections which do not result in mass mortalities (Kent and Fournie, 1993). Dramatic die-offs of wild fish have often been associated with abrupt environmental changes, although outbreaks of infectious diseases have also been reported (Sindermann, 1963; Moller and Anders, 1986; Kent and Fournie, 1993). The main reason for the uncertainty regarding the role of disease in fish populations is that the outcome of interaction between a fish and a disease causing organism is under the influence of a large variety of ecological and environmental factors. This variability leads to often unpredictable outcomes of the fish-agent-environment relationships. Under one set of conditions, a microorganism may be harmless to a group of fish, whereas in other situations, the organism may result in mass mortality. The detection of an agent theoretically capable of causing disease or the detection of a particular symptom in some fish rarely provide the basis from which to reliably predict the nature of population effects that will occur.

Attempts to study diseases in wild fish are fraught with methodological difficulties, perhaps the most significant being our inability to readily or regularly detect sick fish in the wild. Methods used to capture wild fish are often biased. Hook and line fishing tends to capture fish that are healthy or hungry enough to take the bait. Net-capture methods are more likely to catch fish that are unable to escape capture. A variety of studies have shown that sick fish tend not to keep up with their cohorts due to behavioural or physiological limitations (Guthrie and Kroger, 1974; Stephen and Ribble, 1994). For many species of fish, individuals that appear different than others in the immediate area are more likely to be captured by predators than fish that look and behave normally (Wolf, 1985). It is often assumed that many sick fish are lost to natural predators before man has an opportunity to catch them (Kent and Fournie, 1993). Finally, the way a fish interacts with its cohorts or other species can be affected by disease (Stephen and Ribble, 1994). Therefore, non-random samples of wild populations have the potential of seeing only a portion of the spectrum of disease or infections that may afflict a wild population. The spectrum of disease that is observed may over or under-estimate the extent or impact of disease in wild stocks. The nature and distribution of disease seen will vary with study methods, disease investigated and species sampled; thus samples of wild fish rarely provide disease information that can be readily extrapolated to the entire population.

Efforts to understand wild fish diseases are further complicated by the lack of knowledge of the pathophysiology of many wild species (Kent and Fournie, 1993). Although there exist several textbooks and scientific publications regarding diseases of salmonids and other commercially important species, little is known about the way non-commercial species respond to disease under natural conditions. Not all fish are the same when it comes to disease. The ability to ward off infectious diseases may differ between fish species as well as between strains of the same species. The natural history, behaviour and geographic distribution of a particular species can all affect the type of disease risks a fish will face in its lifetime. It is, therefore, not reasonable to assume that all fish in a given area will face the same disease risk.

Disease in cultured fish

Although investigations of disease in cultured fish have also been limited in their ability to see the "whole picture" in fish populations, they have the advantage of having the entire population of concern confined and more readily accessible for observation. While the role of subclinical disease may not yet be clear for many fish diseases, the importance of many lethal diseases is well described for commercial farming and stock enhancement programs. Disease has "plagued the life of the hatcheryman through the years" (Wood, 1979). The prevention of losses due to disease is a constant activity for many fish enhancement operations (Meyer *et al*, 1983). Disease has also been the most important limiting factor in the success of many fish farms. Kent and Fournie (1993) identified several reasons for the increasing prominence of disease in fish culture in recent years including; (1) the cultivation of larger numbers and new species, (2) the development of new methods for fish rearing, (3) the use of new geographic locations for fish rearing and (4) the involvement of more researchers in the field. Perhaps one of the more important reasons for the detection of more disease in farmed fish than in wild fish is the relative ease with which we can observe illness and death in cultivated fish. With their movement restricted and the lack of predators in fish culture systems, aquaculturists and diagnosticians have an increased opportunity to observe, collect and examine sick and dead fish.

Net-cage rearing can reduce the costs of fish production by decreasing construction costs and the need to pump water. However, this form of aquaculture provides an unregulated water supply which can potentially expose captive fish to a variety of toxins, parasites and pathogens (Kent, 1992). The exposure to ubiquitous environmental pathogens coupled with the stresses associated with captive rearing can create opportunities for diseases that occur in natural stocks at low levels to become significant causes of mortality in farm-reared fish. This situation is not unique to aquaculture. The management of disease has always been an essential part of all forms of intensive animal agriculture. The alteration of animal ecology through the artificial management of housing, feed, movement and density, coupled with new physiological demands placed on animals reared for food production, can often combine to create opportunities for disease to arise. For example, the condition known as "shipping fever" in feedlot cattle is considered a disease of confinement (Ribble, 1992). While susceptible calves and the bacteria and viruses that cause shipping fever exist in calves outside of the feedlot, large outbreaks of the disease tend not to occur until calves are brought together in a feedlot. As with all forums of animal husbandry, the juxtaposition of a dense population of susceptible fish in the presence of disease causing agents in a stressful environment creates an opportunity for disease to become a significant population regulating factor.

B. DISEASE IN BRITISH COLUMBIA FARMED SALMON—A BRIEF HISTORY

The control of disease has been a primary concern of salmon farmers since the inception of the industry. In a report entitled "Aquaculture: British Columbia's Future," disease was identified as a critical factor limiting the growth and development of the industry (Anon, 1992). Similarly, in 1996, funding agencies such as the National Research Council viewed disease research as an industry priority.

The British Columbia salmon farming industry, prior to the culture of Atlantic salmon, was largely established from eggs provided by two major federal salmon enhancement hatcheries. As a wide variety of infectious and noninfectious diseases had been previously diagnosed in these stocks, it was not surprising that early attempts at raising chinook and coho salmon in B.C. were frustrated by diseases outbreaks. Ever since the first attempts at marine rearing of salmon in B.C., salmon aquaculturists have faced the challenge of intensively rearing fish in an environment which provided ample opportunity for exposure to native pathogens. Alone or when coupled with toxic algae blooms, endemic indigenous diseases such as bacterial kidney disease and vibriosis were often key factors that led to the failure of many of the early Pacific salmon farms (Keller and Leslie, 1996). The majority of the diseases of commercially reared salmon in B.C. were observed in wild or enhanced stocks in the province many years before the development of a commercial salmon farming industry (Bell, 1982; Hoskins *et al*, 1976). However, the intensive conditions associated with fish farming allowed these indigenous diseases to create significant mortality problems on farms. While improvements in husbandry and the development and refinement of disease control programs reduced the impact of a number of disease problems, in particular vibriosis, bacterial kidney disease remained a significant limiting factor for producers of Pacific salmon. Its ability to be transmitted through the egg, coupled with the lack of effective methods for its control, kept this disease as an important problem for many Pacific salmon farmers. With the intensification of diagnostic efforts that accompanied the growth of the industry, other diseases began to be reported. While agents such as Loma salmonae and Hexamita sp.(Kent *et al*, 1989; Kent *et al*, 1992) were previously reported in other species or situations, diseases such as marine anemia and net pen liver disease (Stephen *et al*, 1996; Kent, 1990) were first described in B.C. farmed salmon.

In the late 1980s, salmon farmers began to look at Atlantic salmon as an alternative to chinook and coho salmon as the main species for cultivation. Their superior growth characteristics and preference by the world market played a major role in prompting this transition (Hicks, 1991). Atlantic salmon also were considered to be more resistant to the effects of R. salmoninarum, the bacterial cause of bacterial kidney disease. In addition, some of the important diseases affecting farmed Pacific salmon in the late 1980s, such as marine anemia, had not previously been reported in Atlantic salmon. Along with their potential for becoming a more economically efficient farm species than Pacific salmon came a new disease concern. Unlike the Pacific salmon farming industry, there were no local sources of Atlantic salmon broodstock from which to get the number of eggs required to initiate the broodstock programs needed to support a commercial Atlantic salmon industry. Seed-stock from outside of the province was needed. Scotland, Ireland, the United States and New Brunswick all served as sources of Atlantic salmon for B.C (Winsby *et al*, 1996). The potential introduction of exotic pathogens with imported Atlantic salmon became a major concern for commercial and sport fisheries groups and environmental agencies. Previous experience with shellfish transfers and fish stocking programs in other parts of the world suggested that the risk of introducing foreign pathogens with the importation of non-indigenous fish was to be taken seriously (Munro, 1988). In order to restrict the likelihood of introducing pathogenic organisms exotic to B.C. waters, the Fish Health Protection Regulations together with new regional import policies were applied to companies bringing Atlantic salmon from outside of the province into B.C.

While bacterial kidney disease did not prove to be as significant a factor for rearing Atlantic salmon as it was for Pacific salmon, Atlantic salmon farmers were faced with other disease challenges. Some of the agents that were not of significance for Pacific salmon became important factors for some Atlantic salmon farms. Furunculosis, infectious hematopoietic necrosis, sea lice and Kudoa infestations are examples. As with Pacific salmon, the pathogens associated with the major health and productivity problems facing Atlantic salmon farmers had been found in B.C. prior to the advent of commercial Atlantic salmon farming. Like their predecessors, Atlantic salmon farmers refined their fish management practices and utilized preventive measures such as immunization to reduce the impact and importance of diseases in their stocks. However, disease control and health promotion remained priorities for the industry.

The importance of disease in fish farms in B.C was not unique. Catfish in the southern United States, salmon in Europe, and carp in Asia all face disease control challenges. The prevention and control of disease is also an essential component of stock enhancement programs that require the spawning, incubating and rearing of fish in artificial situations. As the salmon farming industry grew, local and international efforts provided new tools and techniques to control and treat disease problems of farmed fish. Improvements in our understanding of the environmental and nutritional requirements of salmon helped not only to combat specific disease problems, but also to improve the general health of cultivated fish. The development of vaccines and disease screening programs assisted in reducing the prevalence and impact of disease in farmed salmon in B.C. Despite the success of the efforts to improve the health of cultivated salmon, reduced survival to market due to disease remained a priority concern for fish farmers, both locally and abroad.

As with all forms of animal management, it is not possible to prevent all diseases of cultured fish. There remains a need to treat sick fish, whether in a hatchery or in a marine cage. As many of the diseases affecting farmed salmon are infectious in nature, many of the chemicals used to combat fish disease are designed to kill or control bacteria, viruses and parasites. There exist few cost-effective and efficacious drugs for treating viral diseases in any species. Thus they are rarely used in commercial acquaculture. Antibacterial agents such as oxytetracycline have a long history of use in fish cultivation. Whether applied topically, in feed, in baths or by injection, antibacterial drugs have been important tools in controlling disease in fresh water hatcheries and marine rearing systems. However, the limited range of available antibacterial agents has restricted the options fish culturists have for the drug therapy of their stocks.

Diseases and the methods used for their control have been a focus of concern for many critics of the B.C. salmon farming industry. The concerns about the use of antibacterial agents by fish farmers mirror the concerns of consumer and environmental groups regarding the use of these agents by land-based farming. Although debated in the scientific literature (Janzen, 1990; Smith *et al*, 1994), some feel that the use of antibacterial agents in food production systems can lead to the development of antibacterial resistant strains of bacteria and the exposure of human consumers to residues of these drugs in the food. Other concerns involve the impacts and risks of fish pathogens to seafood consumers. Examples of bacterial and viral contamination of seafood products are best known for shellfish, where contamination with fecal coliform bacteria and toxic algae can be significant public health issues. Yet, little is reported in this area for farmed salmon.

Critics of salmon farming have also expressed concern regarding the exchange of disease causing organisms between farm and wild fish. Despite a lack of direct evidence, there are concerns that, by concentrating a large number of sick or infected fish within the confines of a farm, wild fish will be exposed to unique disease challenges. These concerns are most acute regarding the possibility of the introduction of an exotic pathogen.

C. DEFINITIONS AND MAJOR CONCEPTS

Before proceeding to explore the Key Issues of this report, it is important to discuss some central concept of disease. Whether it be first hand experience with a bout of influenza or participation in a disease investigation, we all have some experience with disease. Through this experience, we each have developed our own notion of what disease is and how it works. However, our personal or profession concepts of health and disease may not be shared by others. Appendix A presents some defintions for a variety of key concepts, including Disease, Health, Infection, Pathogen, Cause of Disease and Disease Control. The reader is encouraged to refer to these definitions before proceeding so that it is clear how the terms are used throughout this report.

II. KEY ISSUES AND METHODOLOGY

A. TERMS OF REFERENCE

Issue statement

In the terms of reference developed by the B.C. Environmental Assessment Office for this review, the following issue statement was made for Fish Health:

A number of diseases occur in both farm and wild fish. These diseases fall into groups: bacterial, viral, fungal and parasitic. Concern has been expressed that farm salmon may expose wild fish (salmonids and others) to disease. The potential for disease to be transmitted between farm and wild species will vary according to the pathogen involved, the susceptibility of the host fish, and environmental factors influencing the number, movement and survival of pathogens and the susceptibility of the host. Concerns exist that fish health management practices to control disease on fish farms may also impact wild stocks and the surrounding environment. The importation of Atlantic salmon gametes from eastern North America and Europe is of concern due to the possibility of inadvertent introduction of exotic fish diseases to the Pacific coast.

The Terms of Reference provide the following issues for review:

- Identify and assess the risk of adverse fish health effects arising from the interaction between farm and wild fish.
- Evaluate the adequacy of current methods, processes, practices and procedures used to prevent or mitigate adverse fish health effects arising from the interaction between farm and wild fish.
- Recommend improvements to current methods, processes, practices and procedures used to prevent or mitigate adverse fish health effects arising from the interaction between farm and wild fish.

During the course of this review, health concerns beyond the interaction of wild and farm fish were raised by public submissions and by comments provided to the Technical Advisory Team by members of the Review Committee. In particular, issues of human health impacts were raised by First Nations representatives, members of local communities and environmental organizations. On the recommendation of the Environmental Assessment Office, these issues were also considered in the review of health impacts associated with salmon farming in B.C.

B. CASE STUDY

All medical investigations begin with a case. The key issues as described in the Terms of Reference are sufficiently broad to complicate a focused review of health and disease concerns associated with salmon farming in B.C. To facilitate discussion, we have chosen to use a specific case to help illustrate and evaluate some of the concerns that arose during public comments on the draft Terms of Reference and through interviews conducted as part of this review. **The utilization of this example in no way implies that a causal relationship has been established or refuted between the specific outcomes of this case and the practices of salmon aquaculture in B.C.** The passage of time and lack of required information prevent us from determining the true reason for the disease events represented in this example. Information regarding this case was provided by residents of the Broughton Archipelago who managed the hatchery and/or lived near it, and from members of the Department of Fisheries and Oceans who had knowledge of the facility and the outbreak investigation.

Case history

In 1982, a community-operated coho salmon enhancement hatchery supported by the Department of Fisheries and Oceans was established on an island in the Broughton Archipelago. At this hatchery, mature fish return to the stream and are captured, transported and held in Capilano troughs until a sufficient number are available for egg selection. Eggs are collected, fertilized and incubated at the facility each year. For the nine years preceding the outbreak, hatchery workers report the broodstock mortality rates on site averaged less than 3%. In 1991, 28% of the returning fish that were collected died when being held prior to egg and milt collection. This coincided with a nearby recent introduction of farmed Atlantic salmon that later were revealed to be suffering from furunculosis. A diagnosis of furunculosis was provided for the enhanced stocks by the Fish Health Section of the Pacific

Biological Station. Until this time, furunculosis had not been diagnosed at this facility. The Fish Health Section had no disease information on this stock prior to 1990, although hatchery workers reported that prior to the introduction of farms to the region coho broodstock deaths were primarily due to fungal infections and that disease had not been a problem in this stock prior to 1991. To reduce fish losses in 1991, broodstock were treated with oxytetracycline injections. The hatchery lost 37% of its held broodstock in 1992 and 47% in 1993. Furunculosis was again diagnosed in 1993. In this year, some bacterial isolates collected from affected fish showed evidence of resistance to oxytetracycline upon laboratory testing conducted by the Pacific Biological Station (D. Kieser pers. comm.).

In 1991, Atlantic salmon had been introduced to a farm in the vicinity of this hatchery. Subsequent owners of this site later reported to local residents that an outbreak of furunculosis had occurred at the site in 1991. Local residents and hatchery managers were informed of other outbreaks of furunculosis on salmon farms in the Broughton Archipelago in later years including 1993. Analysis of the 1993 farm isolates showed evidence of resistance to antibacterials commonly used to treat fish diseases, yet in a pattern dissimilar to that seen in the enhanced fish. In this episode, the members of the hatchery advisory board felt that the lack of history of furunculosis in the hatchery prior to the establishment of Atlantic salmon farms, the concurrent reports of furunculosis in wild and farmed salmon, the geographic proximity of the outbreaks, and the appearance of antibiotic resistant strains of the causative agent of the disease was evidence that farmed salmon were spreading disease to wild salmon. In addition, some concluded that the virulent nature of the organism in the coho indicated that this may not have been an indigenous strain of the organism to which local stocks were adapted, but instead an imported strain. The lack of reported changes in management practices before the outbreaks and similar environmental stressors during the period of 1991-1993 further led some to believe that this case was not an example of increased susceptibility to an indigenous pathogen due to changed environmental stress. Significant debate has erupted about this case, with resulting conflicts in interpretation of the available data.

However, this case illustrates several of the key areas to be explored in this review, namely:

- exchange of endemic pathogens between farmed salmon and wild fish;
- importation of new pathogenic organisms with introduction of non-indigenous species; and
- effects of antibacterial use by fish farms.

This case will be revisited throughout the text and will serve to illustrate the conflicting and inconclusive evidence that is often associated with investigations of disease interactions between wild and farmed fish.

C. METHODS OF INFORMATION COLLECTION

Literature review

Published scientific papers were identified through a computer-based literature search conducted at the University of British Columbia. Details of the literature review are presented in Appendix C. The search was supplemented by papers provided by Review Committee members, personal contacts, and searches of private databases. Government reports, published and unpublished, were also reviewed, as were proceedings from pertinent conferences, workshops and meetings. Previous assessments of the B.C. salmon farming industry were also reviewed. Finally, these references were supplemented with reviews of recent textbooks concerning local, national and international fish health and aquaculture issues.

Personal communication

To understand the nature and level of concern for disease issues surrounding the B.C. industry, discussions with Review Committee members were supplemented with interviews with members of government agencies, academic institutions and other concerned individuals. In addition, experts outside of British Columbia were contacted by electronic mail, telephone and postal mail. The people and agencies that provided personal communications for this report are listed in Appendix C.

Unpublished data

Attempts were made to acquire data relevant to the Terms of Reference and specific to B.C. Several agencies were approached including the Department of Fisheries and Oceans Fish Health database, the B.C. Provincial Fish Health database, the B.C. Animal Health Centre, the Western College of Veterinary Medicine, the Ontario Veterinary College, the Atlantic Veterinary College and the B.C. Salmon Farmers Association. Information on drug use or residues of drugs in seafood products were requested from the Bureau of Veterinary Drugs (Western Regional Office), the Inspection Branch of the Department of Fisheries and Oceans (Pacific Region), the Bureau of Biologicals (Agriculture and Agri-Food Canada), and the office of the Provincial Veterinarian.

D. RISK ASSESSMENT

Risk Assessment in a bio-medical context

A broad definition of risk is “the probability times the consequence of an adverse or hazardous event” (Whyte and Burton, 1980). Environmental risks have other characteristics in addition to their probabilistic nature:

- Risks involve a complex series of cause and effect relationships that are connected from the source to the impact through a series of environmental, technical and social variables.
- Risks are connected to each other as well as to benefits. Reduction of one risk often means a decline in benefits or the generation of new risks.
- Risks can never be measured precisely. Their probabilistic nature causes risk assessments to be estimates. The precision of the estimates is dependent on the nature of information available.
- Risks are evaluated differently in different social settings. Therefore, risk evaluations of similar processes can generate dissimilar conclusions (Whyte and Burton, 1980).

There are a wide variety of factors that are perceived to threaten the health and well-being of people, animals and the environment. Decisions must be made as to which hazards to ignore and how much risk reduction should be sought. Often these decisions are societal and not scientific. The primary goals of a risk analysis are to identify significant hazards, stimulate basic research and develop agreement in health goals and priorities (Lave, 1987). Given our current knowledge, quantifying health risks is often somewhat arbitrary. Assumptions that are inserted into a risk assessment often reflect the assessor’s personal experience or interpretation of what society desires. This is particularly true for fish diseases, where methodological limitations make it difficult to measure the incidence of disease or probability of adverse outcomes. Disease incidence (the number of new cases of disease in a population per unit time) is a direct measure of disease risk. Lave (1987) identified the following as reasons why many disease studies are unsuitable for risk evaluations: too few subjects are included to allow for confident conclusions, important confounding factors are not controlled, there is little or no data regarding the level of exposure to hazardous substances or events, experimental studies often use exposures much higher than those naturally encountered or use test subjects that are significantly different than the population of concern, and outcomes are inadequately diagnosed. Each of these problems is evident in the information available to review health and disease risks associated with salmon aquaculture. Unlike for the assessment of human health risks, critical information is generally unavailable available to conduct quantitative risk assessment for fish and wildlife species. Thus assessors often rely more on qualitative descriptions of potential hazards and judgements as to the likelihood of adverse outcomes.

Approach for this review

As outlined above, important voids exist in our understanding of the complex interaction of fish with disease causing agents and the environment. Most of the information needed to create models of disease risk for aquaculture is not currently available (Kent, 1994). The nature and quality of information that was available for this review did not allow for quantitative estimates of the probability of the adverse outcomes associated with salmon aquaculture practices. Details of these limitations will be included in the discussion of each of the key issues. The time frame of the review prevented an assessment of the size and direction of biases associated with data and observations surrounding salmon diseases in B.C. Therefore, the assignments of probabilities to outcomes would run the risk of being arbitrary in some cases, inaccurate in others and potentially misleading in the rest.

The inability to quantify the risk associated with interactions between farmed and wild fish does not prevent a review of the risks. Similar circumstances are encountered in other environmental assessments (e.g., Gandy, 1990). In such cases, the reviewer must rely more on analogy and judgement to develop a reasonable argument than in cases where a more quantitative approach is possible. Such hazard or endangerment assessments focus upon primary factors that affect the number of cases that occur in a population and consider if the activities being reviewed could be of sufficient magnitude to change the incidence of adverse outcomes beyond background levels. There are three main ways by which the number of cases of a disease can increase in a population:

- A new or improved method for diagnosing, detecting or monitoring a disease is applied;
- The population is exposed to a new disease risk factor or is exposed more often to an existing risk factor; and,
- The populations become more susceptible to the effects of a disease risk factor.

This paper reviews the technical and scientific aspects of the key issues described in sections 2.1 and 2.2. Interpretations and recommendations were based primarily upon the evidence that was found in published and unpublished scientific investigations or risk evaluations. Opinions and concerns expressed by individuals or agencies were used as a guide for identifying important aspects of the key issues to be examined. However, opinions or concerns that were not substantiated by direct evidence were not given as much weight when developing conclusions than those that were based on valid scientific or technical information. It is the view of the author that sufficient alternative routes for informing the Environmental Assessment Office of these opinions or concerns were available. For this review, the principal question to be addressed was, "Is there a reasonable basis from which to conclude that the current practices and regulation of salmon farming in B.C. create new opportunities for exposure to disease risk factors or alterations in the susceptibility of non-farmed species in such a way as to create serious or irreversible damage to the health of non-farmed animals?"

III. DISEASE INTERACTIONS: INDIGENOUS DISEASE

A. BACKGROUND AND DEFINITIONS

There is a variety of classes of disease including genetic, nutritional, developmental, immunological, infectious and neoplastic. Virtually all of the published information and community concerns regarding interactions of diseases of farmed salmon and wild fish involve infectious diseases. There are likely five main reasons for this: (1) much fish disease research has involved infectious diseases, (2) infectious and parasitic diseases are the most frequent form of disease observed in cultured stocks, (3) similar pathogens and parasites are found in wild and farmed fish, (4) there has been a recent surge in public awareness of infectious diseases issues in man, (5) potential routes of interaction for other forms of disease are less well known.

For the purposes of this review an **indigenous disease is one for which there is a history of its presence and experience of the local populations with the disease. This term should not be confused with an endemic disease**. There are three basic forms in which a disease can be manifested in a population: epidemic, endemic and sporadic (Martin *et al*, 1987). Epidemic diseases are those that occur at a rate greater than would be expected in the population. Endemic diseases are those that occur at a specific regularity in a population. Sporadic diseases are those that are expected to occur in a population, but at low rates (usually isolated cases) and at irregular intervals. An indigenous disease can manifest itself in any of these forms.

The word disease has been defined in Appendix A. It is important to remember that the presence of pathogens or parasites is not equivalent to the presence of disease and that the expression of a disease is the result of complex interactions between hosts, agents and their shared environment. In assessing the risks of the transmission of pathogens, one must considered the characteristics of the pathogens including their ability to multiply and remain viable in water, survival time outside of the host, number of infectious units required to cause infections and pathogenicity. One must also consider host factors such as susceptibility to infection, exposure to pathogens, age, health status, pre-existing conditions and culture conditions. Environmental considerations must also be included such as the effects of climate, hydrography and water quality. For the purposes of this review, evidence that there is an exchange of pathogens or parasites between cultured and wild fish was also sought. An indigenous pathogen or parasite was defined as one that is associated with an indigenous disease. Many of the elements of this section of the report also apply to the later discussion on exotic disease issues.

B. DIAGNOSIS AND DETECTION OF SALMON DISEASE AND PATHOGENS

Background

All health and disease information relies upon an assessment of a patient or a population. This generally requires the application of some form of a diagnostic test, whether that be the collection of historical information, a physical examination, microbiological examinations, or population surveys. The objective of each is to better classify the true health status of the individuals or populations of concern. Therefore, it is important to understand the strengths and weakness of diagnostic methods when trying to assimilate the following information. A general discussion of the nature and assessment of diagnostic tests is presented in Appendix D. This appendix has been created to provide the reader with background information on concepts pertaining to how diseases are recognized and should assist in the interpretation of information derived from diagnostic laboratories.

Diagnostic tests for salmon

Detection of infectious diseases of salmon may be achieved in a number of ways including, culturing the associated organism, fluorescent tests to detect antibodies or antigens, enzyme-linked immune assays, genetic probes or immunoelectrophoresis. The performance of these tests have been seen to be affected by the species and population in which they are used (Bruno, 1987; Cipriano *et al*, 1985), the fluid or tissue that is being sampled (Hiney *et al*, 1994; Griffiths *et al*, 1991; Mulcahy *et al*, 1987; McArdle *et al*, 1986; Daly and Stevenson, 1985), and when the sample is collected relative to the time of infection (Lovely *et al*, 1994; Olea *et al*, 1993; Scallan and Smith, 1993; Oliver *et al*, 1992; Rose *et al*, 1989, Bruno, 1987; Mulcahy and Batts, 1987; Mulcahy and

Pascho, 1986). Some diagnostic methods are also limited in their ability to distinguish one organism, antibody or substance from another (Wood *et al*, 1995; Frerichs and Holliman, 1991; Rose *et al*, 1989; Schultz *et al*, 1989). Few diagnostic tests or procedures for fish have been subjected to standard epidemiological assessment of their clinical performance. As it is often difficult to establish the true disease status of a fish, many tests are compared against standard or previously accepted tests. Therefore, assessment of their performance should be considered as a relative assessment or a measure of test agreement. In addition, few tests have been properly evaluated for their performance under field conditions. Instead, many are evaluated under artificial laboratory conditions. These limitations have implications for design and interpretation of disease monitoring programs. As they were formulated to prevent the entry of exotic agents into Canada, often, the emphasis of current fish health regulations is on the detection and exclusion of pathogens instead of the detection and management of risk. Many of the existing fish disease regulations rely upon a test or series of tests to determine the infection status of a population with little or no quantification of the false positive or false negative rates of the tests. These points are discussed in more detail below. Although rare in the past, research efforts are now being directed towards quantifying the accuracy of diagnostic tests and protocols under typical field conditions (e.g., Stephen *et al*, 1995; Stephen and Ribble, 1996; St. Hilaire, 1996; Saksida, 1995).

Although important, the issue of test validity with respect to the identification of disease in individual fish is of less concern for this assessment than is the correct classification of the health status of groups of fish. When coupled with clinical or gross post-mortem signs, in many cases, a medical history which includes the source of fish, species, strain, age and environmental conditions can provide sufficient information with which to diagnose a specific disease in a individual fish with sufficient certainty to develop a rational management plan.

C. DISEASES OF WILD AND FARMED SALMON IN B.C.

Salmon farming has provided increased opportunities to observe salmon in marine habitats throughout their life cycle, thus increasing opportunities to detect previously undescribed diseases, pathogens or parasites. This has allowed for an expansion of knowledge of the type, distribution and impacts of indigenous pathogens and parasites in salmon. Table 1 lists the major infectious diseases that have been diagnosed in commercially farmed salmon in B.C. This list was compiled through review of published reports, government disease surveys and interviews with fish health personnel in the province, and, therefore, represents several years of data. Table 2 lists the diagnoses of disease obtained from the federal fish health database. This database includes diagnoses for fish from salmon enhancement facilities and wild fish for 1995. Only 10 wild non-salmon fish submissions (four Pacific herring and six flounder {species unrecorded}) were included in this record. The Pacific herring samples yielded sporocytophagosis, *Vibrio* sp. infection, and viral hemorrhagic septicemia, while the two flounder showed signs of fungal infection. Table 3 lists the diseases detected in enhanced salmonids held at provincial hatcheries in 1995. Table 4 provides a list of organisms and diseases that have been diagnosed in case submissions to the provincial Animal Health Laboratory through the Fish Health Veterinarian. As this laboratory currently does not provide routine diagnostic service to the industry, Table 4 represents only cases submitted for confirmatory diagnosis and does not include cases routinely handled by a farm’s attending veterinarian; nor does it include disease diagnoses that require histopathology or screening tests as the Animal Health Laboratory does not routinely offer these services to aquaculture. A comparison of these tables illustrates the similarities in the diseases diagnosed in fish held in different culture conditions in B.C. Inadequate sampling opportunities have prevented a full description of the diseases of local wild fishes, making it unlikely that we have complete knowledge of the diseases of wild and farmed salmon in B.C. None of the sources of data listed above are capable of estimating the incidence (number of new cases in a population/unit time) or prevalence (number of existing cases in a population per unit time) as none of the methods are designed to randomly sample the population at risk; nor do they allow for a complete description of all parasites or pathogens infecting a host. Instead, they indicate the diseases for which diagnoses are more frequently sought. Data which are derived from representative samples of a population, such as well designed broodstock or smolt screening programs, would better reflect prevalence. It was not possible to access such data for this review as this information was considered confidential by the laboratories conducting the tests. In their submission to this review, the B.C. Salmon Farmers Association indicated that in 1995 and 1996, 0% (0/2213) Chinook and 0.018% (1/5565) Atlantic salmon broodstock screened positive for virus by evidence of cytopathic effects in cell culture.

Laboratory data tend not to reflect the true pattern of disease in a population. Work conducted on Ontario trout farms revealed that fish farmers who choose to submit laboratory samples were not representative of the entire population of trout farmers (Thorburn, 1993). Although incapable of being used to determine the prevalence of specific diseases in fish populations, laboratory submissions can serve as crude indicators of changing or emerging patterns of disease patterns. A limited number of active surveys have been conducted in salmon farms in the Pacific Northwest (Brackett and Newbound, 1990; Brackett *et al*, 1991a; Brackett *et al*, 1991b; Elston, 1994). As these surveys did not sample the entire population, but instead focussed on sick and dead fish, they likely over-estimated the prevalence of specific diseases in fish farms. The types of diseases seen in these surveys did not conflict with what was being seen in diagnostic laboratories at that time.

The Provincial Fish Veterinarian was involved in 13 farm investigations between 1993 and 1996. These investigations were initiated either upon invitation of the farmer or his/her veterinarian, requests from enforcement officials or public inquiries. Table 5 summarizes the investigations. It should be noted that the Provincial Fish Veterinarian is not consulted on all incidents of increased mortality or morbidity or for all production problems. Therefore, this listing should not be taken as a record of all outbreaks in fish farms, but instead of the nature of problem for which the province has been consulted. Many of the endemic diseases affecting farmed salmon can occur in an outbreak or epidemic fashion (at rates beyond normally anticipated) (Kent, 1992). In their submission to this review, the David Suzuki Foundation reports a series of salmon disease outbreaks including those involving furunculosis, infectious hematopoeitic necrosis, marine anemia, sealice, and infectious pancreatic necrosis (Ellis, 1996). Although the validity of the diagnosis of infectious pancreatic necrosis has been questioned, the reports of other outbreaks is consistent with published and anecdotal information regarding the occurrence of these diseases in netcages in that they can occur in an outbreak fashion. Care must be taken in evaluating the significance of these reports as previous research has demonstrated that sampling biases inherent in previous methods for investigating fish disease outbreaks may inaccurately document the significance and distribution of suspected outbreaks (Stephen and Ribble, 1994 and 1995; Stephen *et al*, 1996). As local veterinarians and industry have experience in managing these occurrences, they do not routinely consult the province for assistance. An overview of the actions taken in response to each incident is listed in Table 5 to illustrate the role of the province in such cases.

Table 1. Infectious and parasitic disease agents or organisms associated with disease described for farmed salmon in British Columbia in published literature.

Diseases or class of infection	**Agent**	**Disease**
Bacterial	*Renibacterium salmoninarum*	Bacterial Kidney Disease
	Vibrio anguillaurm	Vibriosis
	Vibrio ordalli	
	Aeromonas salmonicida	Furunculosis
	Yersinia ruckerii	Enteric Redmouth
	Piscirickettsia salmonis	Salmon Ricketssial Septicemia
Viral	Infectious hematopoietic necrosis virus	Infectious hematopoietic necrosis
Parasitic		
Myxosporeans	*Parvicapsula sp.*	
	Kudoa thyrsites	
Microsporidia	*Loma salmonae*	
	Enterocytozoan salmonia	
Cestodes (tapeworms)	*Gilguinia squali*	
Trematodes (flukes)	*Neascus sp.*	Discoloration
Monogean flatworms	*Laminiscus strelkowi*	
Nematodes	*Philonema aqubernaculum*	
Sea Lice	*Lepeophtherius salmonis*	
	Caligus clemerisi	
Suspected infectious disease	possible viral cause	Plasmacytoid leukemia

Sources: Kent, 1992; Hicks, 1989; Brackett and Newbound, 1990; Brackett et al, 1991a; Brackett et al, 1991b.

Table 2. Infectious or parasitic diseases or agents recorded in the Federal Fish Health Database—Fish Pathology Laboratory, Pacific Biological Station, January 1 to December 31, 1995.

Bacterial Diseases	**Viral Diseases**	**Parasitic Infections**	**Other microbes**	
Bacterial kidney	Infectious hematopoetic	*Acanthocephala*	Chaetocerusdisease	necrosis
Bacterial Gill Disease	Viral hemorrhagic	*Anasakis*	Parenthese Disease	septicemia
Furunculosis		*Costia*	Saprolegniosis	
Myxobacteriosis	infection	*Eubothrium*	Unspecified fungal	
Vibriosis		*Gyrodactylus*		
Motile aeromonad infection			*Hexamita*	
Fusiform bacterial infection			*Trichodina*	
Enteric Redmouth		Proliferative Kidney	Disease	
Pseudomonas infection		*Phoma herarum*		
Enterobacter infection		*Caligus/copepods* *Myxidium*		

Table 3. Conditions or pathogens recorded in the Provincial Fish Health Database—Fish Health Section, Fish Culture Section, January 1 to December 31, 1995

Bacterial	**Parasitic**	**Fungal**	
Furunculosis bacteria)	*Ichthyoboda*	Fungal dermatitis	(with secondary
Bacterial Gill Disease			
Enteric Redmouth			
Systemic myxobacteriosis			
Gram -ve septicemia			

Table 4. Pathogens and diseases diagnosed in cases submissions to the Animal Health Centre, Fish Health Veterinarian1993 to 1996.

Year	**Pacific or Atlantic**	**Salt/fresh water**	**Pathogen**	**Diagnosis**
1993	Atlantic	salt	*Aeromonas salmonicida*	Furunculosis
	Pacific	fresh	*Aeromonas salmonicida*	Furunculosis
	Atlantic	salt	*Vibrio ordalli*	Vibriosis
	Atlantic	salt	*Vibrio spp.*	Vibriosis
	Atlantic	salt	Not identified	Fungal infection
1994	Atlantic	salt	*Aeromonas salmonicida*	Furunculosis
	Atlantic	salt	*Kudoa thyrsites*	Kudoa
	Atlantic	salt	*Vibrio ordalli*	Vibriosis
	Atlantic	salt	*Vibrio anguillarum*	Vibriosis
	Atlantic	salt	*Vibrio spp.*	Vibriosis
	Atlantic	salt	*Myxobacteria*	Mouthrot/tailrot
1995	Atlantic	salt	Infectious hematopoeitic necrosis virus	IHN
	Atlantic	fresh	*Yersinia ruckerii*	Enteric redmouth
	Atlantic	salt	*Vibrio anguillarum*	Vibriosis
	Pacific	salt	*Renibacterium salmoninarum*	Bacterial kidney disease
	Atlantic	salt	*Pseudomonas spp.*	Pseudomoniasis
	Pacific	salt	*Nephrocalcinosis*	Nephrocalcinosis
1996	Atlantic	salt	*Aeromonas salmonicida*	Furunculosis
	Atlantic	salt	Infectious hematopoeitic necrosis virus	IHN
	Atlantic	fresh	Identified fungus	Mycotic pneumocystitis
	Atlantic	fresh	not identified	Bacterial gill disease

Table 5. Farm investigations conducted by the Provincial Fish Health Veterinarian from 1993 to 1996.

1993

INCIDENT	**ACTIONS**
1. High levels of mortality associated with multiple drug resistant furunculosis	Help confirmed diagnosis, reviewed fish health records. Traced movement of fish and investigated hatchery sources.Sampled wild salmon in the vicinity. Fish at one site destroyed (Based on consulting veterinarian's advice). Monitored drug reistance patterns on remaining site. Follow-up the next year at hatcheries and lake-pens.
2. Fungal disease post-vaccination at a lake-pen	Collected samples for diagnosis. Fungal disease confirmed, low level drug sensitive furunculosis also detected. Developed fungal disease management and monitoring program.

1994

INCIDENT	**ACTIONS**
1. Three separate investigations of mortalities due to furunculosis (1 at a lake-pen, 2 at sea sites)	Implemented control (vaccination) programs. Monitored mortality rates and treatments. Sampled to monitor drug resistance patterns. No resistant strains isolated
2. Elevated losses at a sea site	No dead fish fish available at visit. No diagnosis from moribund fish. Fish harvested.
3. M.A.F.F. staff concerned about high losses at a farm	Bacterial kidney disease and gastric bloat diagnosed. Control programs recommended.
4. Atlantic salmon found in effluent pond in a hatchery.	Samples taken for diagnostic work-up. No diseases found. Hatchery licence requirements enforced.
5. Atlantic salmon parr spilled into a lake	Fish sampled. No diseases or pathogens found.

1995

INCIDENT	**ACTIONS**
1. High mortality rates due to infectious hematopoietic necrosis in Atlantic salmon at sea	Follow-up fish sources and movement Develop disease management plan and establish a working group Some companies voluntarily destroyed fish at affected farms
2. Massive loss at a trout farm	Diagnostic investigation. Deaths due to water quality problem.

1996

INCIDENT	**ACTIONS**
1. Massive acute losses at an Atlantic salmon sea site	Diagnostic samples and environmental sampling conducted. No definitive diagnosis, but water quality problem suspected.

Source: J. Constantine

In general, the diseases, pathogens and parasites described in farmed salmon in B.C. have also been reported in wild fish (Kent, 1992; Bell, 1982; Hoskins *et al*, 1976). Several of these agents were known to occur in wild and enhanced species prior to the development of a commercial farming industry in B.C. Vibriosis, bacterial kidney disease, furunculosis, infectious hematopoetic necrosis, sea lice, and *Kudoa* infection are examples of diseases of farmed fish that have a long history of occurrence in the Pacific Northwest and are also found in regions of the province remote from salmon farming (D. Kieser pers. comm). With the advent of new diagnostic tools, previously unrecognized pathogens have also been found. In some cases, such as viral hemmorhagic septicemia virus, these new agents were first found in wild fish, then later in farmed salmon (see Section IV for a more detailed discussion). In other cases, such as marine anemia, the development of more sensitive diagnostic tests allowed for the detection in wild fish of new agents first seen in farmed fish (Eaton *et al*, 1994). When coupled with knowledge of population movement and disease biology, the existing evidence supports the assertion that the current diseases of farmed salmon in B.C. are indigenous to the province. Because of the greater intensity of observation and regularity of sampling of farmed salmon compared to wild fish, it can be anticipated that other previously unrecognized diseases will continue to be described in farmed salmon before they are detected in wild stocks.

Salmonid pathogens and parasites can also be found in non-salmonid fishes. For example, viral hemorrhagic septicemia has been found in Pacific cod and herring (Traxler *et al*, 1995) and *Kudoa* has been found in Pacific hake (Kabata and Whitaker, 1986). Recent unpublished studies conducted at the Pacific Biological Station sought evidence of other salmonid pathogens in non-salmonid species in and around sea cages. This research was limited by their very small sample sizes. The studies were unable to find infectious hematopoeitic necrosis virus, viral hemorrhagic septicemia virus, *Renibacterium salmoniarum* or *Aeromonas salmonicida* in hake (n=2), ratfish (n=3), rockfish (n=1), sculpin (n=1), greenling (n=1) or sablefish (n=1) caught accidentally in prawn traps during a prawn survey conducted in Kingcome Inlet in July, 1994. In the fall of 1994, fish were collected from inside and outside of net pens on the west coast of Vancouver Island. A total of eleven perch, four hake and two dogfish were examined. All were negative for infectious hematopoeitic necrosis virus, viral hemorrhagic septicemia virus, *Renibacterium salmoniarum* and *Aeromonas salmonicida*, except for two hake which cultured positive for *Renibacterium salmoninarum*. The authors concluded that finding this microorganism in hake was an indication that this species was susceptible to infection by the organisms, but they were unable to make conclusions regarding the source of the organism or the implications of their finding for local hake populations.

D. SHARED DISEASES OR PATHOGENS IN WILD AND FARMED STOCKS AS EVIDENCE OF INTERACTION

The presence of the same lesions in wild and farmed fish does not necessarily imply there is an exchange of disease causing agents between the two groups. Netpen liver disease is a good example of this. This disease was first described in farmed Atlantic salmon in B.C. (Kent, 1990). Pathological lesions virtually identical to those of netpen liver disease have been observed in salmon returning to spawn in enhancement facilities in the province as well as in non-salmonid fishes residing in polluted waters elsewhere (Stephen *et al*, 1993). Although the liver lesions in all three cases are virtually identical, the cause of the lesions is not. An ingested algal toxin is thought to be the cause of the lesion in farmed salmon while chemical pollutants cause the same lesions in some wild fishes (Stephen *et al*, 1993; Kent, 1990). Marine anemia presents another example where the same pathological lesion may result in more than one diagnosis (Stephen *et al*, 1995) and be caused by more than one inciting factor (Stephen *et al*, 1996). The presence of the same pathogen in wild and farmed stocks also should not be taken as evidence that pathogens are interchanged between the two groups. Information obtained in relation to our case study illustrates this point.

It has been hypothesized for our case study that the enhanced population acquired their infections from Atlantic salmon in nearby farms. Previous examples from Europe have suggested that pathogens may move from farm locations into wild fish (e.g., Johnsen and Jensen, 1991, 1994; Wichardt *et al*, 1989). Reports of furunculosis in wild Dolly Varden and cutthroat trout were made in B.C. as early as 1933 (McCarthy and Roberts, 1980). Furunculosis was also described in sablefish in B.C. prior to the development of the commercial fish farming industry (McCarthy and Roberts, 1980). Review of fish disease diagnoses made by the Fish Pathology Section of the Pacific Biological Station confirm that furunculosis has historically been diagnosed in wild and cultured fish (farmed and enhanced) in the province, that it was diagnosed in wild and enhanced fish before the development of the aquaculture industry, and that it has been found in fish from regions remote from salmon aquaculture (D. Kieser pers. comm.). Available evidence from elsewhere shows that furunculosis occurred in wild stocks prior to the development of the salmon farming industry (McCarthy and Roberts, 1980). Despite the long history of the organism and disease in B.C. waters, the lack of knowledge of furunculosis or *Aeromonas salmonicida* in our example prior to 1990, coupled with the concurrent report of the disease in nearby farmed stocks, generated the hypothesis that fish farms were amplifying or spreading unusually high amounts of the pathogen to wild stocks, thus presenting new disease challenges to wild fishes. It is important to note that no diagnostic work was available for coho at the example facility prior to 1990, when furunculosis was diagnosed. Therefore, we are unable to determine if the pathogen was present or absent in an asymptomatic form in the stocks prior to this time. However, hatchery managers report that similar disease occurrence had not been noted in this hatchery prior to this outbreak. Although the temporal association of the outbreaks in farmed and wild fish provided a basis for such a hypothesis, additional biological data challenged the association between the outbreak of furunculosis in wild and farmed fish in our study case. Antibiotic resistance patterns determined for organisms recovered from the enhanced coho and the implicated farmed fish were sufficiently dissimilar that investigators concluded that the isolates from the enhancement facility were of different origin than those recovered from the farm despite time delays between sampling of the organisms from the farm and those from the hatchery (D.Kieser pers. comm.). Because of the relatively small sample sizes and the knowledge that there can be variation in resistance patterns among *Aeromonas salmonicida* samples taken from the same populations, it is not possible to rule out some connection between farmed and wild fish in this case based on such data. It also does not allow us to conclude whether the pathogens moved from farmed to wild fish or vice versa. This case does illustrate how the coincidental finding of the same species of a pathogen in two different populations is insufficient evidence with which to determine that the pathogens have been exchanged between the two groups. Further details of this case are presented in Section IV.

E. SALMON FARMING AND THE INCREASE IN THE FREQUENCY OR SEVERITY OF DISEASE IN WILD FISH

International information

Infectious diseases are a serious problem for salmon farming (NASCO, 1993). Their occurrence is documented in farmed fish more often than in wild salmon. This has led to the conclusion by some that the fish farming industry acts as an origin of infectious diseases in wild stocks (Hastein and Linstad, 1991). However, there is little evidence of significant adverse effects due to transmission of disease agents from farmed to wild fish (NASCO, 1993). When diseases do occur in wild stocks inhabiting the waters shared with cultured fish, it is difficult to determine if the infectious agents were acquired from wild sources or from the culture facility (Saunders, 1991). Some of the examples of disease interactions cited from other jurisdictions did not deal with commercial net-cage farming, but instead looked at the release of enhanced stocks as sources of disease for wild fish. In other cases, the authors utilized coincident changes in disease pattern over time and biological analogy as the principal criteria by which to hypothesize a causal relationship. Yet, the potential for disease interactions between wild and farmed fish continues to be the subject of significant discussion. It has been difficult to find evidence that clearly demonstrates the transmission of pathogens from farmed salmon to wild stocks. Upon critical review, none of the reports uncovered in the preparation of this report were capable of establishing a causal relationship between the activity of salmon farming in B.C. or elsewhere and the occurrence of diseases in wild stocks. Many of the attempts to establish such a link fail to provide adequate evidence to accept or refute the hypothesis that the occurrence of disease in farmed fish increases the level of disease in wild stocks. Most information regarding the transmission of pathogens and parasites from cultured to wild fish is circumstantial in nature and often equivocal (Iwama, 1991). Generally, cases presented as evidence of interaction are only capable of presenting hypothesized routes of interaction and impacts. This reflects the methodological difficulties inherent in trying to document changing disease patterns in wild stocks and in establishing causal relationships when basic information on disease dynamics is lacking. As there exists no definitive work that documents adverse impacts on wild stocks due to the presence of disease in farmed salmon with a reasonable level of certainty, several pieces of information will be examined in order to review the potential for adverse disease interactions between wild and farmed fish with respect to indigenous pathogens.

It is widely held that there exists evidence that fish pathogens move from wild fish to cultured fish (Kent and Fournie, 1993; Moller and Anders, 1986). What is less clear is the magnitude of disease transfer in the opposite direction, from farmed to wild fish. The critical question is whether the amount of exposure to disease causing agents from farmed fish is capable of increasing the occurrence of disease in wild stocks to levels that would put wild fish populations at a biological disadvantage. Munro *et al* (1976) demonstrated that a variety of native species could acquire infectious pancreatic necrosis virus from farmed fish in Europe. However, the low prevalence of the virus in each of the wild species examined, the limited distribution of the virus, and lack of clinical signs in any of the wild stock examined suggested that the virus posed little threat to wild stocks (Munro *et al*, 1976). Similarly, Yersinia ruckerii (the agent of enteric redmouth) can be transferred in water, but surveys of wild fish around fish farms did not reveal any evidence of the disease (Roberts, 1985). The finding of this organism in wild fish, farmed fish and aquatic mammals suggests a shared environmental source, such as aquatic birds, is more likely to account for the distribution of the organism rather than transmission from a single source (Collins *et al*, 1996). In a review of the environmental impacts of salmon cage culture, Phillips *et al* (1985) concluded that, although poorly understood, available data provides no evidence for an adverse impact of disease on wild fish stocks caused by salmonid farming.

British Columbia information

It is not possible to describe how the rate of disease in wild stocks has changed in B.C. since the advent of fish farming. Neither the Ministry of Environment, Lands and Parks nor the Department of Fisheries and Oceans have incidence data for diseases of enhanced salmon or wild fish. The reasons for this are discussed elsewhere, but reflect the dependence on passive surveillance as the primary method for acquiring fish health data in B.C. It is, therefore, not possible to quantify the degree of pathogens or disease transfer from farmed to wild stocks. The Provincial Fish Health Veterinarian has indicated that, based on patterns of diagnostic submissions to the Animal Health Centre, interviews with private veterinary practitioners, and the results of farm investigations, including reviews of health records, a number of health issues have been or are being resolved in the B.C. industry (J. Constantine pers. comm.). The lack of historical farmed fish health data precluded independent evaluation of this statement. As part of this review, a survey of local knowledge and observations of 84 residents of the Broughton Archipelago indicated that 14% of the concerns about salmon aquaculture were related to fish health issues. Increased observations of clinical signs of disease in wild salmon and non-salmonids were reported by local residents after the introduction of salmon farms in the area. In contrast, some people stated that, when captured, escaped farmed fish appeared to be healthy. The survey also revealed concerns that farmed fish presented food-borne infectious disease risks to consumers.

A review of submissions to the Fish Pathology Laboratory, Pacific Biological Station, does not reveal a convincing increase in the overall frequency of diagnostic submissions over the past ten years (Table 6). This laboratory receives submissions as part of screening programs for federal salmon enhancement hatcheries as well as part of investigations of unusual mortality rates in those facilities. Similarly, the detection rate for selected pathogens at salmon enhancement hatcheries in B.C has also not changed significantly in the past ten years (Tables 7 and 8). There were statistically significant year-to-year differences in the annual proportion of submissions yielding *Renibacterium salmoninarum* (p= 0.0002), *Aeromonas salmonicida* (p= 0.018) or infectious hematopoietic necrosis virus (p= 0.0003), yet there is not an apparent trend of increasing rates of positive submissions over time. Diagnostic data from salmon enhancement hatcheries on the east coast of Vancouver Island, north of Big Qualicum River in 1975, 1985 and 1995 are consistent with the provincial pattern (Table 9). The small sample sizes in these data limit their generalizability to the entire enhanced population and restrict the ability of statistical tests to detect small differences. It should be noted that Tables 6 to 9 were based only on a search for the five specific pathogens indicated on the tables. A more detailed review of the conditions diagnosed in 1995 in all federal salmon enhancement facilities is presented in Table 2. Of the 285 cases reviewed in 1995, there was either no agent identified or no diagnosis made for 111. This table is merely a list and does not represent the significance of each diagnosis in the sample. Truly wild fish or non-salmonid species were virtually nonexistent in the data retrieved from the Federal and Provincial Fish Health Databases.

Table 6. Number of cases submitted by year and species to the Fish Pathology Laboratory, Pacific Biological Station from January 1, 1985 to December 21, 1994 for examination for *Renibacterium salmoninarum, Aeromonas salmonicida,* Infectious Hematopoietic Necrosis Virus, Infectious Pancreatic Necrosis Virus and Viral Hemorrhagic Septicemia virus.

YEAR	**TOTAL**	**PINK**	**CHUM**	**COHO**	**CHINOOK**	**SOCKEYE**
1985	241	6	27	124	78	6
1986	213	5	8	88	85	27
1987	213	2	10	115	78	8
1988	247	5	14	109	84	35
1989	227	2	13	116	83	13
1990	280	8	19	147	86	20
1991	214	4	9	111	82	8
1992	218	3	6	102	91	16
1993	239	1	32	121	58	27
1994	239	2	28	106	83	20
TOTAL	**2331**	**38**	**166**	**1139**	**808**	**180**

Note: A case may represent samples from more than one fish.

Table 7. Summary of Pacific salmon cases of *Renibacterium salmoninarum, Aeromonas salmonicida,* and Infectious Hematopoietic Necrosis Virus detected in submissions to the Fish Pathology Laboratory, Pacific Biological Station from January 1, 1985 to December 21, 1994.

		TOTAL NUMBER OF POSITIVE DIAGNOSES (%)			
SPECIES	**TOTAL NUMBER**	***R.SALMONIARUM***	***A. SALMONICIDA***	**IHNV**	**EXAMINED**
PINK	824	6 (0.7)	2 (0.2)	0 (0)	
CHUM	4,582	1 (0.02)	7 (0.2)	2 (0.2)	
COHO	24,757	231 (0.9)	161 (0.7)	2 (<0.01)	
CHINOOK	13,298	105 (0.8)	55 (0.4)	6 (0.05)	
SOCKEYE	5,639	26 (0.5)	10 (0.2)	38 (0.7)	
TOTAL	**49,100**	**369**	**235**	**48**	

Note: No cases of Infectious Pancreatic Necrosis or Viral Hemorrhagic Septicemia viruses were found in this time period.

Table 8. Proportion (and number) of Pacific salmon submissions to the Fish Pathology Laboratory, Pacific Biological Station from January 1, 1985 to December 21, 1994 testing positive for *Renibacterium salmoninarum, Aeromonas salmonicida,* and Infectious Hematopoietic Necrosis Virus.

YEAR	***R. SALMONINARUM* (N)**	***A. SALMONICIDA* (N)**	**IHNV (N)**
1985	0.10 (25)	0.13 (32)	0 (0)
1986	0.11 (23)	0.08 (17)	0.04 (8)
1987	0.12 (25)	0.11 (23)	0.02 (5)
1988	0.15 (38)	0.04 (11)	0.06 (14)
1989	0.16 (36)	0.07 (16)	0 (0)
1990	0.17 (48)	0.11 (30)	0.01 (4)
1991	0.16 (35)	0.11 (23)	0.01 (2)
1992	0.27 (58)	0.16 (35)	0.03 (6)
1993	0.16 (38)	0.11 (27)	0.03 (6)
1994	0.18 (43)	0.09 (21)	0.01 (3)

Table 9. Proportion (and number) of cases in North-east Vancouver Island Salmon Enhancement Facilities (including Big Qualicum) where Furunculosis, Bacterial Kidney Disease (BKD) or Infectious Hematopoietic Necrosis (IHN) were found by the Fish Pathology Laboratory, Pacific Biological Station

YEAR	**BKD**	**FURUNCULOSIS**	**IHN**
1975	0.07 (5)	0.13 (9)	0 (0)
1985	0.06 (6)	0.15 (15)	0.01 (1)
1995	0.16 (9)	0.02 (1)	0 (0)

F. LAKE-CAGE CULTURE

Less data exist regarding interactions in a lake-cage rearing system than for marine production systems. In B.C., the following diseases or agents have been seen in wild or cultured fish in B.C. in fresh water settings: infectious hematopoietic necrosis, bacterial kidney disease, columnaris disease, furunculosis, fungal diseases, proliferative kidney disease, *Diphyllobothrium, Eubothrium, Philonema* and external parasites. The following factors could increase the likelihood of pathogen or parasite exchange between fish and should be considered when evaluating lake pen rearing sites: warm water conditions, confined stocks, lakes with low flushing rates, presence of resident salmon with the diseases of concern, and diseases having limited control and treatment options. Experience in the United Kingdom with freshwater net-cage production suggest that the considerations for disease interactions are based on the same principles as for sea cage sites (Phillips *et al*, 1985).

G. TRANSMISSION OF FISH PATHOGENS AND PARASITES

Vertical transmission

Pathogens and parasites can be spread horizontally (between fish in the same generation) or vertically (between parents and progeny). Infectious diseases are not transmitted, only their agents are. The transmission of an infectious agent does not ensure that disease will occur in the recipient. Whether a disease will occur or not depends on the nature of the exposure and susceptibility of the host. The principal vertically transmitted pathogen of concern in B.C. is *Renibacterium salmoninarum*, the agent of bacterial kidney disease. Infectious hematopoetic necrosis virus can be found in reproductive products of salmon as well, but the role of vertical transmission in spreading and maintaining the virus is unclear (Traxler and Roome, 1993; Meyers *et al*, 1990). Of the diseases exotic to B.C. that are listed in the Federal Fish Health Protection regulations, only infectious pancreatic necrosis virus is vertically transmitted (Kent, 1992). Thus the number of known vertically transmitted pathogens of concern for B.C. is small.

A primary method to prevent vertical transmission has been the surface disinfection of eggs. By balancing levels of disinfectant that are lethal to pathogens, but not to eggs, several diseases can be virtually eliminated from hatcheries (Meyer *et al*, 1983). A variety of methods have been used, with varying success, to disinfect eggs including the use of iodine-based products (Goldes and Mead, 1995) and erythromycin phosphate rinse of newly fertilized eggs (Jensen, 1981). However, egg treatment is not a fail-safe method for preventing vertical transmission of diseases. While very effective at removing pathogens such as infectious hematopoeitic necrosis virus (99.9% of virus removed), iodine based disinfectants are not 100% under laboratory conditions (Goldes and Mead, 1995). In addition, *Renibacterium salmoninarum* can be found within eggs and is thus inaccessible to surface disinfection (Brown *et al*, 1994). Infectious hematopoeitic necrosis virus can be found adhered to fish sperm which is generally not subjected to disinfection, although the significance of this route of transmission in maintaining and spreading the virus is unclear.

Broodstock screening can also be used to reduce the likelihood of vertical transmission of pathogens. This consists of applying specific diagnostic tests to parent fish to detect the presence of vertically transmitted pathogens. The gametes of infected parents are discarded, thus breaking the transmission cycle to the next generation. Broodstock screening has been very effective in reducing infectious hematopoeitic necrosis in enhanced Alaskan sockeye (Meyers *et al*, 1990) and is a common management tool used by the B.C. industry (J. Thornton pers. comm.). In addition to screening, the likelihood of fish vertically transmitting *Renibacterium salmoninarum* is further reduced by treating brood fish with appropriate antibiotics prior to collecting their eggs (Evelyn, 1987). This is commonly practised on B.C. commercial farms (M. Sheppard, pers. comm.)

Vertical transmission of pathogens between wild and farmed fish requires that a sufficient number of infected broodstock or their progeny successfully reproduce and encounter wild fishes. An example of this was the transfer of *Renibacterium salmoninarum* to farmed fish through the use of eggs derived from wild and enhanced stocks. Initially, the dependence of the B.C. salmon farming industry on non-domesticated stocks for eggs provided ample opportunity for the introduction of “wild” pathogens or pathogens from enhancement facilities into commercial culture facilities. As the industry grew, it was able to provide more and more of its own broodstock, thus decreasing the chances of introducing bacterial kidney disease. Broodstock screening, isolation of hatchery facilities and treatment of broodstock prior to spawning further reduced the likelihood of vertical transmission of pathogens from wild to farmed stocks. The probability of vertical transmission of disease from farmed to wild stocks in less clear. The inability to control, prevent or treat vertically transmitted organisms in wild stocks, plus their indigenous and endemic nature in wild and enhanced fish, has led some authors to suggest that wild stocks present a greater risk to farmed stocks than vice versa (Hastein and Lindstad, 1991).

As enhanced fish are capable of returning from the wild carrying vertically transmitted pathogens (Fryer, 1986), the question arises as to whether an escaped farm fish can carry a vertically transmitted pathogen and transmit it on spawning grounds. In order for this to occur, an infected farmed fish must escape its cage and enter natural spawning areas and survive long enough to shed its gametes, which in turn must be fertilized, hatch and live long enough for the infection to progress so that disease develops or pathogens are shed. Only bacterial kidney disease and possibly infectious hematopoietic necrosis are vertically transmitted in B.C. Both of these diseases may also be transmitted horizontally (from fish to fish in the same generation). Both are disease indigenous to B.C. and, therefore, many wild stocks may have had previous exposure and some degree of pre-existing defence. Unpublished research has suggested that vertical transmission may also occur for cold-water disease due to *Cytophaga psychophilia* (L. Brown, pers. comm.).

The likelihood that a sick escaped fish will survive long enough to successfully spawn is less than that for a healthy escaped fish. A recent study of B.C. chinook salmon farms revealed that the 68% of clinically ill fish that were accessible for capture from the surface of the pens died within 48 hours of first observation (Stephen and Ribble, 1994). Moribund fish living beyond three days survived an average of two weeks. These observations likely overestimate the survival of moribund salmon under wild conditions as fish in captivity have better access to food and are not subjected to predation pressures. This study also revealed that the nature of the disease affecting a fish will affect its behaviour in relationship to its cohorts. Visibly ill salmon tended to be found at the periphery of the entire population. This was more pronounced for fish with chronic illnesses than those with diseases that tended to kill rapidly. Field observations of sick wild menhaden support the previous observation that parasitized or injured fish tend not to aggregate or school with their healthy cohorts (Guthrie and Kroger, 1974). In general, fish that appear different than others in their group, due to size, shape or behaviour, will be more prone to predation (Wolf, 1985). Therefore, the likelihood that a sick fish will reach a spawning ground and spread a pathogen is very low. In addition, it is unlikely that a sick escaped salmon will spend sufficient time among healthy wild salmon to allow for the effective spread of pathogens. It is unknown how sub-clinical infection or carrier states affect the movement, social behaviour and reproductive success of escaped salmon and therefore affect the probability that transmission of pathogens to wild fishes will occur.

A location-based search of the federal Fish Health Database was conducted to look for evidence of a risk of escaped Atlantic salmon transmitting pathogens to wild fish in spawning streams in B.C. The database was searched for the names of rivers and lakes in which Atlantic salmon were reported to be found in 1995 and 1996 and which had been provided in the portion of this environmental assessment that dealt with escaped salmon. In the case of the Fraser River, only information on the lower Fraser was requested. The database yielded 15 entries corresponding to eight cases. Six of the submissions were escaped Atlantic salmon from either the Salmon River near Alert Bay or the Quatse River and hatchery. No infectious agents were found in any of these fish. For Pacific salmon species, there was one isolation of *Anasakis* sp. worms from a sockeye salmon. This parasite has not been identified in farmed salmon but is frequently seen in wild fish. The only other finding was furunculosis in the coho salmon in the same stream that services the hatchery of the case example in this report. Although these river systems were under more scrutiny due to efforts to locate escaped salmon, it is unlikely that all cases of disease in wild fish would be detected; however, it is more likely that a significant epidemic would have been seen. Interviews with Department of Fisheries and Oceans staff suggested that this pattern was similar to that of previous years. In the 1995 federal Fish Health database, a number of Atlantic salmon samples were evaluated which were not identified in the search above. One fish, submitted from the Rosewall Creek hatchery, was diagnosed with a myxobacterial infection. Twenty-one Atlantic salmon submissions were from research facilities. These fish yield diagnoses of copepod (sea lice) infection, (n=1), pancreatic disorder (n=2), parentheses disease (n=1), sporocytophagosis (n=1), toxic liver problems (n=2) and *Vibrio* sp. infection (n=2). The remainder either provided no diagnosis or isolated no infectious agents. Seven submissions of Atlantic salmon came from near shore locations near Alert Bay and Bamfield. None showed evidence of either disease or infectious agents. One Atlantic salmon submitted from a private producer was positive for viral hemorrhagic septicemia virus. It is important to remember previous cautions regarding the generalizability of results from such small samples.

Assuming a random distribution of disease in a population, very small samples are more likely to not find infected fish in a population if the disease is rare than to find the disease.

The likelihood that vertically transmitted pathogens will be associated with serious or irreversible effects in wild stocks in B.C. is reduced because of: (1) the limited number of vertically transmitted indigenous pathogens, (2) the presence of all vertically transmitted pathogens identified in B.C. in wild stocks before fish farming, suggesting there exists some level of population immunity or adaptation in wild stocks (the magnitude and protective effect of this is, however, speculative), (3) the small proportion of escaped fish that have been seen to return to rivers, and (4) the lack of reports of unusual vertically transmitted disease outbreaks or vertically transmitted agents occurring in rivers where escaped salmon have been found in B.C. or in escaped fish. Inadequacies in surveillance and sampling, however, prevents exclusion of the hypothesis that vertically transmitted pathogens can be shared between wild and farmed fish.

Horizontal transmission

Diseases can be spread horizontally through direct contact, through vectors, through contaminated equipment and through environmental media such as air and water (Thrusfield, 1995). The high densities and restricted movement of salmon in sea cages has been suggested to be one reason that disease occurs more commonly in farmed situations. The closer contact and decreased distance between fish allow a pathogen to spend less time in the inhospitable marine or aquatic environment before contacting a susceptible host and increasing the likelihood of random contact between host and parasite. Bacterial or viral pathogens do not have active host seeking mechanisms. Most are spread through direct contact with susceptible fish or through opportunistic contact through environmental sources. In vector-borne diseases, an intermediate host passes the pathogen from primary host to primary host. The role of vectors in fish diseases is unclear. *Aeromonas salmonicida* can be isolated from sea lice (Nese and Enger, 1993). However, it is not known if these parasites transmit the pathogen between salmon. The species of sea lice involved in this report were surface feeders whose activities would rarely allow for blood-borne transmission of pathogens between fish (M.Kent, pers. comm.). No vector-borne diseases have been demonstrated for salmon, although vectors have been suggested as a mode for spreading infectious salmon anemia in Europe (Nylund and Jalobsen, 1995).

Direct contact between wild and farmed fish is unlikely because of differences in the behaviour of species within the net pens. Non-salmon species in netpens tend to frequent the periphery of the salmon group, avoiding interactions with the rest of the cage population (Stephen and Ribble, 1994; C. Stephen, unpublished data). Moribund fish can also be found at the periphery of the main group in chinook sea cages (Stephen and Ribble, 1994). No published reports of direct contact between wild fish and sick captive salmon in sea cages were found.

Direct contact between escaped fish and wild fish will depend on social interactions. The marine survival of wild Atlantic salmon in the Atlantic Ocean has been found to be twice as high as hatchery fish (NASCO, 1993). The lack of substantial returns of escaped salmon in the Atlantic Ocean supports the hypothesis that escaped farmed fish also suffer higher marine mortality rates (NASCO, 1993). Quantitative data on the survival of escaped Pacific salmon from sea cages is not available. Several studies have demonstrated that the physical fitness, ability to avoid predation, return rates and spawning success are all lower in cultivated fish than in wild fish (Hindar *et al*, 1991; Hindar and Jonsson, 1992; Miller, 1953). The majority of work in this area involves hatchery reared fish for use in re-stocking or enhancement projects, although it has been suggested that the additional selection pressures created by sea cage rearing further decreases the survival of escaped farmed salmon under natural conditions (Hindar *et al*, 1991). Although survival will be influenced by fish size and time of escape (NASCO, 1993; Winsby *et al*, 1996), it is reasonable to postulate that disease status will also influence marine survival and therefore reduce the probability that an escaped sick fish will contact other fish.

Behavioural and social obstacles, poor survival of sick fish, and physical barriers to contact (particularly structures like cages and the use of freshwater without wild fish) reduce the probability that direct contact horizontal transmission from sick fish will be a major route of pathogen and parasite exchange between wild and farmed fish. Uncertainty regarding the role of asymptomatic escaped fish in the maintainence and transmission of disease, however, makes it difficult to draw definitive conclusions about risks of horizontal transmission of pathogens from farmed to wild fish.

H. TRANSMISSION OF FISH PATHOGENS THROUGH THE ENVIRONMENT

A wild population may hypothetically be at increased risk of infections from endemic pathogens if salmon farming increases the exposure opportunities for wild fish to concentrations of viable pathogens capable of causing disease. Fish that remain in a net cage can shed pathogens into the environment through a variety of routes including mucus, feces and decaying dead fish. Shed pathogens or parasites can enter the water column or the sediments below the pens. The risk of cultured fish acquiring disease from wild stocks through shared water has long been a concern for fish culturists. A number of key disease control measures at salmon hatcheries prevent cultured fish from contacting wild fish or waters bearing wild fish as the primary barrier to wild fish pathogens (Wood, 1979; Meyer *et al*, 1983; Meyers *et al*, 1990). For example, Enzmann and Konrad (1985) found that 10-41% of wild brown trout caught upstream and downstream from a formerly infected rainbow trout farm showed antibodies specific for viral hemorrhagic septicemia virus. The authors concluded that the source of the virus, although originally thought to be a disease of farmed fish in Europe, was wild brown trout, and preventing contact between culture trout and wild brown trout became a method for preventing the disease. The use of “virus-free” water is a cornerstone of Alaskan efforts to control infectious hematopoeitic necrosis in enhanced sockeye. The use of groundwaters or other non-fish bearing water sources is not universally applied in B.C. private and public hatcheries. Some facilities use groundwater exclusively, others use surface water, and the remainder use mixed sources. A recent Norwegian study reinforced the importance of hatchery utilization of water sources free of fish for fish culture. In this study (Jarp *et al*, 1993), epidemiological evidence demonstrated that the greatest risk factor for the occurrence of furunculosis in cultured fish was hatcheries’ use of water bearing anadromous fish. This study also indicated that hatcheries with two or more fish farms within a 10km radius infected with furunculosis were at a two times higher risk for having the disease compared to hatcheries with fewer than two infected farms within that distance. The authors concluded that a high concentration of fish farms infected with *Aeromonas salmonicida* near a hatchery was an important risk factor for hatchery infection with the organism and speculated that escaped farmed carriers may be the means by which the organism is disseminated from farmed to hatchery or feral fish. These findings complement another Norwegian study that indicated the risk for infectious salmon anemia (a disease thought to be caused by a virus) was increased on fish farms that were adjacent to an infected farm (Vagsholm *et al*, 1994) and reports from B.C. that suggested furunculosis spread from one site to another 10km away (Needham, 1995). It should be noted that the author of the later report did not provide data to support the latter claim.

The uncontrolled water supply in sea cages presents ample opportunity for farmed fish to be exposed to waterborne pathogens of wild fish (Kent, 1992). In B.C., there are several examples in which farmed fish acquire pathogens from wild or enhanced stocks. Parasitic diseases provide good examples. Sea lice are marine organisms that farmed fish acquire from wild marine sources (Nagasawa *et al*, 1993). Although sea lice infestations can be maintained on multi-year class farms by horizontal transmission from farmed fish to farmed fish, examples of sea lice problems on farms that have been fallowed, are single-year class sites or have no history of lice demonstrate that the original source of lice for farmed fish is wild fish. *Gilguinia squali* is normally a parasite of dogfish. This parasite is not associated with significant pathology in their normal hosts, but it can result in significant disease when it enters an aberrant host, such as cage-reared chinook salmon (Kent *et al*, 1991). Parasites that do not result in overt disease in farmed salmon but instead reduce marketability may also be obtained from wild fish. For example, *Kudoa thyrsites* can be found in a variety of wild fish, particularly Pacific hake (Kabata and Whitaker, 1986). Atlantic salmon that acquire this parasite do not develop disease. However, the breakdown of the parasite upon the death of the salmon produces unsightly marks and softening of fresh fish flesh to the point that the marketability of the fish is significantly reduced (St. Hilaire, 1996). A shared water supply does not guarantee that pathogens or parasites will be shared by wild and farmed stocks as ecological, behavioural or oceanographic variables may affect the opportunity for exposure. The nematode parasite *Anisakis simplex* provides an example. This zoonotic parasite, which can cause disease in people ingesting raw or undercooked infested fish, is widely distributed in wild salmon, yet attempts to detect this parasite in farmed salmon have been unsuccessful (Angot and Brasseur, 1993; Deardorff and Kent, 1989). The ecologies of farmed and wild salmon are sufficiently different in this case that the two groups apparently do not share the same risk of infection.

Wild fish and farmed salmon do share some of the same parasites. The life cycle of many parasites of salmon is complex, requiring phases of the parasites' lifecycle be spent in intermediate hosts. In some cases, such as *Gilguinia* and *Kudoa,* the salmon are likely inadvertent or accidental hosts for the parasite. In other cases, such as *Anisakis,* the salmon is a normal host. Little concern has been raised regarding parasites other than sea lice in B.C. even though sea lice outbreaks are only rarely seen (M. Sheppard, pers. comm.). Sea lice epizootics in wild fish are rarely reported; only a single report was found for B.C. This involved a population of sockeye salmon migrating up the Alberni Inlet in 1992 which suffered high mortalities that were attributed to sea lice infestation (Tulley *et al*, 1993). Some of these, collected 100 miles from the coast, had heavy infestations indicative of exposure in oceanic waters. This corresponds with findings of sea lice in a high proportion of Pacific salmon in offshore waters of the North Pacific Ocean and Bering Sea (Nagasawa *et al*, 1993). In this study, the authors demonstrated a higher rate and greater levels of infection on pink salmon, which are a slower swimming Pacific salmon species. These authors hypothesize that swimming speed affected the probability that a louse would attach to a salmon and suggest that restrictions on swimming speed due to captivity may be one reason why sea lice are more commonly found on farmed salmon. It is interesting that Atlantic salmon, which are more susceptible to significant sea lice infestations, tend to move slower in sea cages than farmed Pacific species.

Often, an outbreak of sea lice in sea trout in Ireland is evoked as an example of how the presence of salmon farms can increase the amount of an infectious agent in and around a farm, thus increasing the risk to wild stocks. Evidence collected from the aforementioned outbreak is somewhat contradictory. In this case, wild sea trout found in areas of salmon farming had returned early, experienced elevated mortality rates and were infested with sea lice.The high concentration of farmed fish with lice infestations was hypothesized to present the wild fish with unusual and high infestation challenges. Environmental changes which would have altered the dynamics of the host-parasite relationship, such as elevated water temperatures, shorter generation times and increased rates of development, maturation and production of the lice occurred in the eight years preceding the outbreak in wild fish (Tulley *et al*, 1993). The possibility, as was suggested for the sockeye salmon in B.C., that the environmental changes were sufficient to affect the physiology and health of the sea trout to the extent that they were more susceptible to lice infestation remained an unanswered hypothesis in this case. Correlation analysis of the number of lice produced from a farm and the number of lice on sea trout in the vicinity showed a positive trend, but the result do not appear to be statistically significant (the basis from which louse production per farm was determined was not available). In addition, this correlation was evident for only two months of the year. Reports of this outbreak uncovered in this review did not evaluate the intensity of infestation on sea trout that did not return early.

No clear evidence was found to determine how the presence of salmon farms influenced the ecology of lice, although the increased number of susceptible hosts is thought to allow for increased numbers of lice in the area immediately around infested farms, thus presenting wild fish with more intense infestation challenges. Efforts to date to isolate the infectious stage of sea lice from waters around sea farms have been unsuccessful (M. Roth, pers. comm.). This, coupled with the relatively short free-living stage of the parasites, complicates efforts to predict how fish farms will affect the intensity and frequency of lice infestation on wild fish. Sea-lice researchers have not yet been able to determine the relative contribution of sea lice from farmed fish to wild fish (S. Johnson, pers. comm.). In a report from Norway (Berland, 1993), severity of sea lice infestations on wild captured salmon were not markedly different in samples collected in 1973, when the salmon aquaculture industry was in its infancy, than samples collected using the same methods in 1988. However, this same paper reports that infestations with lice were much higher in 1992 than in either of the previous samples. The authors were unable to determine the reasons for this increase, although unusually warm weather was suggested as a contributing cause. This case illustrates the complexity of trying to establish a relationship between salmon farming and lice infestations in wild fish.

Fish pathogens can be found in sediments under fish farms. This is to be expected for pathogens such as *Vibrio* species that normally live in the marine or estuarine environments. Similarly, *Aeromonas salmonicida* is widely distributed in marine and brackish environments (McCarthy and Roberts, 1980). The importance of sediment pathogens in maintaining disease on farm sites or in transmitting disease to wild stocks is, in general, unknown. To be exposed to fecal borne pathogens in sediments, wild fish would need to enter the area of sediments subjected to fecal deposition. As fecal wastes are deposited within close proximity to the net cages, the opportunity for exposure to fecal borne pathogens in sediments will be restricted in space. Recent research has shown that bivalve mollusks that reside around sea cages are capable of ingesting and destroying bacterial pathogens such as *Renibacterium salmoninarum* and *Aeromonas salmonicida* (Paclibare *et al*, 1994; Kent, Traxler and Evelyn, unpublished data). Therefore, the mollusks may reduce the effective exposure of wild stocks to these organisms, while not being adversely affected themselves. These bivalves are, however, unlikely to remove all pathogens from around a fish farm. Some papers demonstrate that *Aeromonas salmonicida* can be recovered from environmental samples in and around operating and abandoned salmon farms (Morgan *et al*, 1991; Effendi and Austin, 1994; O'Brien *et al*, 1994). However, interpretation of these findings is difficult. Most of these studies used advanced molecular diagnostic tools to detect this organism. These tools are capable of detecting fragments of the pathogen. In many of the cases, researchers were unable to grow *Aeromonas salmonicida* from the environmental samples, despite detecting it molecularly or visually. The presence of these non-culturable forms of *Aeromonas* is controversial. While some authors consider them to be a dormant phase of the organisms which present infection risks to fish, others feel they are dying bacteria, incapable of causing disease (Effendi and Austin, 1994).

I. VIABILITY OF FISH PATHOGENS IN THE ENVIRONMENT

Within the confines of a net cage or hatchery the density of fish is high enough that a horizontally transmitted pathogen is unlikely to have to survive very long free in the environment before finding a new susceptible host. This may in part explain the higher frequency and prevalence of diseases in cultured species compared to wild fish. The density of wild and escaped fish around net pens will undoubtedly be less than the density of farmed fish inside the pens. As a result, the time required for a shed pathogen to be picked up by a susceptible wild host will be longer. It follows that a pathogen is more likely to be successfully transmitted from farmed to wild fish if it is able to survive in the open environment. The potential for wild fish to be exposed to concentrations of pathogens of farmed origin capable of causing disease will thus be restricted by the environmental survival time of the pathogens.

Similar to attempts to explore the persistence of drugs in marine and aquatic environment, the variablilty in methods used to examine fish pathogen survival greatly complicates efforts to extrapolate the findings to a farm setting. Temperature, nutrients, water quality, the presence or absence of organic matter and methods used to isolate and quantify pathogens can affect the results of studies of pathogen survival (Perez *et al*, 1995; Effendi and Austin, 1994; Pietsch *et al*, 1977). One of the more frequently examined effects is that of salinity on survival. *Aeromonas salmonicida* can survive best in brackish water (16-24 days), followed by freshwater (7-17 days) and sea water (4-8 days) (Rose, Ellis and Munro, 1990; McCarthy and Roberts, 1980). The relatively short duration of survival of this pathogen in the environment demonstrates its need to reside within a host. There is controversy as to whether or not *Aeromonas salmonicida* can remain viable in a free-living form outside of a fish host (Effendi and Austin, 1994). The persistance of *Renibacterium salmoninarum* in seawater is also limited. Previous studies have demonstrated that seawater is lethal to this organism and that this effect is unlikely to be completely negated by the presence of organic matter in the water (Evelyn, 1988). Horizontal transmission of this organism in sea water likely requires high density populations.

In a study designed to compare the survival of fish viruses, infectious pancreatic necrosis virus survived better in saline water (17 days at 15oC), while infectious hematopoietic necrosis virus survived better in fresh water (25 days at 15oC) (Toranzo and Hetrick, 1982). While some authors feel that environmental conditions in freshwater in the Pacific Northwest are conducive to water-borne transmission of the infectious hematopoietic necrosis virus, it has been concluded that due to the effects of pH and salinity, water-borne transmission of this virus at sea is limited to short distances and times (Pietsch *et al*, 1977; Mulcahy *et al*, 1983). It was also felt that high densities with relatively low water flow were required for water-borne transmission of this virus (Mulcahy *et al*, 1983). Organic enrichment that may occur beneath salmon net cages has been postulated to increase the survival of pathogens. Needham (1995) reported that *Aeromonas salmonicida* could survive for 56 days in organic wastes in seawater; however, supporting data or references did not accompany this claim. Because a number of fish pathogens can be shed in fish feces or from dead fish (Enger *et al*, 1989; Rose *et al*, 1990), sediments under farms have been thought to act as a reservoir for fish pathogens. A study of *Vibrio salmonicida* in Norway suggested that this pathogen (the cause of cold-water vibriosis, a disease that has not been diagnosed in B.C.), was able to survive in sediments under fish farms for up to eight months (Enger *et al*, 1989). They were unable to isolate the organism from sediments under sea cages where the disease had not occurred or in sediments that were not influenced by fish farms. Unfortunately, the authors of this study did not use methods able to determine if the microorganisms from the sediments were viable. Instead, they relied upon immunofluorescent methods which were designed to react to specific antigens on the bacteria of concern and thus can react to dead or fragmented organisms. In addition, this study suffered from problems with one of their tests cross-reacting with other bacteria. The reliance on tests that detect antigens of a pathogen is a particular problem for studies of the survival of *Aeromonas salmonicida* where the organism is felt to persist in sediments in a non-culturable/non-viable form. While studies can detect these forms in environmental samples for two to three weeks, it is felt unlikely that they remain capable of causing disease (Effendi and Austin, 1994). Although Effendi and Austin (1994) could prolong the survival of *Aeromonas salmonicida* in water samples if organic material such as wood and mud were added, Rose *et al* (1990) were unable to prolong its survival by utilizing waters taken from beneath sea cages. It has also been postulated that some pathogens may be able to survive in wild life around sea cages. Although its survival potential in water has been thoroughly examined, Nese and Enger (1993) reported that *Aeromonas salmonicida* has never been isolated from other environmental sources. Therefore, they sought the organism in sea lice. They succeded in detecting and isolating this pathogen in sea lice, but were unable to determine the implications of this finding with respect to the transmission and maintainence of furunculosis. This contrasts with an earlier study in which investigators examined 2,954 vertebrates and invertebrates taken from fish ponds during outbreaks of furunculosis, but failed to find the pathogen in any sample (McCarthy and Roberts, 1980)

The amount of pathogen in the environment not only depends on its ability to survive, but also on the rate at which it is supplied and removed from the environment. In experimental studies by Enger *et al* (1992), the amount of *Aeromonas salmonicida* in tanks with experimentally infected fish was found to be affected by the means of experimental infection and management practices such as the frequency of removal of dead fish from experimental tanks. Their results also demonstrated that pathogens do not distribute homogeneously in the environment. Instead, this pathogen was found to concentrate at the air-water interface. The authors concluded that, given shedding of the organism was not constant from sick or dead fish, the stability of bacterial numbers in the surface layers of water and at 10cm depth suggested that sick and dead fish do not contribute significantly to the environmental numbers of bacteria. Standard recommendations for minimizing spread and impact of infectious diseases advocate that sick and dead fish be removed from the populations in order to reduce the number of pathogens being shed into the environment (Pillay, 1992). Similarily, the disposal of wastes from dead or sick fish into marine or aquatic environments is discouraged (Rose *et al*, 1989; Pillay, 1992).

Rose *et al* (1990) concluded that the spread of furunculosis may be less dependent on its ability to survive than on its rate of shedding from infected fish and the prevailing hydrographic conditions. In his report of furunculosis outbreaks in B.C., based on the observed pattern of spread of disease, Needham (1995) suggested that *Aeromanas salmonicida* spread between two B.C. farms over a distance of 10 km and that reports from Scotland suggested that, based on “antibiotic fingerprinting”, the organisms could be moved up to 19km between farms. The limitations of using antibiotic profiles as a means to trace the movement of bacterial pathogens are discussed elsewhere. In his review of furunculosis, Jarp *et al* (1993) noted that farms that shared equipment or workers were more likely to have outbreak than those that did not. Needham’s 1995 report did not provide the data upon which the hypothesized farm-to-farm spread was based; nor was a description of the relationship between the affected farms given. Jarp et al’s findings demonstrate that the occurrence of the same disease or pathogen on the different farms does not necessarily indicate an water or animal vector-borne spread of the pathogen through the environment.

The presence of a pathogen in the environment is not sufficient to result in an infection in a susceptible fish. The ability of a pathogen to affect a fish is affected by the length of time that the fish is exposed and the concentration of the pathogen that it is exposed to. For example, in experimental work with furunculosis, investigators demonstrated that exposure to 102 to 103 cfu/ml of *Aeromonas salmonicida* for three days did not result in disease (even after stress testing), yet exposure to the same levels for three weeks did result in some mortalities in Atlantic salmon (Rose *et al*, 1989). Little work has been done to examine the environmental concentrations of pathogens that occur during an outbreak of disease at a fish farm. While Needham (1995) claims that as few as 10 *Aeromonas salmonicida* cells per millilitre of seawater can infect a salmon, he does not discuss how this reflects concentrations seen around sea farms nor what proportion of fish infected at this level develop disease. Some authors have estimated that 95% of larval sea lice production in areas associated with outbreaks on farms is contributed by farmed fish and that production of lice (nauplius I stage) can range from 0 to 4 x 107 per day (Tulley *et al*, 1993). However, the capacity for lice to be transfered from farmed to wild fish is not clear. While Tulley *et al* (1993) demonstrated a positive but not statistically significant trend towards higher abundance of *Lepeophtheirus salmonis* lice on wild sea trout and the production of nauplius I from farmed fish, the same author felt that the transmission of *Caligus elongatus* (another species of lice) from farmed to wild fish was negligible (Tulley, 1989). The role of environmental variables in these reports on lice is important to consider. Higher sea-water temperatures at the time of these reports allowed for a greater rate of lice production and increased susceptibility to infection (Tulley *et al*, 1993).

Fallowing is the practice of leaving a fish farm site empty of cultured fish for a specific time. The intent is to reduce the impacts on bottom sediments and to break disease cycles. Some have used the observation of reduced disease in sites after fallowing as evidence that pathogens accumulate in bottom sediments and act as a source of pathogens. However, it is unclear if the effects of fallowing are due to a reduced loading of sediments with pathogens or to other factors such as, breaking transmission cycles between susceptible farmed fish, reducing fouling organisms or reducing attraction of wild stocks that may act as reservoirs or vectors. An epidemiological study conducted on Irish salmon farms indicated that survival advantages of subsequent generations could be realized with fallowing periods as short as three weeks (Wheatley *et al*, 1995). This would suggest that, if the mechanism of fallowing is the reduction of pathogen input, the viability of pathogens in environments around fish farms is not prolonged. A critical assessment of the effects of fallowing on the concentration of viable fish pathogens in sediments or water columns around farms was not found during this review.

J. OPPORTUNITIES FOR WILD AND FARMED FISH INTERACTION

Wild fish in the vicinity of fish farms

Regardless of the concentration or viability of organisms in the environment, in order for transmission to occur, there must be a suitable host available. In general, aquaculture operations attract both pelagic and benthic organisms (Iwama, 1991). Increased biomass around farms can in part be explained by the presence of escaped fish that remain to exploit feed wastes (Carss, 1990). However, other fish species will also be attracted to aquaculture operations due to the availability of food and protective habitat. Wild channel catfish feeding on waste pellets and dense populations of bluegill and sunfish were observed near commercial catfish farms in the

United States (Phillips *et al*, 1985). Other investigators found increased number, growth and survival of predatory and non-predatory fish around channel catfish and rainbow trout farms (Hays, 1980; Loyacano and Smith, 1975; Kilambi *et al*, 1978). A study of roach around rainbow trout farms in the United Kingdom before and after the establishment of cage culture showed a significant increase in growth of first-year roach (Forbes, 1981). Observations of gastrointestinal tract contents of wild fish around farms plus visual observations show that wild fish ingest food and feces of farmed fish (Phillips *et al*, 1985). Little is know about how much time migratory species such as salmon spend around fish farms. Tagging studies of escaped farmed Atlantic salmon in Norway suggest that escaped fish will visit other farm sites (Anon, 1991). However, a recent study in New Brunswick suggest that this may not be the case for wild Atlantic salmon. In this study (Morgan, 1996), 96 hatchery Atlantic salmon smolts were electronically tagged and released into two rivers. Eighty percent of these fish found their way to sea. None of the released fish spent any time near salmon farms. A second study is being planned using a larger number of smaller wild smolts. Similar studies were not found for Pacific salmon. There are few reports about the ecology of wild fish in and around sea cages in B.C. Therefore, it is not possible to directly extrapolate Morgan's results to Pacific species. In their submissions to this review, residents of the Broughton Archipelago area reported that this region served as an important rearing ground for chinook salmon and that salmon in this region may spend significant portions of their lifecycle in coastal zones. They concluded that these fish would have sufficient opportunities to spend periods of time in close proximity to fish farms. Anecdotal reports indicate that a variety of species have been observed in and around salmon marine cages in the province. This list includes Pacific herring, tubesnouts, shiner perch, dogfish, wolf eels, pollack, and rockfish. No studies of the species attracted to net-cages in lake pens in B.C. were found. The critical information lacking in all of these observations is the length of time individual fish spend in and around net-cages and, for fish that reside near them, how far they move. This information is required to determine if pathogens that are exchanged between cultured fish and wild fish are capable of being spread beyond the immediate vicinity of the farm. To date, there is a lack of direct evidence regarding the potential for the exchange of pathogens between farmed and wild fish in B.C.

Escapes

The preceding discussion has largely assumed that farmed fish stay within the net cages. Another mechanism for disease transfer is through escaped fish. As discussed above, it is unlikely that a sick fish will travel far after it escapes. In addition, it is unlikely that a sick fish will behave normally, particularly in its attempts to meet social demands. However, for some diseases, asymptomatic carrier states can occur. Few data are available on the number of pathogens shed by asymptomatically infected fish (O'Brien *et al*, 1994). Some authors believe that, in the case of furunculosis, all survivors of an outbreak will become carriers (McCarthy and Roberts, 1980). Although healthy carrier fish are thought to be involved in the transmission of this organism, technical problems, particularly the ability to detect a carrier fish with certainty, have limited research in this area and generated conflicting results. In one study where a large proportion of fish were found to be carriers of *Aeromonas salmonicida*, no outbreak of furunculoisis was ever reported on the farm from which the fish originated (McCarthy and Roberts, 1980). Similarily, no evidence of furunculosis was found in wild fish in a Canadian stream after a two year restocking program with asymptomatically infected and non-infected brown trout (McCarthy and Roberts, 1980). The existence or role of life-long carrier fish causing transmission of infectious hematopoietic necrosis virus is also unclear, although recent evidence suggests that it may occur in wild sockeye salmon (Traxler and Roome, 1993). Finally, the capacity for fish asymptomatically infected with *Renibacterium salmoninarum* to spread the disease horizontally has come into question (Lovely *et al*, 1994).

In response to a spill of approximately 5,000 fifty gram Atlantic salmon parr into a lake in 1994, the Ministry of Agriculture, Fisheries and Food collected 65 of these fish (50 live and 15 dead) for pathological examination in an attempt to examine concerns that these fish carried pathogens that could be transmitted to wild stocks. Histopathologic, bacteriologic and virologic tests did not reveal evidence of any disease or infectious agents. Theory would suggest that such a sample should be able to detect disease or infection at a prevalence of 5% or more with 95% confidence. As follow-up to this spill, two cutthroat trout were collected in 1995 from traps put in this lake. No evidence of disease was found (J. Constantine, pers. comm.). No other follow-up for this case was found.

The Ministry of Agriculture, Fisheries and Food also conducted a survey in 1993 to explore the possibility of transmission of pathogens from farmed to wild stock. In June of 1993, two salmon farms on Northern Vancouver Island experienced outbreaks of furunculosis which did not respond to commonly used antibacterial agents. Strains of the organisms were later shown to be resistant to all three of the antibacterial products approved for use in food fish. Two rivers were chosen for study. The first (the Kakweiken River) was chosen because it was the nearest river felt by the investigators to be likely to have pink salmon that had migrated past the sites. Local residents indicated that the distance between the affected fish farm and this river was approximately 36 miles. The second (Puntledge River) was remote from the affected sea sites, but was examined because furunculosis had previously been detected in a salmon enhancement facility on this river. One hundred fish were examined microbiologically from the Puntledge and 98 were examined from the Kakweiken River. Four samples from the Kakweiken River were positive for *Aeromonas salmonicida* (the agent of furunculosis), but all of the isolates were sensitive to antibiotics, including the three drugs to which the farm isolates were resistant. This organism was not recovered from any of the salmon taken from the Puntledge River. A period of three months passed between the outbreak on the farms and the river samples. As antibacterial resistance patterns can change over time, these results do not definitively determine the source of the pathogens in the wild fish. Given the large size of wild populations from which samples were derived for both the 1993 and 1994 investigation, it is dangerous to extrapolate these results beyond the study areas.

The low levels of shedding from asymptomatic fish, coupled with social/ behavioural obstacles to interaction and dilution effects of shed organisms in open water reduce the probability that interactions between fish in sea water will be a significant route of transmission of pathogens between escaped and wild fish. Because wild fish are more susceptible to infectious diseases during the smoltification process and at spawning, and concentrations of these fish will be increased during spawning or out-migration, interactions in estuarine zones or in spawning streams may be a more plausible location for disease interactions. However, as discussed elsewhere, no direct evidence exists to support the hypothesis that such interactions have occurred.

K. EFFECTS OF SALMON FARMING ON THE SUSCEPTIBILITY OF FISH TO DISEASE

Exposure to a pathogen is not enough to cause a disease. In order for a pathogen to affect a fish population the following must occur: the exposed population must be susceptible to the strain of pathogen presented, there must be exposure to a sufficient amount of pathogen that remains viable long enough to cause disease, and the dynamics of the population and pathogen must be such that the disease can be perpetuated to cause adverse effects in the population (Scott and Smith, 1994). Unlike for exotic diseases, we cannot assume that a large proportion of a wild population will be susceptible to indigenous pathogens. Depending on their life history, nature of immune response evoked by the pathogen, and previous exposure to the pathogen, populations will have varying degrees of resistance to a particular disease causing organism. In order for an outbreak to occur, the proportion of the population susceptible to the disease must exceed a certain threshold (Scott and Smith, 1994). These thresholds are specific to each pathogen and can be modified through changes in host population dynamics.

For infectious diseases, the susceptibility of a fish to disease can be increased if some internal or external factor compromises its immune system so that the growth and proliferation of the pathogen(s) is favoured. Stress factors (stressors) can act to compromise the immune system. A formal definition of stress is "a state produced by an environmental or other factors which extends the adaptive responses of an animal beyond the normal range or which disturbs the normal functioning to such an extent that in either case, the chance of survival are significantly reduced" (Brett, 1958). For our purposes, stress can be defined less formally as the response of a fish to a stressor such that its success of survival are significantly reduced. The following discussion of stress and susceptibility is skewed towards salmonids, as much of our knowledge regarding stress physiology in fish has been acquired through studies of these species.

Stress and disease susceptibility

There are three levels of stress response. The primary response involves the perception of the stressor and the initiation of the nervous and hormonal response of the fish (Gamperl *et al*, 1994). The secondary response comprises the various biochemical and physiological effects associated with the stressor(s) (Barton and Iwama, 1991). The tertiary response represents the whole animal and population changes associated with stress. If a fish is unable to acclimate or adapt to a stress, whole animal changes may occur as a result of energy diversion needed to cope with the new demands associated with the stress response. Chronic exposure to a stressor, depending on its intensity and duration, can lead to decreases in growth, disease resistance, reproductive success, smolting, swimming performance, etc. At a population level, decreased recruitment and productivity may alter community structure. Although the tertiary response is of most direct interest to fish managers and aquaculturists, most research has focused upon the primary and secondary responses. Therefore, many indicators and effects of stress in fish focus on those responses (ex. Wedemeyer *et al*, 1990; Iwama *et al*, 1995; Woodward, 1982).

Stress can affect the immune system by way of a variety of mechanisms. Stress causes changes in the number of circulating white blood cells (Pickford *et al*, 1971; Ellsaesser and Clem, 1986; Schreck *et al*, 1993). Furthermore, the functional capacity of the white blood cells, such as their ability to form antibodies, can be reduced as a result of stress (Schreck, 1996). Maule *et al* (1989) correlated the susceptibility of stressed juvenile chinook salmon experimentally exposed to *Vibrio anguillarum* with the ability of their white blood cells to produce antibodies. It is interesting to note that stress can, in some cases, enhance disease resistance. Chinook salmon stressed with handling stress for 30-60 seconds showed a reduction in the number of circulating antibody-producing cells in the first 24 hours, but demonstrated increased resistance to disease challenge for one to seven days (Maule *et al*, 1989).

Environmental changes and susceptibility

Environmental stressors include adverse chemical conditions of the water. Although pollutants are commonly thought of as environmental stressors, extreme conditions or changes in water quality parameters, such as dissolved oxygen, ammonia, hardness, pH, gas content and partial pressures can unduly stress a fish and lead to disease (Meyer *et al*, 1983; Wood, 1979). Industrial, domestic and agricultural activities can add a variety of contaminants to the environment that can adversely affect fish at all life stages. The results of studies of the ability of salmon aquaculture to produce environmental stressors vary. Oxygen is essential for survival. Depletion of oxygen can have serious effects on fish. An example of this was seen in California, where water that was heavily polluted with cannery effluent was believed to cause serious mortalities of shad (Haly *et al*, 1967). In eutrophied waters, large fluctuations in dissolved oxygen occur (Snieszko, 1974). Dissolved oxygen levels may be depressed due to the accumulation of wasted feed and fecal material from salmon culture (Parsons *et al*, 1990). Data from Puget Sound failed to reveal decreases in dissolved oxygen at 5m depth significant enough to cause lethal or sublethal effects on wild biota outside of salmon cages (Wash. Dept. Fisheries, 1990). Studies of the effects of salmon cages on dissolved oxygen in Scotland and Norway provided variable results partly due to fluctuations in dissolved oxygen levels observed at the reference stations (Levings, 1994). Research conducted in B.C. has also been limited in its ability to demonstrate biologically or statistically significant differences in dissolved oxygen in waters around salmon marine cages (Levings, 1994).

The possibility of hypernutrification or eutrophication associated with aquaculture activities has also been considered as a possible environmental stressor. The production of ammonia, which when above specific levels can act as a stressor of fish (Stoskopf, 1993), has also been a concern in situations where hypernutrification and eutrophication may occur. Early studies in Norway showed that fish farm wastes can affect near-surface levels of ammonia (Levings, 1994). Samuelsen *et al* (1988) showed that a variety of gases toxic to fish were present in sediments under fish farms including methane, carbon dioxide and hydrogen sulfide. Research in Washington State and Scotland observed increases in ammonia or ammonium near salmon farms as compared to reference sites (Gowen *et al*, 1988; Rensel, 1990). However, these studies also revealed substantial variation in these measures with tidal action. In addition, the Washington studies found the levels of ammonia measures to be only 10% of the chronic exposure criteria for sub-lethal effects on aquatic organisms set by the United States Environmental Protection Agency. Because of differences in dissipation of tidal energy along their coasts, B.C. in general has substantially greater tidal currents than northern Europe (Sverdrup *et al*, 1942, cited in Levings, 1994). Stressors due to hypernutrification may therefore only be a potential problem in poorly flushed fiords in the province (Levings, 1994).

Another important issue related to environmental stress arising from salmon farming is the introduction of chemical contaminants. Chemicals are introduced into the water in aquaculture for a variety of reasons ranging from the control of pathogens and parasites to the preservation and protection of equipment. With respect to drugs used in B.C. salmon farming, only oxytetracycline was found to have potential immunomodulating effects. Tetracyclines have been found to suppress the ability of pigs and poultry to mount an appropriate immune response (Huber, 1982). However, it is very unlikely that similar effects would been seen in wild species frequenting fish farms as (1) pigs and poultry were exposed to therapeutic levels and durations which would be higher than those that would be expected to be found in environmental sources around net cages or in wild fish speices not entirely dependnet on medicated feed, and (2) as described in more detail below, the biological activity of oxytetracycline in fresh or sea water is greatly reduced. Other agents such as chlorophenol wood preservatives or copper-based antifoulant agents are also encountered in sea farm settings. Copper has been seen to increase the susceptibility of rainbow trout to infections with infectious hematopoetic necrosis virus and to the bacterium *Yersinia ruckerii* (Hetrick *et al*, 1979; Knittel, 1981). Peterson *et al* (1990) measured copper levels in fish-pens with copper-dipped nets. The concentration of biologically active copper in water samples from a pen with a recently dipped net was not significantly different than at the control station. Copper levels in muscle tissues taken from fish within the pens were also not significantly different than those of control fish. A survey of copper rockfish caught near two fish farms in Sechelt Inlet revealed that fish captured near the sites had more organic contaminants such as PCB’s than comparison sites (Birch, 1989). Although it was considered that contaminated fish food may have been a source of these compounds, it was thought to be more likely that the differences reflected differences in the study and control sites, the latter being situated further away from urban influences. Levings (1994) concluded that “contamination of coastal habitats and wild fish populations in British Columbia from organic and inorganic chemicals used in routine aquaculture operations is unlikely”. Therefore, it is unlikely that salmon farming activities will alter the environment enough to increase the susceptibility of wild species to disease.

It is most likely that immunosuppressive effects from environmental alterations associated with aquaculture would be first noted in the captive stocks. The ability of captive fish to avoid environmental stressors is limited by their coninement. Harmful algae blooms are an example of this differential effect of harmful environmental factors on wild and farmed fish. During a bloom, the distribution of the algae in the water column is limited. Observations of salmon in sea cages will reveal that they try to seek areas of the cage with lower algal concentrations. As they are restricted by the boundaries of their cages, many of these fish are unable to escape environmental stressors, while wild fish have the option to move away. Because of their ability to move away from stressful situations, transient fish or fish that have large home ranges are unlikely to spend enough time in and around sea cages to be exposed to sufficient amounts of chronic stressors to impact their susceptibility to disease. However, if other factors "tie" a fish to the vicinity of a sea cage, such as territory, nests, or utilization of waste feeds, there may be sufficient opportunity for exposure to chronic stressors. This area has not been studied and any effects of environmental modifications or other chronic stressors on species which spend portions of their life in or around salmon farms is unknown. Because stressors that arise from environmental alterations associated with aquaculture will have their greatest effects on captive fish, monitoring and maintaining environmental water quality forms a basis for aquaculture health management recommendations.

Physical stressors and susceptibility

Physical stressors include those that involve handling, crowding, confinement or other forms of physical disturbance. Chasing fish until they are exhausted has been a commonly used experimental method in some physiological studies. The potential for inducing physical stressors in cultured fish is clear. Standards of culture aimed at reducing fish disease often focus upon the modification, reduction or prevention of physical stress (M. Sheppard, pers. comm.). Simulated transportation for 21 hours was sufficient to increase the mortality rate of Atlantic salmon (Johannson and Bergstrom, 1977). Crowding and handling have been implicated as a cause for significantly higher mortalities of furunculosis-infected brown trout (Pickering, 1987).

Biological factors affecting susceptibility

The development of the stress response and its influence on disease susceptibility changes over time. From conception, fish have the capacity both to demonstrate stress and immune responses. There are times in a salmon's life cycle when the fish becomes naturally more susceptible to infectious diseases or the effects of stress. The cortisol-induced stress response is elevated during parr-smolt transformation. Cortisol is an important hormone to prepare the salmonid fry to survive in sea water. It is also a hormone that plays a significant role in the stress response. Smolts appear to be more sensitive to stress and more susceptible to opportunistic pathogens, relative to fish prior to and after this important phase of development in salmonids (Schreck, 1996). Maule *et al* (1989) found lower levels of white blood cells and antibody-producing cells in particular in the spleens of coho salmon undergoing smoltification. Maturing fish show lower disease resistance than adult stages prior to sexual maturation (Richards and Pickering, 1978; Pickering and Christie, 1980). Circulating levels of cortisol are elevated during spawning in Pacific salmon (Maule *et al*, 1989). A fish is subject to significant biological stressors at the time of spawning. Changes in the hormonal profile coupled with senile changes enhance a fish's susceptibility to disease. While infections acquired by wild spawning fish tend not to prevent a significant number of fish from spawning, when other stressors or increased exposures to pathogens occur, abnormal patterns of disease can occur. In our example case, it has been hypothesized that returning coho salmon were exposed to unusual numbers or strains of pathogens and that their increased susceptibility due to spawning reduced their ability to deal with this exposure. Alternative hypotheses have been proposed. Descriptions of the handling procedures of the fish in this example reveal that they were subjected to significant physical and biological stressors including physical capture, transport stress, and confinement in adverse conditions (G. Bates, pers. comm.). These stressors could have been sufficient to allow for naturally infected, asymptomatic fish express the disease, a typical scenario for furunculosis (McCarthy and Roberts, 1980). Based on the clinical presentation of the fish involved in the example case, their history of significant stressors and the knowledge of the endemic nature of *Aeromonas salmonicida* in B.C., investigators were led to believe that the later hypothesis was more likely than the former. (D. Kieser pers. comm.). However, hatchery managers indicated that their fish handling procedures had been the same for several years prior to this outbreak, suggesting that handling stressors alone were insufficient to cause the furunculosis outbreak.

Species, strain and genetic factors

There are differences in the stress response among species (Vijayan and Moon, 1994) and in the tolerance of different stocks of the same species to applied stressors. The susceptibility of a fish to particular pathogens also has genetic components (see Schreck 1981). Host and pathogen genetic factors play a role in this relationship. Pathogens vary in their specificity of certain hosts. There is, in general, a poor understanding of the specificity of many fish pathogens due to a lack of research involving the contact between a pathogen and a variety of potential hosts, and a lack of understanding of how variations in pathogen strains relate to host tolerance and pathogenicity (Chevassus and Dorson, 1990). The susceptibility of salmonids to infectious hematpoietic necrosis virus varies with the strain of virus (Traxler *et al*, 1993). A number of authors have demonstrated a genetic basis for the biochemical and physiological responses of fish to stress (Fevolden *et al*, 1991; Del Valle and Taniguchi, 1995). There is also evidence of a genetic basis to disease resistance (Fjalestad *et al*, 1991). Different strains of chinook and pink salmon were shown to have different resistances to vibrioisis, furunculosis and bacterial kidney disease (Beacham and Evelyn, 1992). Gjedrem and colleagues have shown that the susceptibility to these diseases in Atlantic salmon have a high heritability (Gjedrem *et al*, 1991; Gjedrem and Gjoeem, 1955). Arctic char also have a high heritability of fungal resistance (Nilson, 1992).

There has been some concern regarding the role of hybridization between escaped farmed salmon and wild salmon. No studies were found that documented changes in disease susceptibility in wild stocks as a result of hybridization or breeding with farmed salmon. The basis for much of this concern comes from evidence that there is a significant reduction of genetic variability in hatchery-reared fish, although a study of farmed salmon in Scotland did not demonstrate the same evidence (Windsor and Hutchinson, 1995). The concerns about possible adverse genetic effects of farmed fish on wild stocks is, in the case of Atlantic salmon in the Atlantic, not based on empirical evidence (Windsor and Hutchinson, 1995). The Salmon Aquaculture Review discussion paper on the impact of escaped fish provides a more detailed discussion on genetic interactions. During the development of the aquaculture industry, farmers have advertently or inadvertently been able to select broodstock for attributes favourable for culture conditions. As broodstock will live in sea cages for a number of years, they have the prolonged opportunity for exposure to pathogens. Thus, it is postulated that the very nature of culture conditions will create selection pressure favouring strains with disease resistance. Therefore, it has been concluded that genetic interaction of farmed and wild fish would not necessarily be negative from a disease susceptibility perspective (Winsby *et al*, 1996). Studies that look at the effects of hybridization on disease resistance have provided variable results. Many of these studies were limited due to the poor viability of the hybrids (Chevassus and Dorson, 1990). In some studies, the hybrids in experimental studies retain the susceptibility and resistance patterns of one or more of their parents (Chevassus and Dorson, 1990). Of unique interest is the possible effects of triploid salmon. Hybrids of triploid salmonids in one study showed an increased resistance to certain viral pathogens compared to parental stocks (Chevassus and Dorson, 1990). As the utilization of all female triploids has been advocated as a means of rearing sterile stocks, concerns regarding triploid hybridization with wild stocks in B.C. are unwarranted.

Variation between and within populations in resistance to certain pathogens is well documented. Although several studies demonstrate improved performance of crosses between populations, most of the work involved only first generation crosses; therefore, the persistence of any changes in disease resistance into future generations is unknown. However, it is generally believed that a program of selective breeding, plus the unintentional selective pressure due to pathogen exposure during rearing, selects for more disease resistant stocks in aquaculture settings. For example, early studies of brook trout (Embody and Hayford, 1925—cited in Chevassus and Dorson, 1990) showed that when surviving fish were selected from a population with furunculosis, the survival rate of offspring in the next three generations changed from 2% in the initial population to 69%. More recent studies (Cipriano and Heartwell, 1985) also were able to increase survival to furunculosis through a system of mass selection. However, attempts to select for disease resistance face practical and theoretical problems such as experimental infection methods that do not simulate real exposures, the potential for increasing resistance to some diseases while decreasing it for others, and genetic variation in pathogens (Chevassus and Dorson, 1990).

Wild fish in B.C. differ in their susceptibility to a variety of the infectious diseases diagnosed in farmed salmon. Recent unpublished studies conducted at the Pacific Biological Station (Kent *et al*, unpublished), have explored how a variety of wild species respond to experimental challenges with viral hemorrhagic septicemia virus, infectious hematopoietic necrosis virus, *Aeromonas salmonicida, Renibacterium salmoninarum* and *Loma salmonae*. Their results suggest that viral hemorrhagic septicemia virus is endemic in several marine species. In experimental challenges, only shiner perch exhibited significant mortality. Atlantic salmon, herring and stickleback were all relatively resistant to the virus. The investigators concluded that shiner perch were unlikely to be put at increased risk due to this virus from farmed fish because of the presence of numerous natural hosts, such as herring in B.C. These studies were able to induce mortality due to infectious hematopoietic necrosis in approximately one-half of tubesnouts, shiner perch and herring injected with the virus. However, only a few fish developed infection by water-borne exposure, suggesting that this would be an unlikely means of causing epidemics in wild marine fishes. When exploring the potential for transmission of *Aeromonas salmonicida* from farmed to wild fish, the investigators used a more “natural” route of exposure, cohabitation with infected salmon. The term natural is used loosely as, due to the close confines of the experimental tank, the challenged fish were undoubtedly exposed to higher concentrations of shed bacteria than would occur in a net cage setting. A sub-sample of challenge fish were examined before exposure and no *Aeromonas salmonicida* could be found. The study did show that tubesnout and herring were susceptible to *Aeromonas salmonicida* infection and disease under experimental conditions. The authors were not able to conclude if, under natural conditions, infected tubesnout or herring would be able to leave the net cages, maintain the infection and transmit it to others in its population. In addition to fish, the investigators looked to see if mussels could be long-term reservoirs of *Aeromonas salmonicida*. They found that mussels readily cleared the organism from the water and that viable pathogens persisted in the mussels for only a limited time (7-21 days). No adverse effects on the mussels were reported. Experimental studies also revealed that shiner perch were considerably more resistant to *Renibacterium salmoninarum* than were chinook salmon and concluded that shiner perch are unlikely to act as reservoirs for the pathogen. Finally, experimental studies at the Pacific Biological Station indicate that Loma salmonae is host specific to salmonid fishes.

Density, stress and susceptibility

Crowding is a stressor that can be part of many intensive aquaculture operations. Patino *et al* (1986) showed that plasma cortisol levels in coho salmon were related to density and metabolic waste levels in the water. They also found an inverse relationship between rearing densities and resistance to experimental challenge with *Vibrio anguillum* (Schreck *et al*, 1985). It is important to separate the effects of crowding due to alteration in water quality from those arising from forced behavioural interactions. Biological stressors can be manifested by dominance hierarchies which develop within the confines of experimental tanks and perhaps under farm and wild settings as well. There is evidence showing that within dominance hierarchies, the subordinates are stressed. Ejike and Schreck (1980) showed an inverse relationship between social rank and plasma cortisol concentrations in coho salmon. Peters (1988) showed that subordinate rainbow trout were stressed and showed greater infection rates when challenged with *Aeromonas hydrophila*. Between species, aggressive interactions have been shown to cause stress and impact on health (Faisal *et al*, 1989; Peters, 1988). Little work has been done to explore the relationship of biological stressors due to social factors and the occurrence of disease in net cage reared salmon. One of the factors cited in regulations and recommendations governing salmon farming in other jurisdictions is density or crowding. Crowding stress can, and does, occur in some aquaculture settings because this economically relevant factor is pushed to the limit. The level of crowding that is stressful to fish depends on many biological factors. Arctic char prefer highly crowded conditions, whereas most other salmonids are very susceptible to stress caused by crowding. Domesticated rainbow trout tolerate crowding far more than wild Pacific salmon. Some of the reasons for this are social, as aggressive behaviour and territoriality are sources of stress. Other causes of stress in crowded conditions relate to degradation of water quality as oxygen availability and carbon dioxide and ammonia washout can be compromised in heavily crowded rearing units. Data from government hatcheries in the United States show that salmonids can be reared at densities of 60-120kg/m3 without causing stressed states (Westers, 1984). Atlantic salmon can be reared at densities up to 21kg/m3 without adverse effects on growth, survival or fish condition (Wedemeyer, 1996). Such static densities are overly simplistic. Water flow and water quality levels may allow for density guidelines to be exceeded without ill effect or may require that densities be reduced. Therefore, loading densities should be adjusted to meet the water quality parameters and needs of the cultivated species.

Summary

The relationship between physical and biological stressors and disease outcomes is not well understood. The preceding discussion on susceptibility must be interpreted with caution. For example, the resistance or susceptibility to one pathogen cannot be generalized to other pathogens. Winter *et al* (1980) have shown that the strong correlation between one marker of stress, serum transferrin, and resistance to bacterial kidney disease in salmon does not hold for vibriosis. Furthermore, the intuitive expectation of high stress to be correlated with low disease resistance does not always hold. In genetic groups selected for their stress response, rainbow trout selected as “low” stress lines, were less resistant to *Vibrio anguillarum* but more resistant to *Aeromonas salmonicida* (Fevolden *et al*, 1992). Temperature shock in rainbow trout did not increase susceptibility to *Flexibacter columnaris*, and in some experiments even increased resistance (Poston *et al*, 1985). Several aquaculture practices can result in stressors to cultured fish (Wedemeyer, 1996a). The effects of a particular stressor are difficult to predict in a precise manner. The above discussion has presented the relationship between stress and disease in a very simplistic fashion. The effects of environmental quality on fish health depend on factors such as species, age, size and previous experience. The nature and impacts of stress can be modified by management practices, the intensity and duration of the stress, environmental quality and the nature of the fish being exposed. It is apparent that the almost endless combination of relevant factors requires that each situation be considered unique. Therefore, it will be difficult, if not impossible, to formulate precise regulations or recommendations intended to reduce the effects of stress on the basis of scientific data. Instead, only general guidelines based on past fish farming experience and basic biophysical principles that encourage reduced stress farming can be formulated.

L. FOOD SAFETY CONCERNS FROM FISH DISEASE FOR HUMANS AND OTHER TERRESTRIAL SPECIES

There are few fish pathogens that man can acquire from fish, particularly salmon. Those that occur in B.C. are those associated with the consumption of wild fish (ex. Anisakisasis) or due to poor handling or preparation of food products (exs. Botulism, Listeriosis). None of the following agencies of the Ministry of Health were aware of, or expressed concerns about, human diseases that may arise from pathogens or parasites of farmed fish origin in B.C.: the Provincial Laboratory (Food Poisoning and Enteric Laboratory), the Epidemiology Services, B.C. Centre for Disease Control, or the Public Health Protection Program (Food Protection Programs) (M. Pierce, L.D. Copeland, pers. comms.). Diseases that occur in salmon may reduce the aesthetic value of foods or reduce carcass quality, such as muscle degeneration seen with *Kudoa* infections (St. Hilaire, 1996) or the external and musculature lesions seen with bacterial kidney disease (Kent, 1992). However, these do not reflect diseases of known human health significance. No evidence is available to suggest that any ethnic group is uniquely susceptible to infection from fish pathogens due to unique aspects of their immune system (I. Sobol, pers. comm.). Specific cultural practices including food preparation and collection methods may however affect the likelihood that a person will be exposed to pathogens or parasites of fish origin.

It is not known if changes in the bacterial flora in the vicinity of a sea cage present food-safety risks concerning shellfish harvested nearby. As disussed above, shellfish appear to utilize common fish pathogens as food sources, metabolizing them without untoward effects. Fish will produce a variety of coliform organisms that may be part of their normal intestinal flora and are discharged into the environment through fecal wastes. Contamination of shellfish with coliform bacteria represents a common public health concern. Typically, the sources of these bacteria are human sewage or agricultural run-off. Studies of changes in bacterial communities near sea cages are rare. In one study, a higher number of coliform bacteria were found adjacent to sea cages, while a second study found no significant change (Rosenthal *et al*, 1995). Near-surface water samples around fish farms have shown higher coliform counts than reference sites, but these have been attributed to birds roosting on farms and defecating into the water (Rosenthal *et al*, 1995). The discussion paper on waste discharges in the Salmon Aquaculture Review provides a more complete discussion of the subject of organic waste discharges from fish farms.

Terrestrial species and marine mammals can share some of the same pathogens or parasites of salmon. For some parasites, a bird or mammal is the definitive host for a parasite and fish are the intermediate host (Kent, 1992). In other cases, such as enteric redmouth, birds have been postulated to act as reservoirs of the agent but are not clinically affected. There are some organisms, such as *Neorickettsia helminthocea*, that mammals, particularly dogs, can acquire from fish and become ill, but these diseases are rare. Other shared pathogens are similar to those for people in that they often represent a shared environmental exposure, rather than direct transmission. The Wildlife Branch of the Ministry of Environment, Lands and Parks was unaware of and did not express concern regarding the transmission of indigenous disease agents from farmed fish to wild non-fish species, although they advocated caution because research regarding such interactions is lacking (H. Schwantje, pers. comm.).

M. MONITORING AND MANAGING INDIGENOUS DISEASE IN BRITISH COLUMBIA

In order to assess and manage the risk of disease in any population, a system of disease monitoring and surveillence is necessary. Information acquired from monitoring and surveillance allows disease managers to detect changing patterns of disease in populations of concern as well as to assign resources to disease control programs. As disease monitoring and surveillance is closely coupled with disease management, the following discussion will provide details regarding private and public efforts to monitor diseases of wild and cultivated fish. As the development of a disease monitoring program is part of the province's Salmon Action Plan, the reader is referred to Appendix E for background information on monitoring and surveillance.

Industry

In their submission to this review, the B.C. Salmon Farmers Association quoted an unpublished survey by Karreman regarding the disease management practices conducted by the industry. This report indicated that "the majority of producers follow similar (fish health practice) protocols"; however, the precise proportion of producers was not included in the submission. Among the activities cited in this report were the following:

1. Single year class sites and fallowing between year classess. This practice was said to be dependent on the availability of sufficient sites for rotation.
2. Utilization of veterinary services for disease diagnosis, treatment and monitoring.
3. Presence of fish health personnel on all farms to assist in monitoring and managing disease.
4. Biosecurity measures. At hatcheries this included ozonation of intake water and bird and rodent control as well as restricting or controlling access of people to various parts of the hatchery facility. Hygienic procedures reported for sea sites included disinfection and ordering of farm activities to avoid potential transfer of pathogens within and between farms.
5. Broodstock screening for viral pathogens and bacterial kidney disease. All virus positive stocks were said to be culled. Culling and segregation of broodstock positive for bacterial kidney disease is done, but not universally. Fish with “low positive” bacterial kidney disease test results may not be culled.
6. Surface disinfection of eggs.
7. Vaccination of stock for vibriosis, furunculosis and infectious hematopoietic necrosis was said to be conducted on all Atlantic salmon. Vibrio and/or furunculosis vaccination was reported for Pacific species. In his submission to the review, Dr. D. Groves of Sea Spring Salmon Farms indicated that hatchery stock may also be immunized against *Aeromonas hydrophila* and enteric redmouth.
8. Culling of eggs before the eyed egg stage and routine disease sampling of fish prior to smoltification.
9. Routine disease monitoring of fish at sea.
10. Chemical treatment of fish in hatcheries and at sea. Culling may also be used to manage disease.
11. Harvesting by separate crews and disposal of blood and offal in accordance with waste discharge permits.

A 1994 survey conducted by the Ministry of Agriculture, Fisheries and Food indicated that 85% of Atlantic salmon produced were vaccinated for furunculosis and/or vibriosis.(J. Constantine, unpublished). Only one of the ten hatcheries surveyed did not vaccinate their fish.

Discussions with fish farmers, farm owners and veterinarians revealed the following. As disease control is an important part of salmon farm management, most farms have some level of disease surveillance. This may be generated and used strictly “in-house” or may be part of larger initiatives such as the C.A.S.H. program described below. Mortality records are kept on a regular (daily, weekly, semimonthly) basis on all farms. These records are accessible to government officers as a condition of fish farm licences. As this reflects the disease status and thus the potential profitability of a farm, it is treated as proprietary information. Historically, farm health records and health information were not openly discussed within the industry. However, in order to address health issues, cooperation and information sharing between companies have dramatically improved in the past decade (AAVBC, pers. comm.). This can be witnessed by summary reports from the C.A.S.H. program (see below), and cooperative efforts to support and coordinate applied disease research. However, recent breaches in the confidentiality of disease information by government officials led to the withdrawal of the B.C. Salmon Farmers Association support of a proposed government disease monitoring program.

As a service to their clients, the major fish feed companies in B.C. offer veterinary services to farm customers. Therefore, farmers have access to expertise in the identification and diagnosis of disease and cost is not a deterent. Some companies also employ or contract additional veterinary support. Larger companies may have sophisticated, in-house facilities to detect specific pathogens and many have staff dedicated to fish health. Some staff have post-graduate training in some aspect of fish disease, microbiology or parasitology. In addition, many farms employ a fish health technician with community college level training in basic techniques for identifying and managing fish disease. Training programs for fish health technicians are offered at a variety of colleges in B.C.

Veterinarians

The involvement of veterinarians in fish health has grown with the expansion of the aquaculture industry. Although opportunities for learning about fish diseases were limited in previous years, Canadian veterinary schools now provide undergraduate and graduate level training in fish diseases. Most active in this area at the undergraduate level is the Atlantic Veterinary College. The Western College of Veterinary Medicine has been involved in graduate fish health research in B.C., as have the Ontario and Atlantic Veterinary Colleges. Fish disease information has become more commonplace in professional and scientific journals as well as in continuing education programs

For a veterinarian to provide a prescription to a client, he/she must have a valid veterinarian/patient/client relationship. For such a relationship to exist, the veterinarian must have made timely and medically appropriate visits to a site so that he/she has knowledge of the facilties housing the fish, has a basis for establishing a diagnosis, and has knowledge of the health history of the patient or patient group. As a veterinary presciption is required for most drugs used in aquaculture, veterinarians are consulted on a large proportion of disease problems requiring drug treatment. Although veterinarians were previously utilized primarily for their prescription services, aquaculture veterinarians in B.C. today offer more comprehensive health services analagous to those offered to other species. These services include the design of disease prevention programs, nutritional advice, and diagnosis and treatment of non-infectious diseases (AAVBC submission to review). As veterinarians are required to keep medical records, they have historical and current data on disease problems being diagnosed. Some veterinarians have developed databases that allow for cross-company comparisons to assist in detecting trends in health problems within their client base. Veterinarians regard information in their possesion about their patients or clients as confidential. This is to ensure full and open communications between veterinarians and their clients and to allow clients the opportunity to divulge information pertainent to establishing a diagnosis without the preception of penalty. The confidentiality of veterinary records is based in general property law, which provides that a veterinarian cannot use a client’s property (in this case, medical records) without the permission of the client (D. Leung, pers. comm.). Veterinarians are required by federal or provincial regulations to report reportable diseases and to follow reporting requirements of the *Health Act* . However, there are currently no reportable fish diseases. The by-laws and code of ethics of the B.C. Veterinary Medical Association stipulate the standards of practice veterinarians must follow in regard to the confidentiality of client information and obligations to report health threats or specific diseases.

C.A.S.H. program

The Cooperative Assessment of Salmonid Health (C.A.S.H.) was established in 1990 by producer members of the B.C. Salmon Farmers Association. Its goal is to "enhance competitiveness and focus on increasing efficiency and decreasing the cost of production" (Karreman and Ohara, 1996). It is the first large production information and management system that has been successfully implemented across several competing aquaculture companies.

C.A.S.H. is a voluntary, confidential, fee-for-service program. As with veterinarians, the operators of the C.A.S.H. are not exempt from the duty to report diseases as specified by provincial or federal legislation or regulations. Data are generated by the producers on a daily or weekly basis. Monthly summaries are supplied to the C.A.S.H. program for reconciling, summarization and interpretation. Participants in the program receive feedback on their own sites as well as aggregated biological and economic data from the other participants.

Fish health is one of the biological factors that is monitored. Mortality rates are generated on a daily and cumulative basis. In a submission to this review, the C.A.S.H. program indicated that, after 24 months at sea, Atlantic salmon sites in 1993 reported slightly less than 20% cumulative mortality rates—the same as was seen for Chinook sites. In 1994, the average production period for Atlantic salmon was less (23 months), as was the average cumulative mortality rate (15%). When possible, producers attempt to estimate the proportion of deaths attributable to specific causes. However, the C.A.S.H. currently does not attempt to confirm these diagnoses. The basis for diagnoses in the C.A.S.H. can vary between sites. They may involve producer diagnoses (within company diagnoses based on observation or in-house testing). In-house testing capabilities vary between companies, but can be very sophisticated. Not all farms in the province are involved in the C.A.S.H. program. The C.A.S.H. model is very similar to Record of Performance programs that have been in place in the Canadian agriculture industry since the 1960s.

Private laboratories

In B.C., the Animal Health Monitoring Centre is a diagnostic laboratory that is privately funded, but housed within the provincial Animal Health Centre(AHC). It was set up to address the diagnostic testing needs of disease control problems in the poultry and fur industries primarily. It is a fee-for-service laboratory that has recently began to provide screening diagnostic testing for the local salmon farming industry. This facility is supervised by a veterinarian.

There is currently one independent private laboratory serving the B.C. salmon farming industry in the province. In addition, there is a private histopathology service in B.C. as well as a large laboratory in Oregon which offers a specialized test for bacterial kidney disease screening. None of these organizations has a veterinarian on staff. The *B.C. Veterinary Act* prevents anyone other than a licensed veterinarian from providing a diagnosis on an animal that is not theirs or their employer's. Therefore, the existing private laboratory services, apart from the Animal Health Monitoring Centre, are unable to provide fish farmers with diagnoses. Instead, they focus on identifying and describing pathogens or lesions in samples that are submited. This information may be provided back to the farmer or to his/her veterinarian. Broodstock and smolt screening form a large proportion of the data generated by private laboratories. These programs allow for the sampling of a large portion of the population in question including apparently healthy fish. Results are viewed as the property of the submittor.

Private laboratories that are not providing diagnoses are not subject to provisions established by the *Veterinary Laboratory Act*. In B.C., quality control and training standards are based, by default, on the federal Fish Health Protection Regulations because the largest private laboratory employes a number of Local Fish Health Officers. A Local Fish Health Officer must have an approved training history and access to adequate test facilities and equipment.

Provincial government

The Ministry of Agriculture, Fisheries and Food (MAFF) is responsible for monitoring diseases that are of concern to farm stock and which may be of significant economic importance to the B.C. salmon farming industry.

It is within the ministry's mandate to provide information on diseases of potential human or animal health concern to other provincial and federal agencies. Provincial regulations that govern fish diseases and their control in B.C. include the *Animal Disease Control Act* and the Aquaculture Regulations of the provincial *Fisheries Act*. The purpose of the *Animal Disease Control Act* is to control disease on farms. It deals with issues of detecting diseases, controlling sources of disease and pathogens, implementing measures to reduce the spread of disease and implementing measures to reduce its impact on farms. To assist in this, the Act allows for the Provincial Veterinarian to require a disease be reported by those with knowledge of its occurrence. Generally, diseases are made provincially reportable if: (1) there is sufficient concern regarding the diseases impact, (2) the disease or its agents can be readily identified, and (3) effective measures of control are available. Currently, no fish diseases are reportable under current provincial regulations. A primary reason given for this is that diseases of farmed fish in B.C. are due to indigenous pathogens, and therefore there are external or wild sources of the pathogens or disease that cannot be controlled, thus complicating control of diseases on farms (J. Constantine, pers. comm.).

MAFF meets its obligation to monitor fish disease through its Fish Health Extension Program. MAFF fish health services are provided through the AHC and Health Management Veterinarians. It provides state-of-the-art diagnostic facilities to support the province's animal production industries as well as some diagnostic support for companion animal species. The nature of involvement of this facility with the aquaculture industry has evolved over the past several years. Between 1989 and 1993, the AHC employed a full-time fish pathologist. During this period, many samples were submited for pathological diagnosis. Unfortunately, the AHC at that time did not have a data storage system that allowed for diagnoses to be entered into a retrievable data bank; thus historical disease data are not readily available (R. Lewis, pers. comm.). In 1993, the fish health veterinary pathologist was seconded to coordinate a national fish therapeutant consortium. Instead of replacing this person with another diagnostic pathologist, the province created a Fish Health Veterinarian as a health management position. These veterinarians provide an "on-farm" service to animal producers. Their emphasis is to develop and deliver programs that assess the importance of specific disease and management problems that affect animal welfare and productivity as well as designing programs to prevent or control animal disease. In 1995, the AHC began to increase their expertise and capacity to perform specialized diagnostic tests, particularly those involving polymerase chain reactions. These methods have been used to examine fish samples for infectious hematopietic necrosis virus and *Renibacterium salmoninarum*. Diagnosticians at the AHC have received recent specialized training in fish microbiology. All cases submitted to the AHC are assigned to the Fish Health Veterinarian, who is responsible for interpreting and communicating results to the client. Between January and October, 1996, the AHC examined 1,079 fish representing 98 diagnostic cases. As these cases were assigned to the Fish Health Veterinarian and not the AHC pathologists, the diagnoses were not entered into the laboratory's pathology database. Instead, the Fish Health Veterinarian retained hardcopies of her findings. Because of budgetary and personnel resources, the AHC is not able to provide a full range of diagnostic services to support the industry, practising fish health veterinarians or the province's fish health extension veterinarian (R. Lewis, pers. comm.). It is therefore difficult for the AHC to provide an accurate assessment of the health status of farmed salmon since such estimates are at least partially dependent on receiving representative samples and the provision of a complete diagnostic service, including pathology, which they presently lack (R. Lewis, pers. comm.).

The ability of MAFF to evaluate the significance of disease of farmed salmon depends to a great extent on the information provided by the Fish Health Veterinarian (R. Lewis, pers. comm.). The role of the Fish Health Veterinarian is to cooperate with private veterinarians and industry to identify those diseases and health issues which cause significant losses and have an impact on the viability of the industry as well as those of importance to animal welfare and public health. In 1994/1995, 66 of 88 (75%) licensed sites, including hatcheries, lake rearing operations and all seawater sites, were visited by the Fish Health Veterinarian. A similar number of sites were visited in 1993/1994 (J. Constantine, pers. comm.). Decreased fiscal resources and increased emphasis on specific health issues have been cited as reasons for a reduced number of site visits in 1996. This veterinarian can be involved in routine site inspections that are part of the duties of the aquaculture licence. During a visit, the Fish Health Veterinarian has the opportunity to review farm health records, review farm disease control practices and procedures, identify specific health concerns and discuss disease control recommendations with the farm's regular veterinarian and/or fish health staff. The farm's regular consulting veterinarian accompanies the provincial veterinarian on approximately half of the visits, thus facilitating communication and providing the provincial veterinarian with knowledge of the site's recent medical history. These visits are sometimes made at the request of the consulting veterinarian in response to a particular fish health issue, as part of ongoing health programs, or for specific disease outbreaks. However, many of the visits with private veterinarians are scheduled to gather information on the farm's stock health and to discuss health and disease management on site. The information gathered on these visits is used by the Ministry to; (1) identify gaps in knowledge of specific health issues, disease management and diagnostic needs; (2) identify ways the Ministry can facilitate access to information or assist in disease management and (3) provide the Ministry with knowedge of the disease concerns in the industry. The Fish Health Veterinarian produces monthly and annual reports that summarize her activities and communicates them to others in the Animal Health Branch.

The Fish Health Veterinarian assisted in the investigation of ten disease outbreaks (unusual levels of disease or mortality or a problem in the management of stock on farms) since 1993 (1993/94, n=3; 1994/95, n=5; 1995/96, n=2; see Table 5). The ministry's role in outbreak investigations involves site visits, diagnostic evaluation when required, review of health records and practices, provision of information and recommendations on disease control, and enforcement if required. Of the five outbreaks investigated in 1995, only one required additional diagnostics and follow-up investigation. The Fish Health Veterinarian was also involved in the investigation and response to cases of antibiotic resistant furunculosis. Some details of this investigation are given to illustrate the role of MAFF in disease investigation. In 1993/94, this disease was considered one of the most important facing the industry. Problems were experienced on a few farms with furunculosis that was not responsive to licensed and available antibacterial drugs. The Fish Health Veterinarian assisted in describing and confirming this problem through a focussed sampling program. A deficit in diagnostic capabilities needed to address this issue was identified, and additional staff training was provided at the AHC. The ministry then was able to act as a reference laboratory for the province and to become involved in studies of the efficacy of alternative therapeutic options. Continuing education programs were developed and provided to fish farmers to improve their ability to prevent and control the disease. Efforts were also made to improve the understanding of the effects of this disease on farmed fish. With the application of immunization programs, the incidence of furunculosis decreased. This was seen in reviews of farm records, reduced numbers of laboratory submissions and interviews with veterinarians (J. Constantine, pers. comm.). The ministry does not provide this level of support for all disease outbreaks in fish farms, but only to those brought to its attention by consulting veterinarians, government staff or the public.

The ministry is also actively working to improve methods for the diagnosis and management of infectious hematopoietic necrosis, bacterial kidney disease, mouthrot (a form of myxobacterial infection), *Kudoa* and rickettsiosis. As part of its disease control efforts, since 1993 the ministry has organized four educational workshops for industry regarding the occurrence and control of *Kudoa,* furunculosis, mouthrot and infectious hematopoietic necrosis. The role of the Fish Health Veterinarian also includes monitoring the use of drugs on farms, reviewing treatment records on farms reviewing and evaluating reports from licensed medicated feed manufacturers. These activities allow this person to review the types of medication being used and the diseases being treated. The lack of a computerized database makes this effort cumbersome and precludes a frequent review of drug use. The review of medicated feed records described later in this report required more than two months to be completed.

The province has no structured programs intended to prevent or control diseases of farmed salmon other than educational workhops. Instead, they rely upon the Fish Health Veterinarian to react to emerging problems. This is unlike other agricultural industries in the province for which herd health and quality management programs have been developed and/or administered by the province. MAFF also has, in cooperation with other ministries, developed programs intended to reduce the risk of disease transference of domestic species to wildlife. One example is their flock health program for sheep grazing on logged land.

In response to the province's Salmon Action Plan, MAFF had begun to develop a Disease Monitoring and Reporting program for salmon aquaculture in 1995. The Fish Health Veterinarian developed this program in consultation with the province's Chief and Assistant Chief Veterinarians as well as with the Ministry of Environment, Lands and Parks (MELP). Discussions with participants in this program revealed a number of key reasons why the program has not been launched despite its completion and approval within MAFF and its initial industry support. First, in response to an alleged release of confidential information by a government agent, the industry became concerned that sufficient safeguards against the release of confidential information were not in place and thus withdrew its support of the project. Second, philosophical and jurisdicational differences prevented MAFF and MELP from reaching a clear consensus on the objectives and design of the program and the use of the information derived from it.

Legislation in New Brunswick requires that holders of a fish farm licence maintain records of diseases and mortality on their farms and that these records must be made available to government agents. In addition, they require that a written report of the results of any diagnostic test or the performance of any drug treatment be submitted by the licensee to the Ministry in a timely fashion. Conversations with New Brunswick's Fish Health Veterinarian indicated that compliance with these requirements is low and few reports are received by the ministry (J. Mullens, pers. comm.). In addition, reports may not be received quickly enough to allow for government involvement in an immediate response. Currently, a committee has been struck in New Brunswick to review the Fish Health Guidelines in their *Aquaculture Act*. This lack of compliance with reporting requirements is consistent with experience in other food animal industries where, unless coupled to disease control programs or compensation, compliance with requirements to report diseases is often poor. In Norway, diseases that are exotic or considered serious threats must be reported to the Norwegian Animal Health Authority, which can be considered equivalent to Agriculture and Agri-Food Canada. Summaries of disease reports are publicly released on a national level but not on a site-specific basis. The Norwegian Animal Health Authority has a much larger cadre of veterinarians available to assess fish health issues than is present either nationally or provincially in Canada.

The Ministry of Environment, Lands and Parks' involvement in fish health primarily involves the Fish Culture Section of the Fisheries Branch. The Wildlife Branch does have a veterinarian on staff, but this person is not involved in fish health issues. The primary role of the Fish Health Section's Fish Health Biologist is to provide health and diagnostic support to the province's enhancement projects which involve inland fish species (although some, such as cutthroat trout, can have a marine phase in their lifecycle). This section provides diagnostic support for wild non-marine fish, but this is a very small proportion of its workload. The province maintains a separate fish health database at the Pacific Biological Station.

Federal government

The Department of Fisheries and Oceans has the responsibility of protecting and conserving wild fish stocks. This department has internationally recognized expertise in its Fish Health and Parasitology Section at the Pacific Biological Station in Nanaimo. This facility provides diagnostic support to federal salmon enhancement program through its Fish Pathology program. This department is also responsible for investigating and managing health problems in wild fish; salmonid and non-salmonid. Investigations of disease problems in wild fish are rare. Results of diagnostic tests performed by the Fish Pathology Section are recorded in the federal Fish Health Database, which creates a longitudinal record of diagnostic works in a searchable form. As there is no veterinarian on staff, this agency does not have the legal authority to provide diagnoses to private citizens or industries. However, because of the expertise at the Pacific Biological Station, this facility often assists industry representatives or veterinarians in the investigation of new or unusual disease occurrences in farmed salmon.

Unlike at the beginning of the B.C. industry, the Pacific Biological Station no longer offers routine diagnostic support to salmon farmers. Instead, it is restricted to enforcing importation and quarantine regulations under the federal Fish Health Protection Regulations. This includes housing Local Fish Health Officers (with their associated training and laboratory support), the certification of farms for export, and monitoring the health status and quarantine of imports. Therefore, this organization is wellsuited to tracking the introduction of new diseases or agents into B.C. Results from Local Fish Health Officers are forwarded to the National Registry of Fish Disease in Ottawa. This keeps track of annual reports from Local Fish Health Officers from across the country as well as federally reportable disease incidences associated with the Fish Health Protection Regulations.

The Pacific Biological Station is involved in numerous fish health research projects including a recently initiated program to explore potential disease interactions between wild fish and farmed salmon at sea. The station has provided substantial information over the years regarding the mechanisms and management of diseases of salmon. As there is significant overlap between the diseases of enhanced, farmed and wild salmon, the results of this research have provided significant information for the industry. Results of the research are presented in the scientific literature as well as at periodic local, national and international workshops and conferences.

The other potentially important piece of federal legislation that is relevant to this review is the *Health of Animals Act.* Administered by Agriculture and Agri-Food Canada, this Act and its regulations deal with the control of diseases and toxic substances in animals. It is primarily applied to diseases of national importance, which are often identified by their trade implications or pubic health significance. Through this Act, the federal government has developed detailed procedures and policies for monitoring and controlling animal diseases. These can include import/export inspections, quarantine, slaughter, mandatory treatments, disposal of dead and diseased animals, compensation mechanisms and disease reporting requirements. This Act has disease control procedures that are more risk management based and more detailed than those of the Fish Health Protection Regulations, which are the main federal legislation applied to fish disease. Although fish are not excluded from the *Health of Animals Act*, to date it has not been applied to fish. Therefore, there is no federal duty to report fish diseases under this Act. In addition, the Department of Fisheries and Oceans does not have any disease control or prevention programs targetted at privately farmed fish other than imports in B.C.

Academic institutions

Three of Canada's veterinary schools have some involvement in B.C.'s salmon farming industry: the Western College of Veterinary Medicine, the Atlantic Veterinary College and the Ontario Veterinary College. All three offer research support to the industry, but only the latter two routinely provide diagnostic services. In fact, these two veterinary colleges are major sources of diagnostic support to the industry. They can provide a full spectrum of diagnostic services from pathology to microbiology to toxicology. In interviews with the Association of Aquaculture Veterinarians of B.C., when supplemented with local and international resources, these facilities meet the current diagnostic needs of the industry. Once again, results of tests conducted at these facilties are viewed as the property of the client (farmer) and are thus confidential.

None of these institutions provide health extension services to the B.C. industry. The Western College of Veterinary Medicine (which receives partial funding from the B.C. government and is viewed as the province's veterinary college) has no post-graduate residency programs in aquaculture. Instead, aquaculture involvement has been restricted to post-graduate research training in epidemiology. Research involvement by the veterinary colleges has been focussed primarily upon specific disease issues although there has recently been increased involvement in clinical trials to assess disease management strategies.

IV. MOVING PATHOGENS AND PARASITES: THE INTRODUCTION OF EXOTIC DISEASE

A. INTRODUCTION AND DEFINITION

People have long practiced the deliberate movement of fish from one body of water to another. Welcomme (1988) describes three main waves of fish transfers in recent history: (1) salmonid introductions for sport fishing in the late 19th and early 20th centuries, (2) the movement of tilapiine chichlids for aquaculture and fisheries from 1950 to 1970, and (3) movements of Chinese carp from 1970 to the present. Canada and the United States have a history of large-scale movements of fish through their conservation and enhancement programs. Literally billions of fish have been distributed to thousands of lakes, streams and rivers throughout North America. The needs of aquaculture also provide incentive to move fish between and within watersheds and zones. The development of an Atlantic salmon farming industry in B.C. has been founded upon stocks imported from jurisdictions outside of B.C. As the transfer of pathogens is seen as one of the major disadvantages of fish movements (Munro, 1988), the introduction of species of fish exotic to this province has generated anxiety about the introduction of new diseases.

It is essential to differentiate the term exotic from previously unrecognized. **A pathogen can be considered exotic if it does not normally reside in a particular area and/or the population of concern has no previous experience with it.** This is a somewhat unsatisfying definition as it does not take into account variations in efforts to document previous exposure or experience and does not have a time period associated with it. Once a pathogen is introduced, a population will have experience with it and thus it can no longer be considered exotic. An example of this is smallpox virus in humans. This was originally exotic to the Americas but over a short time became an indigenous pathogen that circulated in the human population. The designation of a pathogen as exotic must therefore include a description of the geographic bounds, time frame and population of concern. Unique physical or biological parameters may result in a particular pathogen being exotic to fish in one watershed, while indigenous to fish in another (Halvorsen and Hartvigsen, 1989). Whether or not a pathogen is designated as exotic is often based on political and not biological boundaries.

An exotic disease need not come from another country. Pathogens do not recognize political boundaries. Even within the same country, movement of pathogens between close geographic locations but different watersheds may allow for the introduction of a new disease causing organism. For example, the pattern of spread of whirling disease in the United States follows watershed boundaries rather than state lines (Horsch, 1987). Similarily, the description of the biogeography of *Gyrodactylus salaris* suggests that the belief that Norway (as defined by political boundaries) was once free of the parasite did not consider the biological and geological history of the region (Halvorsen and Hartvigsen, 1989).

It is important when determining the geographic movement of a pathogen or parasite to account for the movement of the population or changes in efforts to detect the agents or diseases in question. An example of this consideration is the case of marine anemia in farmed chinook salmon in B.C. Diagnoses of marine anemia were initially restricted to Sechelt Inlet. Within a few years, the disease was diagnosed in every major chinook farming region in the province. Some concluded that this expanding range of marine anemia was evidence of a new pathogen of farmed fish that was spreading throughout the province. When the demographic changes in the population were evaluated in conjunction with patterns of submissions to diagnostic laboratories, it was shown that the apparent spread of marine anemia was due to increased surveillance efforts in new regions that accompanied the growth and expansion of the industry (Stephen and Ribble, 1995). Through increased monitoring efforts, it was shown that marine anemia was more likely an endemic indigenous disease seen in both wild and farmed species rather than a spreading epidemic of a new pathogen (Stephen and Ribble, 1996b). Regulations to restrict the movement of pathogens and parasites must, therefore, consider the ecology and demographics of at risk populations and must be developed in cooperation with neighbouring provinces and states.

Time factors must also be considered when trying to classify a pathogen as exotic. It is unknown if new pathogens were introduced to the province or if the geographic range of old ones increased via earlier restocking programs in B.C. (Hoskins *et al*, 1976). The pattern of diseases and distribution of pathogens in B.C. today, may not reflect historical disease ecology. The case of gyrodactylosis in Norway illustrates this point. Wild salmonids in Norwegian rivers have in recent years been found heavily infested with *Gryrodactylus salaris*. Early in the investigation of this outbreak, a connection was made between the distribution of this parasite in Norwegian rivers and deliveries of stock fish from certain hatcheries or with the accidental spill of imported smolts in Norwegian waters (Johnsen and Jensen, 1991). The importation of infected fish from Sweden to a Norwegian hatchery was thought to have allowed the parasite to pass its normal geographic boundary, the Scandinavian mountains, and reach a new area (Malmberg, 1989). Dissemination of these fish coupled with the supposed total susceptibility of Norwegian salmon was thought to have allowed the parasite to spread rapidly and to cause mass mortalities. This hypothesis failed to consider the biogeographic or historical aspects of the parasite or the salmon populations. The lenthy duration of the fish-parasite relationship, the immigration history of salmon in the region, the close proximity of watercourses and the long history of moving fish between watersheds led Halvorsen and Hartvigsen (1989) to hypothesize that *Gryrodactylus salaris* was indigenous to Norwegian waters. The patchy distribution of fish parasites coupled with the low intensity of fish diseases surveillance resulted in these authors concluding that it was to be expected that this parasite would not be discovered in all salmon rivers even if it was endemic. However, the available evidence neither proves or disproves either of the hypotheses, endemism or introduction.

B. CONCERNS REGARDING IMPORTATION OF PATHOGENS OR PARASITES

There are several instances where the movement of fish from one region to another has been blamed for changes in the occurrence of fish diseases. The movement of fish associated with re-stocking and conservation programs has been, in the opinion of Klontz (1988), the main mechanism for the movement of fish pathogens and parasites throughout North America and beyond. Recently, examples of disease emergence in Norway have been used to illustrate the potential risks of introducing disease into B.C. with fish importation. The original detection of furunculosis in Norway was associated with an importation of rainbow trout from Denmark (Heggberget *et al*, 1993). The movement of smolts from Scotland to Norway in 1985 is thought to have brought with it a variant of *Aeromonas salmonicida* not previously believed to have existed in Norway. Increased detection of this disease in wild salmon followed both of these events (Heggberget *et al*, 1993). Conclusions regarding the impact and relationship of furunculosis of cultured fish to wild fish in Norway are polarized in public and scientific circles. The movement of *Yersinia ruckerii* into Norway with shipments of post-smolts from Finland and the possible introduction into that country of a non-indigenous strain of the parasite *Gyrodactylus salaris* with Swedish smolts are other notable examples (Munro, 1988). In the latter case, extensive programs of poisoning streams to eliminate infected fish was utilized as a control measure, resulting in large economic and biological costs. In Sweden, some believe that the “typical” *Aeromonas salmonicida* found in that country is not a ubiquitous species, but is derived from aquaculture (Wichardt *et al*, 1989) and conclude that the organism could be traced back to importations.

All of the examples found linking disease outbreaks with movements of fish relied largely on three of the criteria for causation listed in Appendix B. The co-occurrence of fish introductions at the same time, or shortly after the discovery of a new pathogen in a region is the principle evidence used link the events. For example, although imported eggs were considered to be the source of furunculosis in Sweden, there is no direct proof as the eggs were not subjected to microbiological examination. Instead, the causal relationship was established on historical findings regarding the occurrence of disease following the importation of possibly inadequately disinfected eggs (M. Thorburn, pers. comm.). Two subsequent findings of this disease in Sweden were however either linked epidemiologically to the first farm, its river, or other imports (M.Thorburn, pers. comm.). Unfortunately, reports available for review generally failed to discuss incubation and latent period for infections, nor the time delays in movements of fish or water when developing hypotheses regarding the relationship of disease spread with the introduction of fish. A critique of the expansion of a suspect exotic pathogen in Norway illustrated the importance of considering different time scales when investigating exotic diseases (Halvorsen and Hartvigsen, 1989). The second causal criterion that has been used is biological plausibility. Based on fundamental principles of diseases ecology and an understanding of the dynamics of the exotic pathogens, it is often assumed that an exotic pathogen could be moved along with fish or their products. The final piece of reasoning used to relate outbreaks of exotic disease with fish transfers is that of historical consistency. As a relationship between host movement and disease spread has been described or hypothesized in fish and other species in the past, it has been concluded that it could happen again. Great care must be taken to identify circular reasoning when evaluating past reports of exotic diseases. In many of the reports of possible outbreaks of exotic diseases, authors concluded that a pathogen or parasite had been introduced because of the presence of an unusual epidemic and used the occurrence of the epidemic as evidence that the pathogen was introduced. The following discussion illustrates that there are other factors that must also be considered when categorizing a pathogen or parasite as being exotic to a region. Despite these limitations in casual evidence, several agencies such as the North Atlantic Salmon Conservation Organization and the International Council of the Exploration of the Sea feel that the importation of non-indigenous anadromous salmon pose particular risks to wild stocks. This belief has been shared by members of the public as well as by some senior fisheries biologists and managers in the province.

C. EVIDENCE OF EXOTIC DISEASES OR PATHOGENS IN B.C.

A recent review of federal fish health records concluded that there have been no known outbreaks of diseases in B.C. that are certifiable under the Federal Fish Health Protection regulations traceable to the movements of fish or eggs that were authorized under the regulations over a 15-year period in Canada (Carey and Pritchard, 1995). Certifiable diseases include viral hemorrhagic septicemia, infectious hematopoietic necrosis, infectious pancreatic necrosis, any filterable replicating virus causing cytopathogenic effects, whirling disease, ceratomyxosis, enteric redmouth, and furunculosis. Several diseases of concern listed in the Fish Health Protection Regulations, including furunculosis, bacterial kidney disease, enteric redmouth, and infectious hematopoietic necrosis, have historically occurred in wild and cultured fish in B.C, but have not been detected in other provinces or territories (Carey and Pritchard, 1995). Systematic disease surveys conducted in B.C. and Washington state have failed to reveal diseases exotic to the Pacific Northwest (Brackett and Newbound, 1990; Brackett *et al*, 1990; Brackett *et al*, 1991; Elston, 1994). However, submissions to this review revealed that operators of the enhancement facility serving as our case example concluded that the outbreak of furunculosis in their facility may been caused by the introduction of an exotic strain of organism.

During the discussion that followed the cluster of furunculosis in our case study, it was suggested in letters to officials at the Department of Fisheries and Oceans that the strain of *Aeromonas salmonicida* associated with this case had possibly arrived in Canada with imported farmed Atlantic salmon. Although this pathogen is widely distributed through B.C. marine waters and had historically been reported in wild salmonids in the province (McCarthy and Roberts, 1980), it was suggested that the occurrence of antibiotic resistant strains in the Broughton Archipelago coincided with the introduction of new strains of the pathogen with imported Atlantic salmon. As discussed in Section III, the antibiotic resistance patterns of strains isolated from enhanced coho and farmed Atlantic salmon during the outbreaks were sufficiently different for the Department of Fisheries and Oceans investigators to believe that the strains were not of the same origin. However, there were significant time lags (five months) between evaluation of isolates from the enhanced stocks and isolates from the farm outbreak. Alone, antibiotic resistance patterns are not capable of definitively establishing the source of an organism, particularly if there has been a prolonged time between sample collections. To help characterize the strains of

Aeromonas salmonicida involved in this case, investigators at the Pacific Biological Station forwarded bacterial isolates from these and other sources to federal laboratories in Halifax for biophage typing. A variety of types were identified, none appearing different than what had previously been isolated in B.C. Ten isolates from the hatchery were tested and seen to belong to the same strain (lysotype H) regularly isolated in B.C. (D. Kieser pers. comm.). Two other pieces of information led investigators to conclude that this was not a case of importation of an exotic strain of this pathogen. First, this pathogen is not considered to be vertically transmitted (Kent, 1992). Second, there were no records of fish being imported from the source implicated in Scotland (D. Kieser pers. comm.). However, in 1993 DFO investigators did not examine fish that had not been treated or fish taken from the river. Therefore, it was not possible to determine if fish returned to the river carrying this organism or if they had been exposed at the hatchery. Finally, it remains controversial as to the best method for differentiating strains of *Aeromonas salmonicida* in a sensitive enough manner to reach conclusions regarding the routes of spread of the disease. Even if we were able to demonstrate that the strains were the same, it would not be possible, given the other information available for this case, to definitively conclude that one population infected the other (M. Thorburn. pers.comm.). The ultimate source of organisms in this outbreak therefore remains unresolved. As most routinely cultured fish pathogens are not regularly evaluated for molecular markers such as serotypes or biotypes, it often not possible to conclude on the basis of molecular epidemiological evidence whether or not a new strain of an indigenous pathogen has entered the province through the importation of fish.

A single isolate of an infectious pancreatic necrosis-like virus was made in B.C. in 1989 from a group of Atlantic salmon post-smolts. As this virus is prevalent in pen-reared Atlantic salmon in Norway and can be vertically transmitted (Kent, 1992), this finding was considered by some to be evidence of the importation of an exotic pathogen from Europe. Tests conducted on the isolate indicated that the strain was most similar, but not identical to a strain of the virus previously isolated from brook trout in Jasper (Kieser *et al*, 1989). Experimental challenges with the isolate were unable to induce disease in fry of chinook, coho, Atlantic salmon and rainbow trout, thus leading investigators to conclude that the isolate should be more appropriately identified as another birnavirus (the family to which infectious pancreatic necrosis virus belongs) rather than infectious pancreatic necrosis virus itself. There has been no other isolation of a similar virus in B.C. since 1989 (Carey and Pritchard, 1995; Carey pers comm October, 1996).

Despite the lack of evidence of introduction of exotic pathogens or parasites due to commercial aquaculture activities in B.C., it must be recalled that risk is defined not only by probability but also by the adversity of the possible outcome. Although the likelihood of introduction of exotic pathogens appears to be very low, the potential for adverse effects for both the aquaculture industry and wild stocks demands that we remain vigilant.

D. INTRODUCTION OF EXOTIC PATHOGENS AS A SUFFICIENT CAUSE OF IRREVERSIBLE ADVERSE EFFECTS

Pathogen transfer as a sufficient cause of irreversible damage

Species, including pathogens, have always moved around the globe. This is evidenced by the global distribution of a number of disease causing agents. Either the same species of microorganisms co-evolved in different locations over time, or they were distributed from their origins. With the advent of human intervention, the rate of movement has increased and normal geographic barriers to movement have been overcome. Hoffman (1970) found that at least 48 freshwater parasites could be linked to the movement of fish. However, with the exception of a monogean parasite that was moved from the Caspian to Aral Sea, 47 out of 48 of these translocated parasites continued to cause problems only in hatcheries and farms after their introduction to a new region. It remains unclear how many of these 48 parasites became established in their new niche. No pathogen or parasite is known to have resulted in the extinction of any species. Yet, significant initial mortality rates due to novel infectious diseases in local populations have been described. The most commonly cited examples involve the movement of fish into Norway and the associated changes in the rate of detection of *Gryodactylosis* and furunculosis in wild stocks.

When reviewing reports of new or imported diseases, it is important to isolate the effects of the exotic microorganism from the effects of efforts to control that microorganism or from natural fluctuations in population numbers. The case of *Gyrodactylus* in Norwegian rivers illustrates this point. Reviews of population trends indicated that the salmon populations had recently experienced a peak in number and density, and that they were in decline before the parasite was implicated as a negative population regulating factor (Halvorsen and Hartvigsen, 1989). *Gryrodactylus* was detected rather late in the declining phase of the population expansion. It is unknown if the lack of previous detection reflects a recent introduction of the parasite or inadequate disease surveillance. In response to the detection of the parasite, officials implemented a parasite control program consisting of killing all fish in the river through the introduction of the chemical Rotenone. It therefore becomes very difficult to determine the true impact of the parasite against the backdrop of drastic control efforts and natural population fluctuations. Similarly, confounding effects of high densities, high temperatures, low water flows and aggressive interactions at spawning have prevented researchers from determining the nature and magnitude of negative impacts that furunculosis places on wild fish in Norway (Johnsen and Jensen, 1994). The true effects of these diseases on wild salmon populations in Norway continue to be debated.

It can be assumed that infectious agents have been moved without detectable effect. As the usual reason for investigating the presence of an introduced pathogen is the occurrence of unusual patterns of death or illness, investigations are unlikely to be initiated where pathogens do not cause detectable effects in populations of concern. This problem is compounded by the general lack of disease surveillance programs for wild fishes. Reports of fish or other animal movements that have not resulted in adverse effects are undoubtedly underrepresented in the literature due to publication biases (the tendency for scientific journals to not publish negative findings) (Sackett *et al*, 1991). This possiblility does not advocate the careless movement of fish and their associated pathogens or parasites, but does indicate that movement of species does not guarantee movements of infectious agents which cause measureable adverse health effects.

Exposure to exotic pathogens can occur when fish are moved to waters in which they have not previously resided. This involves moving the fish to the pathogen rather than the pathogen to the fish. The significant history of fish transfers in recent years has provided an opportunity to assess the ability of native fish to withstand the challenge of exotic pathogens. For example, Pacific salmon (primarily chinook) have been transplanted to the Great Lakes region, an area to which the fish were exotic. Transplanted fish were exposed to a spectrum of pathogens or parasites to which they had not evolved specific defence mechanisms. Today, the population of Pacific salmon in the Great Lakes flourishes despite opportunities for these fish to be exposed to novel pathogens and parasites. This example illustrates that exposure of fish to unique microbial and parasitic flaura does not predetermine significant outbreaks of disease. However, this example does not serve as a basis upon which to conclude that the movement of fish is without effect particularly since the pathogen characteristics of the Great Lakes has not been completely characterized.

Disease dynamics—the pathogen perspective

From a pathogen perspective, the world is divided into two types of hosts: susceptible and immune. In order for a pathogen to result in an epidemic, a threshold proportion of susceptible hosts must be exceeded (Scott and Smith, 1994). The term epidemic must not be confused with the severity of the disease. An epidemic is simply the occurrence of a disease at a rate higher than normally expected. An epidemic disease may not result in serious illness or death. The nature of the impact in terms of morbidity and mortality will depend upon the virulence of the organism and the susceptibility of the population. The exact size of the threshold that must be exceeded to initiate an epidemic will vary with disease. Threshold levels are not established for fish pathogens. As a general rule, a disease is better able to spread in populations that are entirely susceptible than in populations where immunity exists as immune individuals act to break the transmission cycle (Scott and Smith, 1994). For populations without previous exposure to a pathogen, the majority of the population will likely be susceptible, therefore the probability of an epidemic is higher than for populations with experience, and thus some level of immunity. This may not hold for all pathogens, such as *Renibacterium salmoninarum*, where repeated exposure may lead to immunological tolerance and thus increased disease effects (L. Brown, pers. comm.).As fish have general or innate means of defence against infectious agents, not all new pathogens will result in epidemics or severe outcomes. In addition, it is uncommon that susceptibility or exposure is randomly distributed in a population. More often, pathogens and diseases do not follow the general distribution of the population, but will cluster. Despite published reports of severe outcomes arising from the introduction of an exotic pathogen, variation in disease dynamics make it difficult to predict the outcome of exposure of a native population to a specific agent. Even knowledge of the virulence of the exotic pathogen is insufficient to predict population impacts as a wide variety of ecological factors will affect the ability of the pathogen to spread, become established and be maintained in the new population.

Co-evolution of host-pathogen relationships

Depending on the nature of the host and pathogen, populations exposed to exotic diseases may be able to rapidly evolve in response to the disease challenge to the point where the pathogen no longer is able to devastate the population. It is a general epidemiological tenet that over time, the relationship between a pathogen (or parasite) and a host changes from one that favours the pathogen (disease) to a more commensal state (Martin *et al*, 1987). Given a stable environment, the disease changes from epidemic to endemic to sporadic. In the United Kingdom, cases of furunculosis in wild fish peaked at the beginning of the century and now occur at a low level (Heggberget *et al*, 1993). A similar pattern has been seen in fish in some Norwegian rivers affected with this disease level (Heggberget *et al*, 1993). This has been taken by some as evidence of adaptation of the population to the pathogen.

For many, but not all, pathogens death of the host rarely favours the pathogen's spread; thus fewer pathogenic strains are at a survival advantage. The co-evolution of feral rabbits in Australia to the myxomatosis virus is a well-documented example. It is presented here to illustrate the dynamic nature of exposure to exotic agents. As part of a biological control program, an exotic virus from Brazil was "let loose" in the Australian rabbit population. Due to lack of previous exposure to this virus, it was anticipated that the population would be fully susceptible to the lethal effects of the virus. After three years of exposure, it was estimated that the size of the rabbit population had been reduced by 80-90% (Martin *et al*, 1987). However, within several years, the proportion of exposed rabbits that died began to decrease. Selection for offspring with innate resistance and the co-evolution of a less virulent form of the virus resulted in a diminution of population effects over a relatively short period of time. By 1996, there were around 300 million wild rabbits in Australia (Anderson, 1996). Currently, the Australian government has found it necessary to release a second biological control, the rabbit calicivirus, to once again deal with the expanding rabbit population. This example illustrates the ability of populations to recover from a disease over an appropriate time scale and should be considered when estimating risks of exotic pathogen introduction. Because of differences in their reproductive abilities and natural history, one cannot generalize that a similar response to the introduction of an exotic agent would follow for wild fishes in B.C. Anticipating the possible effects of an exotic virulent agent would require detailed knowledge of the population and identification of factors that would prevent population recovery. In the case of myxomatosis, it is not anticipated that the calicivirus alone will be able to rid Australia of rabbits (Anderson, 1996). An additional program to destroy rabbit burrows and habitat will also be required. Populations that are compromised by concurrent limiting factors such as habitat destruction or food limitations can be anticipated to be more susceptible to the effects of an exotic pathogen compared to uncompromised populations. Although no examples of exotic pathogens destroying a species could be found, negative impacts on local populations within a specific time frame, as seen in the above example, are biologically plausible. Evolution towards benign infection does not hold true for all pathogens or may not occur over a time period compatible with the adaptation of the exposed population. As we lack information with which to predict the effects of the introduction of all exotic pathogens, relying upon the capacity of a population to adapt and evolve to a new infectious threat is not a workable management strategy.

E. NEW DISEASES AND AGENTS VERSUS EXOTIC DISEASES

A common problem in investigations of disease outbreaks is to separate the immigration of a new pathogen from the discovery of a new location for a local pathogen as the result of increased detection efforts (Stephen and Ribble, 1995). The ability to differentiate between a new immigrant parasite or pathogen and the detection of a new indigenous parasite depends heavily on our pre-existing knowledge of the diseases of local stocks. Knowledge of the diseases of Pacific salmon is limited compared to that of many terrestrial species, and our understanding of the pathogens and parasites of non-salmonid fishes and other marine and aquatic organisms is in its infancy. In the past, viral hemorrhagic septicemia virus was thought only to occur in Europe. Detection of this virus in Canada would, until recently, have been considered the discovery of an exotic pathogen. However, with the advent of new diagnostic tools and sampling efforts, an endemic North American strain of the virus was detected in enhanced populations of coho, chinook and steelhead in 1988 (Eaton *et al*, 1991), Pacific cod and Pacific herring in 1990, and recently in shiner perch and tubesnouts (Traxler *et al*, 1995). The North American strain has now been found in farmed Atlantic salmon in B.C. in 1995, almost a decade after its description in enhanced salmon stocks (Traxler *et al*, 1995). It is most likely that the Atlantic salmon acquired this virus from wild fish as it is unique to North America and occurs in regions where there are no salmon farming activities.

When discussing methodological problems in detecting *Gyrodactylus* in salmon, Mo (1987- cited in Halvorsen and Hartvigsen, 1989) noted that a very large number of fish would need to be examined before one would be sure that a pathogen is not present in a population. Thus it is easier to be convinced that a pathogen is present in a population than that it is absent. This complicates efforts to determine which organisms are exotic and which are newly recognized. With changing knowledge of pathogen characteristics and ecology, the classification of a pathogen as exotic or indigenous can change.

Often, a newly recognized virulent disease is used as evidence that the pathogen involved is new to the area. Survival strategies of pathogens are remarkably different. In some cases, it is to the advantage of a pathogen to kill its hosts in order to facilitate its distribution. Anthrax is an example of this where, although an endemic pathogen of Canadian wildlife, it is a highly virulent organism that kills virtually all of its hosts. Spores of the bacteria are released back into the environment through the process of decay and are picked up by another animal that disturbs the contaminated soil (LaForce, 1994). On the other hand, for diseases that are disseminated through eggs, such as bacterial kidney disease, it is to the pathogen's advantage to not kill its host before it matures and spawns. It is dangerous to assume that a pathogen is recently introduced or exotic based on the severity of the outcome without considering other host, agent or environmental factors, particularly demographic changes in the populations at risk and changes in efforts to monitor diseases over time.

While there is no evidence that an exotic disease has been introduced to B.C. by way of movement of farmed salmon, previously unrecognized conditions have been documented. Examples of this would include marine anemia and its associated salmon leukemia virus (Eaton and Kent, 1992), a seawater form of hexamitiasis (Kent *et al*, 1992), and new micropsoridian encephalitis (Brocklebank *et al*, 1995). As discussed above, the detection of viral hemorrhagic septicemia in B.C. likely represents the detection of a previously unrecognized endemic strain of the pathogen, rather than the introduction of the exotic one. There are several reasons why a disease may be indigenous but remain unrecognized. The first is the lack of surveillance of local species. As discussed throughout this text, few resources have been assigned to monitor diseases of wild stocks. Most effort has historically been focused upon looking at early life stages and returning spawning stages of enhanced fish stocks. Little information is available on the disease conditions of adult stages outside of hatcheries or for species not included in enhancement programs. Therefore it is not surprising that most of the previously unrecognized diseases reported for salmon farms have been detected in fish in grow-out facilities at sea, and not in commercial hatcheries.

The preceding discussion has illustrated the importance of distinguishing a newly described disease from an exotic disease as well as how it may be difficult to do so. Because of the ease with which farmed salmon can be observed, the intensity of diagnostic efforts targeted at these fish, and the lack of background information about their diseases, new parasites, pathogens and diseases will undoubtedly continue to be identified in cultured fish, whether at enhancement hatcheries or in commercial production facilities. Future management plans must include mechanisms through which new occurrences of disease in salmon in B.C. can be properly interpreted so that appropriate disease control actions can be initiated.

F. ROUTES FOR SPREADING PATHOGENS AND PARASITES

The water that fish live in serves many purposes. It provides the oxygen that the fish “breathes”, provides physical support, removes metabolic waste products, acts as a source and a sink for nutrients, and is the medium through which a fish communicates. It also serves to house and transmit a number of obligate, opportunistic and potential pathogens.

A pathogen can enter a fish by many routes. Because of their permeability, the gills, skin and gastrointestinal tract are all potential sites of pathogen entry. The gills have the thinnest membrane of these three areas and are constantly exposed to the water. Therefore, the gills are the route of entry of many fish pathogens including bacteria such as *Vibrio anguillarum* (Smith, 1982; Nelson *et al*, 1985; Budin-Laurencin and Germon, 1987), *Aeromonas salmoncida* (Tatner *et al*, 1984; Bruno *et al*, 1986), *Yersinia ruckeri* (Zapata, 1987) and possibly *Renibacterium salmoninarum* (Murray *et al*, 1992). Experimental evidence also shows that the gills are sites of entry for viral pathogens (Ahne, 1978; Chilmonczyk, 1980; Mulcahy, 1983).

Because of its acidity and digestive enzymes, the gastrointestinal tract is a less hospitable place for pathogens. However, many of the major fish pathogens can utilize this route to enter a fish. Two notable exceptions are *Aeromonas salmonicida* (Cipriano, 1982; Tatner *et al*, 1984; Perez *et al*, 1996) and *Vibrio anguillarum* (Chart and Munro, 1980; Kodera *et al*, 1974). This reduces the likelihood of wild fish being exposed to the agents of furunculosis and vibriosis by ingesting farmed fish feces or fecally contaminated materials. The gastrointestinal tract may, however, be a more important route of pathogen entry in larval fish in which acid secretions may not be as harsh or limiting (Evelyn, 1966). Of the three routes, intact skin is probably the most difficult for a pathogen to penetrate. However, when the skin is compromised through cuts, abrasion or illness, or if the protective mucous coat is damaged, it is much easier for a pathogen to take hold of its host. Several ectoparasites attack hosts not by penetrating but by living on skin or other surface membranes. A pathogen can also enter a host during egg development. A very small number of pathogens can be transmitted by the parent’s eggs or sperm to its offspring. *Renibacterium salmoninarum*, infectious pancreatic necrosis virus and possibly infectious hematopoietic necrosis virus are the three relevant to salmon culture in B.C. (Evelyn, 1996). In some cases, such as *Renibacterium salmoninarum*, the pathogen resides inside the egg. Compared to the relatively large number of pathogens or parasites living in, on or around a fish, vertically transmitted pathogens are rare.

As many fish pathogens have an environmental stage, they can be moved by moving some of the fish’s environment. This has been a concern regarding the international trade in crustaceans and shellfish that are often shipped live in waters taken from their home regions and for the trade in aquarium species (Munro, 1988; Anderson *et al*, 1993). The inclusion of invertebrates that may act as intermediate hosts or reservoirs for fish parasites or pathogens in shipments of live fish must be considered. Fish themselves act as important sources of parasites and pathogens. As discussed elsewhere, fish can carry disease causing organisms without demonstrating overt signs of disease. The stresses of transportation may be sufficient to cause an outbreak of a previously undetected infection in asymptomatic fish (e.g.; McCarthy and Roberts, 1980). Fish products, particularly those shipped in an unprocessed form, may also allow for the movement of pathogens. Fish meal used in commercial salmon feed contains fish products from regions outside of B.C., including South America. Because of concerns regarding possible importation of pathogens with contaminated fish meal, representatives from Agriculture and

Agri-Food Canada routinely inspect foreign sources of fish meal to ensure that the products are properly handled and treated. After a recent inspection visit to South America, Agriculture and Agri-Food Canada representatives were satisfied that the imported product did not present a risk to Canada (C. Mercier, pers. comm.).

Historically most, if not all, examples of movement of fish pathogens have been associated with the movement of fish as opposed to their gametes, embryos or food-products. The detection of *Gyrodactylus salaris*, new strains of *Aeromonas salmonicida* and *Yersinia ruckerri* in Norwegian salmon were associated with the movement of smolts. Similarly, the movement of fish within the United States has resulted in the expansion of the range of whirling disease (Hoffman, 1970; Horsch, 1987). There are instances where the importation of fish for aquarium display purposes has been implicated as a source for exotic diseases (e.g., Anderson *et al*, 1993; Humphrey *et al*, 1986). Similarly, baitfish can also serve to introduce pathogens into a region (Ostland *et al*, 1987; Carey, 1996). Because of the smaller number of vertically transmitted diseases, it is not surprising that pathogen movement via the movement of eggs or gametes is rarely documented. There are some indications, however, that infectious hematopoeitic necrosis virus moved from North America to Europe by way of contaminated and improperly disinfected eggs (Arkush *et al*, 1989; Yoshimizu, 1996).

Public concerns regarding disease introduction through the importation of eggs into B.C. were identified through input to this review. These concerns were apparently based on several lines of reasoning. First, eggs are the only route by which salmonids can be moved into B.C. Second, although methods of egg disinfection remove the vast majority of surface pathogens (99.9%), they are not 100% effective under all conditions (e.g., Goldes and Mead, 1995). Third, the large number of eggs that have been and can be imported into the province is felt by some to increase the probability that the unlikely event of pathogen importation could occur. Between 1985 and 1995, 10,964,000 Atlantic salmon eggs were imported into B.C. The number of imports peaked in 1988 and averaged approximately 762,000 each year in 1994 and 1995 (Winsby *et al*, 1996). Finally, it is difficult to completely quarantine fish once in sea cages due to the inability to regulate water flow and the possibility of fish escaping. Several letters of correspondence between private organizations and government agencies highlight these concerns. These letters reveal that, in general, neither the aquaculture industry nor environmental groups supported the concept of importing eggs at a production level. Representatives of the Department of Fisheries and Oceans, the Ministry of Environment, Lands and Parks and various aquaculturists recognized the need to continue to import eggs to support broodstock development programs. Disagreements arose as to what level of importation is required to meet this need.

G. REGULATIONS AND PRACTICES FOR REDUCING THE RISK OF MOVING DISEASES INTO AND WITHIN B.C.

The introduction of exotic diseases has been a long-standing concern in Canadian agriculture and fish management. Federal and regional policies dealing with disease control in fish and other animals lay down strict rules regarding the importation and movement of animals or their products within and between Canadian boundaries. In B.C., both provincial and federal Acts, regulations and policies govern the importation of fish into the province and their movement between and within provincial watersheds. Many of the international, national and regional regulations and policies pertaining to salmon aquaculture are concerned with limiting the movement and spread of infectious diseases and their agents. Most countries have some sort of regulation concerning the importation of living organisms across their borders. Such regulations are generally prohibitive, restricting or excluding the importation of specific life-stages or species. Most countries have some regulations that allow for the importation of certain species under specific conditions and permits. In general, international import policies outline sanitary conditions for travel, list specific diseases that would preclude movement, and often refer only to political boundaries (Welcomme, 1988).

Federal Fish Health Protection Regulations

Some of the fundamental regulations concerning fish importation are the Canadian Fish Health Protection Regulations (FHPR). These regulations have been cited as being among the world's model fish import regulations (Carey and Pritchard, 1995). However, a variety of senior provincial and federal fisheries managers have expressed concern that these regulations on their own do not adequately mitigate the risk of importing exotic pathogens into the province. Some of these officials hold the belief that continued importation of non-indigenous stocks would guarantee the introduction of exotic pathogens if the FHPR offered the only protective measures.

The FHPR were established under the federal *Fisheries Act* in 1977 in response to concerns that unhealthy fish released from public or private hatcheries could spread pathogens to wild fishes. These regulations are administered by the Science Branch of the Department of Fisheries and Oceans. The DFO has responsibility, under the Fisheries Act, for conserving and protecting Canadian fish stocks. The FHPR apply only to fishes of the family *Salmonidae* of the following genera: Pacific salmon (*Oncorhynchus* spp.), Danube salmon and Taimens (*Hucho* spp.), Atlantic salmon (*Salmo* spp.), Trout (*Salmo* spp.), Char (*Salvelinus* spp.), Grayling (*Thymallus* spp.), Lenok (*Brachymystax* spp.), Inconnu (*Stenodus* spp.), Whitefish (*Coregonus* spp.), Whitefish (*Prosopium* spp.) and Ayu (*Plecoglossus* spp.).

The regulations are designed to prevent the spread of infectious diseases through the inspection of production facilities' fish stocks and to control the movement of infected fish. They apply to live and dead cultured fish, eggs or unfertilized sex products of cultured or wild fish, and products of dead cultured fish (excluding heat processed canned products) destined to move into Canada or across provincial boundaries within the country. The principal mechanism for achieving the objectives of the FHPR is through certifying a facility that houses *salmonidae* intended to be transferred. The status of the certification determines if fish from the facility can be moved to other politically defined areas. Certification is based upon repeated testing of fish at a facility for the presence of specified pathogens. Four consecutive satisfactory inspections over a period of not less than 18 months must be made at a facility prior to certification. To maintain certification status, a facility must be inspected twice yearly at approximately six-month intervals. The regulations provide for a mechanism to establish specific pathogen-free zones within the country which can lead to modifications of the inspection requirements. The information about the absence of disease agents is needed to consider an area to be a disease-free zone is unspecified but described as "detailed".

All movements of fish into Canada and between provinces require a federal permit. The permits will only be issued to producers whose facilities have been inspected and certified free of designated disease agents. In addition, permits will not be provided unless the Local Fish Health Officer is satisfied that specific pathogens (Schedule IV diseases) will not be harmful to the protection or conservation of fishes in the province of importation. These conditions apply to exporting facilities outside of Canada as well as importing facilities within the country. Certification and movement permits are based upon the detection of the disease agents listed in Table 10. Fish cannot enter Canada except from a certified facility.

Schedule II agents apply to the inspection of live fish or their source. Facilities that test positive for Schedule II agents cannot be certified and can only move fish within provincial boundaries. Detection of these agents lead to de-certification of a facility. Schedule III agents apply to dead fish or their sources. Facilities that test positive for a Schedule IV agent in live fish or their source can get a certificate, but the Local Fish Health Officer (appointed through the *Fisheries Act*) can decide not to issue a permit if the protection or conservation of wild stocks is threatened by the movement of fish from the exporting facility. The regulations do not consider agents not listed in Schedules II to IV. The diseases listed in the FHRP represent diseases that were of concern or were emerging threats in the late 1970s in Canada. The only modification to date has been the movement of bacterial kidney disease from Schedule II to Schedule IV in 1987. This amendment was made in recognition that the agents causing this disease were widespread in cultured and wild salmon.

Table 10. Disease schedules of the Federal Fish Health Protection Regulations

SCHEDULE	**AGENTS**	**DISEASE**
II	*Myxosoma cerebralis*	Whirling Disease
	Ceratomyxa shasta	Ceratomyxosis
	Aeromonas salmonicida	Furunculosis
	Yersinia ruckerii (RM bacterium)	Enteric Redmouth
	Any filterable replicating agent capable of causing cytopathic effects in cell lines	Various viral diseases of fish specified by the Minister including but not restricted to:
	a) Viral Hemorrhagic Septicemia virus	
	b) Infectious Hematopoietic Necrosis virus	
	c) Infectious Pancreatic Necrosis virus	
III	Viral Hemorrhagic Septicemia virus	Viral Hemorrhagic Septicemia
	Myxosoma cerebralis	Whirling disease
IV	Myxobacteria	Myxobacterial infections
	Renibacterium salmoninarum	Bacterial Kidney Disease
	motile *Aeromonas* spp.	Motile Aeromonad Septicemia
	Pseudomonas spp.	Pseudomonal Septicemia
	Vibrio spp.	Vibriosis

The FHPR provide a Manual of Compliance that details testing, sampling and certification procedures as well as outlining procedures for egg disinfection. This guide describes how the suggested procedure should be conducted by local fish health officers or their delegates. The manual was revised in 1984, 1987 and 1992 to reflect changes in diagnostic tests, to clarify the role of Local Fish Health Officers and to modify testing recommendations to better reflect current knowledge on disease risks. The FHPR are currently being reviewed

Pacific and Atlantic salmon import policies

In addition to the FHRP, the importation of salmon into B.C. is subject to regional Atlantic and Pacific Salmon Import Policies. While the Pacific salmon policy is listed as a federal-provincial policy, the Ministry of Environment, Lands and Parks has not agreed to the current Atlantic salmon policy due to concerns over the lack of explicit numbers of Atlantic salmon eggs that can be imported into the province. Salmon cannot be imported into the province unless they comply with these policies. In general, both policies allow only surface disinfected fertilized eggs to be imported. The FHPR do not specify this requirement, but do strongly recommend the practice. Unfertilized eggs are only allowed under special research conditions, but live fish are not allowed to be imported. Both policies also state that the importations must comply with the FHPR.

The Pacific Salmon Import policy allows only for the importation of eggs of Pacific salmon species (chinook, coho, sockeye, chum and pink salmon) that are from broodstock that have resided in Canadian waters or waters off the continental United States for one full generation. The importation of Pacific salmon is permitted only for research or broodstock development programs. The maximum number of eggs imported for these purposes is limited to 20,000 per licence/year. The issue of the *North American Free Trade Act* has been raised in light of this policy in that the Act does not allow for limitations on the numbers of imports unless there is a biologically or scientifically defensible reason. Egg importation for production purposes can be granted in exceptional circumstances but requires the prior approval of the Director General, DFO Pacific Region and the Director of the Fisheries Branch, Ministry of Environment, Lands and Parks.

The policy for the importation of Atlantic salmon into B.C. focuses upon preventing the introduction of new disease agents or new strains of indigenous disease agents. The emphasis is upon agents that have caused significant economic losses in countries around the world with industries that depend upon the harvest of wild and cultured fish. Once again, importations are restricted to surface-disinfected fertilized eggs only. Exporting facilities and their broodstock must comply with the FHPR. All male broodstock must be lethally sampled and screened for viral diseases. If local eggs are fertilized with imported semen (milt), they are subjected to the same policies regarding sampling and quarantine. Eggs will only be allowed to be imported if the broodstock source has been in captivity for one full generation. Exporting facilities must be inspected by a Local Fish Health Officer within 15 days prior to receipt in B.C., have a program of regular fish health monitoring and documentation in accordance with the FHPR, have freshwater facilities that use a fish-free ground water supply and isolation areas for egg incubation, and provide access to complete fish health, mortality, pedigree and production records for the stock from which the exported sex products are derived. The acceptability of the facility as a source of Atlantic salmon eggs or milt is determined by the Local Fish Health Officer. No importations are allowed from facilities or sites in which a salmonid pathogen not known to occur in B.C. exists, in which there exists a fish pathogen considered by the Local Fish Health Officer as a problematic strain because of drug resistance or enhanced pathogenicity, or that do not take measures to prevent the movement, control or eradication of fish diseases of concern to B.C.

All imported Atlantic salmon eggs must be held in strict quarantine immediately upon their arrival in B.C. in an approved facility. Quarantine procedures are outlined in this policy. Effluent from quarantine facilities must be disinfected until all stocks under quarantine reach a size of 3 gms, but for a period no less than 120 days. This is followed by complete isolation of the imports from all other fish until they are introduced to sea. Discharges of all effluent must be "to ground" in an approved manner for the entire quarantine period. Thirty sick and dead fish must be tested every four weeks during quarantine by a DFO approved laboratory. Results of these tests must be reported to DFO within 48 hours. All mortality records and the results of routine or clinical testing carried out during the quarantine and isolation periods must be submitted every four weeks to DFO. An additional 120 fish must be examined per stock two weeks before their introduction to sea water. Additional testing can be required at any time by the Local Fish Health Officer. All dead fish must be placed in 10% formalin for a minimum of five days before removal from the quarantine site and no live fish can be moved off site until they have met the quarantine requirements and written permission be received from the Local Fish Health Officer. The importers bear all costs of the inspection, fish testing and hydrologic surveys required for planning effluent discharge. Importers must enter into a legally binding contract with DFO regarding design, operation and monitoring of their facility. If a disease agent of concern to DFO is detected in the quarantine and isolation periods, all stocks at the facility must be destroyed and the facility disinfected. All requests for importing live Atlantic salmon eggs must be addressed to the Federal-Provincial Transplant Committee described below. As with the Pacific Salmon Import policy, NAFTA issues have been raised in response to this policy. The limitation to eggs only has been challenged, despite supporting evidence for this policy, and restrictions on numbers of eggs imported could be challenged.

Limitations of current policies regarding disease importation

The FHPR are federal regulations and thus not subjected to review in this environmental assessment. However, as regional and provincial policies regarding fish movement utilize the FHPR as a foundation, it is important to consider their limitations. The Canadian FHPR only apply to facilities wishing to transport salmonids across provincial borders. Therefore, they do not recognized potential risks for pathogen importation through the movement of non-salmonids such as ornamental, bait or live food fish into Canada. Regulations concerning the movement of salmon within B.C. are discussed below. The variety of national, regional and provincial policies regarding fish movement has led to some confusion on the part of salmon producers, regulators and the public. Perhaps the most significant limitations of the FHPR are that they allow for considerable interpretation on the part of the Local Fish Health Officer and that they focus upon pathogen identification instead of risk management. Standardized risk assessment protocols are not available in the FHPR or its Manual of Compliance. Although diagnostic tests and protocols are recommended, their use is at the discretion of the Local Fish Health Officer. No information regarding the clinical performance of the tests (false positive and false negative ratios and predictive values) nor the quality assurance and control procedures that must be undertaken are given to ensure that testing is done in a systematic, standardized, repeatable fashion. The current FHPR assume that tests are 100% sensitive and specific. Sampling strategies do not take into consideration changes in the predictive value of diagnostic tests with changes in the prevalence of the disease, nor do they consider the effects of using samples from populations as a means to determine the disease status of the population. In addition, sampling protocols do not consider issues of non-uniform distribution of fish and diseases.

The FHPR do not propose any disease control strategies; they are instead concerned with testing and certification and not with subsequent decisions apart from restricting fish movement. Norwegian disease reporting requirements are often cited as models for Canada. The Norwegian programs have control strategies associated with diseases that are reportable. Their development involved industry and considered wild and cultured salmon production. In Canada, the Norwegian Fish Health regulations (*Interim Fish Disease Control Act* and Other Regulations Concerning Diseases of Aquatic Organisms) are closely approximated by the *Federal Health of Animal Act* and the *Provincial Animal Disease Control Act*. While both of these pieces of legislation contain all of the regulatory "tools" needed to mirror the Norwegian regulations, neither have been applied to fish or fish diseases to date.

The diseases listed under the FHPR do not completely reflect current knowledge or public concerns about disease. For example, there are no provisions for the mandatory reporting of diseases not previously found in Canada. By including indigenous endemic diseases such as bacterial kidney disease and furunculosis in certification protocols without accompanying disease control plans, the regulations encourage salmon producers to conceal their disease status from regulatory authorities. (It must be noted that this review did not acquire information that diseases have been concealed by B.C. salmon farmers apart from unconfirmed anecdotal reports.) Inclusion of endemic local diseases in certification regulations also discourages producers from working with government agencies to develop disease control programs for fear of regulatory reprisal. The lack of a financial compensation program, as is common-place in disease control programs for terrestrial species, also discourages fish farmers from reporting exotic or unusual diseases. As the federal government has assumed a largely regulatory role in commercial salmon farming, there has been little opportunity to develop health extension and disease control programs delivered from a federal department to industry, and thus a cooperative relationship has not been fostered.

The federal-provincial Atlantic salmon importation policy represents an important improvement in the capacity of government to manage or reduce the importation of exotic diseases to B.C. It is this policy and not the FHPR that require only eggs be imported to B.C. The inclusion of quarantine and isolation periods coupled with mandatory disease screening and effluent treatment significantly reduces the likelihood that an exotic disease could enter the province. However, like the FHPR, much of this policy is left to the judgement of the Local Fish Health Officer. As these policies utilize the FHPR as a basis for disease detection, similar concerns regarding the standardization of test accuracy and predictability arise, as do concerns regarding the adequacy of disease sampling methodologies. The policies do not provide guidance as to how a pathogen be categorized as a problematic strain. The lack of information on the pattern of disease in wild fish makes such judgements dependent on the experience and opinion of Local Fish Health Officers instead of on representative disease data.

Perhaps a more significant practical problem regarding the current Atlantic salmon importation policy is its failure to be endorsed by the Ministry of Environment, Lands and Parks. The basis for this is the lack of limitations on the number of Atlantic salmon eggs that can imported per year per licence and the inability of current policies and procedures to guarantee a zero probability of importing pathogens to B.C. Letters obtained through Freedom of Information legislation indicate that officials of the provincial Ministries of Environment, Lands and Parks and

Agriculture, Fisheries and Food, the Department of Fisheries and Ocean, and industry groups such as the B.C. Salmon Farmers Association and the Western Trout Farmers Association all concede that the continued importation of Atlantic salmon gametes will be required to allow for periodic inputs of genetic material to support an Atlantic salmon farming industry, specifically for broodstock development and research, and that importation of eggs for production purposes is undesirable. However, there has not yet been consensus as to what constitutes the appropriate number of eggs to be allowed into the province.

Movement of disease agents within the province

As a part of normal practice fish from commercial farms and enhancement hatcheries are often transferred from one location to another. Several authors have noted that, unlike the movement of surface-disinfected eggs, the movement of live fish presents a reasonable expectation that pathogens or parasites could be transferred along with the fish. Even the transfer of fish over relatively short distances, for example between the Pacific and Arctic watersheds, can be problematic due to differences in the distribution and abundance of disease agents between watersheds. Federal and provincial fisheries regulations prohibit the transport and transplant of live fish unless authorized by licence or permit. In B.C. a federal-provincial transplant committee has been responsible for reviewing applications to transplant live fish, including live eggs since 1977. Between 1977 and 1990, over 4,000 applications were reviewed, with 98% being approved (some with special conditions applied). This committee currently includes two representatives from the Ministry of Agriculture, Fisheries and Food, one from the Ministry of Environment, Lands and Parks, and two from the Department of Fisheries and Oceans.

The B.C. Aquaculture regulations under the provincial *Fisheries Act* require that any person introducing fish into the province or moving fish within the province for the purpose of carrying out an aquaculture business must be the holder of a valid aquaculture license. This controls who may import or move fish for commercial purposes. Due to manpower limitations and the frequent requirements to move fish by commercial and government fish-culturists, the transplant committee devised a system of approval that would allow for a large proportion of transfers to be approved without prolonged approval processes. The Form-A Salmonid Transfer Licence provides immediate approval for a large proportion of the transfers anticipated in the province. This licence is automatically issued to holders of a Ministry of Agriculture, Fisheries and Food Aquaculture license and must accompany every shipment of live fish.

The first condition of transfer under Form-A is the satisfactory health status of the fish stocks that are to be moved. Secondly, the province has been divided into four coastal and five inland zones based on the estimated likelihood of the frequency and distribution of various fish diseases (Table 11) Transfer of healthy fish within zones can occur with few restrictions; however, transfer between zones is more stringent. The conditions attached to the Form-A License are as follows:

The movement of live fish or eggs from one facility to another in the same zone requires:

- the source facility has received only screened eggs that were surface disinfected upon water-hardening or fish that were hatched from screened eggs that were surface disinfected.
- mortalities of any stocks at the facility have not exceeded 1% per day for any four consecutive days of the rearing period
- the source and destination are licensed to possess the species being transferred (unless fish are being moved for processing)
- the stocks do not have any signs of bacterial kidney disease, furunculosis or enteric redmouth and
- the source facility is not known to have any emergency disease or any other infectious agent of concern as designated by the transplant committee. Emergency diseases include infectious hematopoietic necrosis, infectious pancreatic necrosis, viral hemorrhagic septicemia, *Oncorhynchus* masou virus disease, herpesvirus salmonis disease, any filterable agent causing cytopathic effects in tissue culture, whirling disease and cold water vibriosis. These have been designated as emergency diseases either because they are not known to occur in B.C. or are not considered treatable.

To move fish between zones, fish must be reared exclusively on groundwater or surface water free of fish, or in water treated in a manner to kill fish pathogens. Alternatively, any source facility that has Schedule II certification under the FHPR can be moved between licensed facilities. In order to move Atlantic salmon or Arctic char, they must also have been formally released from DFO quarantine or be the progeny of fish that have been so released. Transfer of sockeye salmon requires special considerations of the committee. If the fish being moved fail to comply with Form-A, a special application for transfer must be made. Approval may be subject to proof of disease-free certification of the fish to be transferred.

The federal-provincial transplant committee is currently reviewing their Form-A procedures. Some members of the committee have expressed concern that there is insufficient manpower to audit compliance with the regulations. The federal-provincial transport regulations fail to specify the means by which a farmer must determine that he/she meets the conditions of the licence. Once again, the lack of explicit case definitions and test methodologies does not allow for a uniform standard of disease testing or surveillance before fish are moved throughout the province. There are also no requirements to report disease findings.

Table 11. Definition of salmonid transplant zones for British Columbia

ZONE 1	Trans-Boundary	The watersheds of all B.C. streams whose mouths are located in the State of Alaska
ZONE 2	Liard	The watershed of the Liard River
ZONE 3	Peace	The watershed of the Peace River
ZONE 4	Skeena	The watersheds of all streams flowing into the Pacific Ocean from the southern extremity of the Alaska Panhandle south to Douglas Channel near Kitimat and all coastal islands north of the midline of Nepean, Otter and Douglas Channels and Cridge Pass, except the Queen Charlottes
ZONE 5	Central Coast	The watershed flowing into the Pacific Ocean from the mainland and all coastal islands from the midline of Douglas, Nepean and Otter Channels and Cridge Pass south to a line drawn from Cape Caution, excluding the Queen Charlottes
ZONE 6	Queen Charlottes	All of the Queen Charlotte Islands
ZONE 7	Southern Coast	The watersheds of all streams flowing into the Pacific Ocean from the mainland from Cape Caution south to Point Grey and all coastal islands, including Vancouver Island, lying in a line south of Cape Caution, except the mouth of the Fraser River
ZONE 8	Fraser	The watersheds of all streams flowing into the Pacific Ocean south of Point Grey including the entire Fraser watershed
ZONE 9	Columbia	The watershed of the Columbia River

International guidelines regarding the movement of disease agents through fish transfers

Both the North Atlantic Salmon Conservation Organization (NASCO) and the International Council for the Exploration of the Sea (ICES) have developed protocols or codes of practice for the introduction and transfer of salmonids or other marine organisms. NASCO has clearly stated that introductions and transfers of salmonids create a potential for adverse fish health outcomes that may be serious and irreversible if adequate safeguards are not taken. Based on their review of existing literature, NASCO concluded that damage to wild stocks arising from the introduction of exotic diseases can be so severe as to render certain wild salmon stocks extinct (NASCO, 1995). The North-east commission of NASCO recommended that movement of live Atlantic salmon and their eggs originating from outside the commission area should not be permitted because of concerns regarding genetic impacts. To deal with the movement of disease, this commission recommended that epidemiological zones based upon the distribution of serious diseases be established and that movement from a zone with diseases of concern into zones free of those diseases not be permitted except when eggs can be moved without risk of transmission of specified diseases or parasites. To control movement of unknown diseases, NASCO recommended that zones be further developed to reinforce natural barriers to pathogen movement. Both NASCO and ICES recognize that the movement of eggs is safer and therefore more desirable than the movement of live fish. The current Canadian regulations and policies regarding the prevention of the importation of diseases do not differ substantially from these international guidelines except for one area. Both NASCO and ICES suggest a more comprehensive risk assessment approach than do current Canadian policies. For example, both advocate that the proponent of the transfer provide regulators with supplemental information regarding the necessity of the importation, the anticipated adverse effects and efforts taken on the part of the proponent to prevent adverse effects from happening. While similar information may at times be requested by the Fish Transplant Committee, it is not mandated that it accompany requests for fish movement permits. NASCO has also developed a system for classifying rivers according to the status of their local salmon stocks and modify their recommendations based on these classifications. This information is then incorporated with knowledge of the disease status of the exported fish and other fish in their country of origin into part of a qualitative risk assessment.

V. FISH HEALTH MANAGEMENT PRACTICES

A. INTRODUCTION AND DEFINITIONS

Fish health is managed through the application of a wide variety of techniques. The proper selection of a site and water supply to avoid stressful or disease inducing environmental conditions, the selection and breeding of specific stocks of fish, nutritional management, immunization; manipulation of stocking densities and chemical (drug and pesticide) therapy are among some of the more common techniques used to prevent, mitigate and treat disease in cultured fish. Environmental issues that arise around fish health management practices most often involve the impacts of drugs and pesticides used by the salmon farming industry. The primary environmental issues regarding their use in the B.C. salmon aquaculture industry as raised by the Terms of Reference and public input to this review were: (1) the appearance of drug residues in seafood products (including farmed fish and non-target species), (2) the stimulation of antibacterial resistant strains of pathogens and their transfer to other species including man, and (3) effects on microbial and non-target communities. This paper will focus primarily upon the first two concerns.

For the purpose of this paper, the definition of a drug is based on the B.C. Pharmacists, *Pharmacy Operations and Drug Schedule Act*, in which a **drug** is defined as any substance used in or on a fish or other animal to prevent, diagnose, treat or mitigate a disease, disorder or symptom thereof. It is important to realize that the definition of a drug will vary from agency to agency. The Bureau of Veterinary Drugs, which has federal responsibility for drug use in food producing species, does not include topically or environmentally applied pesticides in its definition of a drug. Pesticide use is therefore not subject to its regulatory control but is instead subject to the *Pesticide Control Act* administered by Agriculture and Agri-Food Canada.

Like other forms of intensive agriculture, aquaculture practices include the use of drugs. Reports of treatments of bacterial infections can be found from the 1930s and by 1948, sulfamerazine was being used to treat furunculosis in brook trout. Prior to the 1980s, the demand for drug use by aquaculture was negligible compared to other drug-users (Weston, 1996). With the development of large scale prawn aquaculture in Asia, catfish farms in the United States and salmon rearing in Norway, the demand for aquaculture use of drugs increased. However, the number of drugs used in fish farming internationally today is small. Some authors estimated that in 1990 the weight of antibacterial drugs prescribed for use in the Norwegian salmon farming industry compared to the amounts dispensed for human use (Midtvedt and Lingaas, 1991). The lack of effluent treatment in marine cages and some hatchery facilities provide opportunities for drugs to enter the environment where they can potentially interact with humans and other environmental components. The ability for drugs to enter the environment in biologically active forms create opportunities for their use to exert effects beyond their intended targets. A lack of data on the aquatic chemistry and ecotoxicology of many of the substances used internationally in aquaculture has exacerbated concerns regarding the use of chemicals to control disease as it has prevented a complete assessment of the environmental risks they may pose (Redshaw, 1995).

The use of drugs and pesticides is accepted as standard practice for the vast majority of animal agriculture. In the United States alone, over one quarter of a billion dollars is spent each year on antibacterial supplements in animal feed (Stinson, 1987). Some members of the public have concerns that inappropriate use of antibacterials and pesticides, particularly those applied by lay-persons or those used in sub-therapeutic doses, may result in adverse effects for humans, animals and the environment. Yet, in North America, the use of drugs in food animals is generally viewed as a low risk by food safety experts. Food-borne infections are instead seen as the predominant food safety issue in terrestrial agriculture (Saschenbrecker, 1995). The adverse effects of human exposure to drug residues in food are rarely documented, and when they occur, tend to be mild (Huber, 1982; P. Riben, pers. comm.). However, it is curious to note that surveys of public opinion in North America generally reverse the ranking of food safety risks as seen by food safety and public health experts, identifying drug and chemical contamination as the primary public food safety concerns (Saschenbrecker, 1995).

In our example case, some of the organisms isolated from affected fish were found to be resistant to the effects of oxytetracycline in laboratory tests. Antibiotic treatment with that drug did not appear to stop the outbreak. The hatchery managers had no previous knowledge of a similar observation in this facility. However, local knowledge indicated that a nearby salmon farm had also suffered from a form of furunculosis that was resistant to selected antibacterial agents. Thus it was hypothesized that the cultured coho had acquired a resistant strain of the pathogen from fish farms. The selection of resistant strains of fish pathogens that could be transferred to non-farmed fish was not the only health concern expressed by residents of the Broughton Archipelago regarding the use of drugs on fish farms. Local residents that utilized marine species for subsistence, commercial or cultural reasons expressed concern that drug use on salmon farms might reduce the safety of local seafood.

B. AVAILABILTY OF DRUGS FOR USE ON SALMON FARMS IN BRITISH COLUMBIA

Overview

Regulations regarding the use of drugs in aquaculture vary with the species being reared and national policy. Japan, for example, has 26 antibacterial agents approved specifically for use in aquaculture (Weston, 1996) compared to only three registered antibacterial drug products in Canada. These are Romet-30 (Ormethoprim and sulfadimethoxine), Terramycin Aqua (Oxytetracycline), and Tribrissen (Trimethoprim and sulfadiazine). Of the large number of drugs available for use in human and veterinary medicine, only a small fraction are employed in the B.C. salmon farming industry. Chemicals used to treat, prevent or control disease in aquaculture around the world fall into four basic categories: (1) basic chemicals such as formalin, (2) hormones, such as methyltestosterone, (3) antibacterials, such as antibiotics and disinfectants and (4) pesticides.
Internationally, significant concerns have been raised about the uncontrolled use of drugs, particularly antibiotics and pesticides, especially in prawn culture facilities in developing countries. Many developing countries have little regulation governing the safe use of drugs in aquaculture and few resources to control their application (Weston, 1996). This situation is very unlike the standards in North America, where several agencies regulate and monitor the use and impacts of drug use in food species. There are strict regulations governing the use and availability of drugs for food fish in Canada. Aquaculture is unlike other major food producing sectors where many of the drugs have been developed for or are registered for use in the species being treated. The Bureau of Veterinary Drugs of the Health Protection Branch of Health Canada has the responsibility to ensure that drugs registered and regulated in Canada are safe, effective and do not leave potentially harmful residues in food products. Safety concerns involve both the animals being treated and humans that may consume them. This agency has, in the past, restricted or excluded the use of specific drugs in food producing animals in response to potential human health risks (Mitchell, 1988). In B.C., the *Pharmacy Act, Veterinary Act , Food and Drug Act,* and *Feeds Act* also regulate the availability and conditions for use of drugs in aquaculture. These regulations provide for four general categories of drugs based on availability: (1) nonprescription drugs registered for use in fish, (2) prescription drugs registered for fish, (3) prescription drugs registered for other species and (4) prescription drugs not registered for use in any species in Canada.

Nonprescription drugs

Nonprescription drugs registered for use in fish can be made directly available to aquaculturists. However, there are set limits on the species and conditions under which such products can be used without veterinary consultation and prescription. They can only be purchased and used at a predetermined dose. The only drug currently available is Terramycin Aqua (oxytetracycline) for use in feed. There are no special reporting requirements for nonprescription registered products other than maintaining farm records which indicate the fish stocks treated, duration of treatment, drug manufacturer, dosage and withdrawal time. As a condition of farm licences this information must be made available for inspection by government agents and must be presented to processors at the time of fish harvest. A fish processing plant licensee who has received a statement of treatment from a farmer must retain a copy of the statement for one year.

The use of nonprescription registered drugs for fish appears to be rare in B.C. At one large fish feed company, only one request for a nonprescription registered drug (Terramycin Aqua) was received in the past five years (M. Sheppard pers. comm.). This request represented 0.02% of the overall veterinary prescription orders at this faciltiy since 1991. Similarily, reviews of medicated feed prescriptions conducted by the Ministry of Agriculture, Fisheries and Food for 1995 indicated that approximately 99.5% of all drugs purchased by feed companies were dispensed through veterinary prescription. The Aquaculture Regulations of the B.C. *Fisheries Act* require that, for drugs not prescribed by a veterinarian, or drugs for which there are no standards for use under the *Food and Drug Act*, farmers must not harvest their fish for 105 days after administering the drug.

A veterinary prescription is not required for a pesticide or many of the basic disinfectants, such as formalin, bleach or iodine based products. (It should be noted that ivermectin is considered an antiparasitic drug and not a pesticide.) Some of these products can be obtained through lay outlets in forms that can be directly applied for aquaculture use. Other products, such as dichlorvos, are available at lay outlets, but not in a form that can be applied to fish. A much wider variety of drugs is available in lay outlets for use in terrestrial species. Antibiotics, drugs to treat internal and external parasites, and some vaccines are available to the general public through outlets such as pet and feed stores for use in a wide variety of birds and mammals.

Prescription and extra-label drug use

A veterinary prescription must accompany the use of drugs that are registered for fish and available by prescription. Conditions of the registration of a drug include species, diseases for use, dosages and treatment duration. Variation of these conditions that consider the effects of temperature on the metabolism and excretion of drugs in fish are also specified. Approved drug withdrawal times are provided for registered products. Two antibiotics fall into this category in Canada and both are potentiated sulfonamides (Romet-30 and Tribrissen). Oxytetracycline is also available in prescription doses and conditions for fish. Oxytetracycline can be used under conditions different than those specified for nonprescription drugs only after veterinary consultation and prescription. Any uses of a registered drug other than those specified on the label instructions are considered extra-label use.

In Canada, licensed veterinarians are allowed to prescribe any product with a drug identification number for use in fish. A drug identification number is assigned to a product if it is deemed by the Bureau of Veterinary Drugs to be safe for human consumers. Its use in a species or at dosages not indicated on the label is also considered extra-label prescription. The veterinarian is responsible for the safe use of the product with respect to the treated animals and human consumers, and for the formulation of appropriate withdrawal periods. The maintenance of records are the same as those for nonprescription registered drugs outlined above.

Because of the strict regulations in Canada which slow the registration and labeling of drugs specifically for aquaculture use and the relative youth of the industry in the country, few drugs are specifically licensed for use in salmon production (known as approved drugs). Therefore, extra-label drug use is not uncommon for the treatment of cultured fish (Mitchell, 1988). This is not dissimilar to other forms of agriculture where the use of new drugs under new conditions requires extra-label drug use. Extra-label use is considered to be essential if veterinarians are to fulfill the expectations of society to control and treat animal disease (Morse, 1988). Several groups have questioned the legitimacy of extra-label drug use. Their concerns include safety for the treated animal, safety for the person administering the drug, food residues and other environmental impacts (Morse, 1988). There is a substantial body of information regarding the pharmacokinetics and withholding times with drug use for fish (eg. Hsu *et al*, 1994; Inglis *et al*, 1991; Martinsen *et al*, 1993; Rogstad, 1991; Roth *et al*, 1993b; Stoffregen *et al*, 1996). There is less information regarding the environmental fate of drugs in terrestrial and aquatic settings, thus necessitating the application of biological analogy, drug dynamics and professional judgement when making extra-label drug use decisions. Unlike in other species, drugs are not allowed for use as growth promotants in salmon farming (Brooks, 1989).

Drugs that are not registered for use in any species in Canada can be made available through a number of mechanisms (Brooks, 1989). Experimental studies certificates can be given for drugs used under controlled experimental conditions. Investigation new drugs can be made available for use in clinical trials under specific conditions. Drugs also can be made available for emergency treatments. In this case the Bureau of Veterinary Drugs will specify the amount of drug to be used and recommends the dosage, duration and withdrawal periods. Drugs used for emergency treatment have additional reporting requirements which include mortality records one month prior, during and two weeks after treatment plus comments on any adverse effects and efficacy observed. This information must be provided to federal authorities by the attending veterinarian within one month of the end of treatment. Failure to comply with these regulations will result in the inability to obtain any drug for emergency use until the information is received. Each of these forms of drug use must be requested and administered under veterinary prescription.

C. PATTERNS OF DRUG USE IN SALMON FARMING.

International experience

The rapid expansion of the salmonid farming industry in Norway led to an increased utilization of drugs, particularly antibacterial agents, in that country (Grave *et al*, 1990). Antibacterial drug use reached its peak in 1987 in Norway at 48.6 tonnes. This decreased to approximately eight tonnes in 1993 (Anon, 1993). When the weight of drug used per biomass of fish is compared, this represents a 20-fold reduction in drug use. While this reduction can be explained in part by the development of improved methods for disease prevention, particularly vaccination programs, it may in part also be explained by shifting patterns of drug use to drugs that required less mass in effective treatments.

Local experience

Interviews with veterinarians, fish farmers and fish health experts suggest that a similar pattern of reduced drug use (on a per biomass basis) has also occurred in B.C. The development of effective *Vibrio* vaccines provided a method for reducing drug use in Pacific salmon. The change to Atlantic salmon production also reduced the need for antibiotic use due to the lower rate of bacterial kidney disease (B. Hicks, pers. comm.). However, drug therapy remains an important part of efforts to treat, control or prevent disease in cultured fish. Table 12 is taken from a report from the B.C. Ministry of Environment, Lands and Parks entitled "Reported use of Substances on Fish Farms 95/96". The report indicated that 45% of active farms reported some use of a drug, disinfectant or feed additive at some time in 1995. These results do not indicate the duration of time a compound was used by a farm and include disinfectants and feed additives to estimate the percentage of farms using compounds.

Table 12. Reported use of chemotherapeutants, disinfectants and feed additives on fish farms in B.C., 1995-96

Antibiotics	**Disinfectants**	**Feed Additives**	**Anaesthetics**	**Antiparasitics**
Oxytetracycline	Bleach	Vitamin C	Tricaine-Methane-	Ivermectin
	Sulfanate (TMS)			
Ormethoprim-suladimethoxine (Romet-30)	Ovadine	Vitamin E	Metomidate	
Trimethoprim-sulfadiazine (Tribrissen)	Kilphor	Canthaxanthin		
Erythromycin	Chloramine T	Astaxanthin		
Enrofloxacin	Formalin			
Florfenicol	Aurueyne Dustban			

The use of drugs is not restricted to commercial salmon farming. Table 13 summarizes the pattern of drug use by federal enhancement facilities in the past year and a half.

Table 13. Prescriptions given for federal enhancement hatcheries in British Columbia from January 1, 1995 to September 30, 1996.

DRUG	**PURPOSE**
Erythromycin	Broodstock prophylaxis
Oxytetracycline	Treat bacterial disease
Ormethoprim-sulfadimethoxine	Treat bacterial disease
Enrofloxacin	Treat bacterial disease
Metomidate*	Anaesthetic
Tricaine Methane Sulfanate*	Anaesthetic
Malachite Green*1	Treat fungus infections

** delivered as bath treatments;* 1 *does not require veterinary prescription*

On behalf of the office of the province's Chief Veterinarian, a detailed review of the 1995 veterinary drug use in aquaculture feeds was conducted for this environmental assessment. The review indicated that 2.1% of the total weight of feed used in aquaculture in B.C. in 1995 was medicated. Only antibiotics were used in these feeds. All of the antibiotics used in aquaculture feeds were prescribed by veterinarians. The Chief Veterinarian indicated that this was unique in agriculture as medicated feed prescriptions are infrequently used in other food animal industries which more often utilize antibiotics in a non-prescription fashion in feeds. More than 99.5% of the antibiotic products used in aquaculture feeds in 1995 were licensed (approved) for use in food fish by the Bureau of Veterinary Drugs. Of the total weight of active antibiotics prescribed, 89.6% was oxytetracycline and 10% potentiate sulfonamides, Tribrissen and Romet-30. The remainder was composed of erythromycin and florfenicol and was given primarily to broodstock or fish less than 250 gms in weight. More than 80% of the medicated feeds were prescribed to fish less than 2kg in weight and/or to broodstock. When the weight of drugs purchased by B.C. fish feed mills in 1995 was compared to 1994, a 22.4% reduction was noted (16.44 to 12.47 tonnes active drug). The figures used to calculate this rate of reduction included feed used for commercial rearing, research and export. When compared to available production figures, approximately 156gms of antibiotics were used on average to produce one tonne of Atlantic salmon in B.C. Citing a 1996 Ministry of Agriculture, Fisheries and Food report, the B.C. Salmon Farmers Association's submission to this review indicated that in 1993, approximately 100gms of antibiotics were used per tonne of Atlantic salmon produced in Norway. This submission went on to say that 84% of drugs used in Norwegian fish feed in 1993 were quinolones while only 3% was oxytetracycline. Therefore a comparison of the weight of drugs used may not adequately reflect differences between Canada and Norway in the frequency or duration of medicated feed use. A review of prescriptions accompanying the medicated feed records indicated that the average duration of antibiotic treatments in B.C. in 1995 was 11 days with a range of 5 to 21 days. Ivermectin is also presented to farmed salmon with feed. However, it does not appear in these feed mill records as it is generally coated onto feed on farms instead of being incorporated into feed at the feed mills.

There was no evidence of the use of hormones as growth promotants in salmon farming. B.C.'s Fish Health Veterinarian reported that 17-alpha-methyltestosterone was the only hormone being used in B.C. currently. It has been used for the past three years in research projects designed to develop non-reproductive, all-female populations of Atlantic salmon and masculinization of chinook. Atlantic salmon during early stages of development are immersed in a solution of this compound. The treatment solution must be disposed to ground and any excess compound that remains unused is returned to the

Provincial Fish Health Veterinarian. The *Food and Drug Act* does not allow for the use of this product in food animals; therefore, exposed fish are identified and separated from fish on facilities which are destined for food production. The Fish Health Veterinarian receives copies of treatment records. Since 1994, a total of 5.9gm of this compound has been used. Facilities using methyltestosterone are annually inspected to ensure that established treatment protocols are observed and that treated fish can be readily identified.

Variation in on-farm patterns of drug use

The amount and frequency of drug use will vary from farm to farm depending on the diseases present, the availability of alternative forms of treatment and the management practices of a farm. A study of four Atlantic salmon farms in Puget Sound, Washington (Weston, 1994) demonstrated that on farms of similar size and stages of production, the average amount of antibacterial (weight of active ingredient) used could vary by up to 40-times between farms. More desirable siting and the use of preventive measures, particularly vibrio vaccination, were associated with farms using lesser amounts of antibacterials.

D. ROUTES OF DRUG DELIVERY AND THEIR POTENTIAL FOR ENVIRONMENTAL ENTRY

Injection

Drugs can be delivered to fish by injection, by topical application, by baths or in medicated feed. Injection has been the route of administration for antibiotic treatment of broodstock and for immunization of young fish. Fish at these life-stages are either unlikely to enter the food chain before the drugs have been completely excreted or metabolized, or are generally not used for human consumption. Therefore, there is little reason to consider injectable drug treatment to be a human health concern. When drugs are injected, a larger proportion of the drug is delivered into the fish than when other routes are used. Therefore, the potential for drugs to enter and impact the environment is reduced significantly. Thus, injection would appear to be a desirable method for administering drugs to fish. However, the labour requirement and stresses on fish that are associated with injection drug use preclude this as the primary method for treating farmed salmon.

Bath treatments

In B.C., bath treatments tend to be restricted to uses for the induction of anaesthesia needed to reduce stress when collecting gametes or when size sampling, for immunization, and for the surface treatment of fungal skin conditions. Standards of practice dictate that the effluent from medicated baths be properly discarded in accordance with the Waste Management Regulations. Because of problems achieving stable therapeutic concentrations while maintaining safe conditions for fish, baths are generally not used in marine salmon cages. Unlike in Europe and eastern Canada, bath application of pesticides in marine cages is not practised on marine farms in B.C. This may in part be due to the relative infrequency of sea lice problems encountered to date in B.C. compared to other jurisdictions (M. Sheppard, pers. comm.). There are currently no products registered for use in the treatment of sea lice in B.C. Emergency permits were granted for the use of pyrethrins and hydrogen peroxide to help control a sea lice problem in New Brunswick in 1995 (O'Halloran and Hogans, 1996). However, it may be anticipated that requests for pesticides could increase in the future if sea lice, to which Atlantic salmon seem more susceptible, become an important problem for the B.C. industry (M. Sheppard, pers. comm.).

In other jurisdictions, the application of pesticides as a bath to control sea lice has been the subject of significant discussion. Some authors consider the potential adverse effects of pesticide application in marine and aquatic environment without full knowledge of their effects and fates to be unacceptable (Ross, 1989). Pesticide agents such as dichlorvos applied as medicated baths to control sea lice is a recognized management approach in the United Kingdom, Norway and New Brunswick (Roth *et al*, 1993). Azamethiphos was used for the first time in 1995 to treat Atlantic salmon for sea lice in New Brunswick when a time-limited registration for the product was granted (O'Halloran and Hogans, 1996).

Unlike in hatcheries, the effluent from medicated baths in marine systems cannot be as readily controlled. To apply pesticides, a sea cage is enclosed in a tarp. The appropriate pesticide is then introduced to achieve therapeutic levels. After adequate exposure to the pesticide, the tarp is removed, allowing the pesticide to be released into the marine environment. In Scotland, the concentration of dichlorvos in a cage can be 1ppm for one hour (McHenery *et al*, 1991). Experimental tank-based studies suggested that dichlorvos at concentrations of 0.1 ppm can be lethal to lobster (*Homarus gammarus*) (Egidius & Moster, 1987). Much higher concentrations were required to induce effects in crabs (*Carcinus pagurus and C. maenas*) and blue mussel (*Mytilus edulis*). The interpretation of the relationship of these results to field conditions is limited due to the lack of study controls, small sample size and other study design flaws. Other experimental studies found that although relatively high concentrations of dichlorvos (10ppm) were toxic to larval lobsters (*H. americanus*), adult lobster, zooplankton and phytoplankton, they did not appear toxic to periwinkles (*Littorina littorina)* or mussels (Cusack and Johnson, 1990). In field trials conducted in the Maritime provinces by Cusack and Johnson (1990) neither juvenile nor adult lobster housed adjacent to salmon cages were killed after application of dichlorvos. This contrasts with reports from Scotland (McHenery *et al*, 1991). Toxicity tests indicate that larval crustaceans are more sensitive to the effects of dichlorvos that are fish. The 96 hour LC50 (concentration required to kill 50% of exposed animals) was 40 times higher for larval herring (*Clupea harengus* L.) than lobster larva (122 vs 5.7 micrograms/l respectively) (McHenery *et al*, 1991).

Dilution and dispersion are important mechanisms for rapidly reducing concentrations of pesticides used in aquaculture to non-toxic levels. The rate of dilution and dispersion will depend on water flows and directions. Although pesticides applied as a medicated bath at sea can be found in the seawater and sediments after release from seacages, the rapid dilution of pesticides released from seacages is felt to quickly decrease concentration of the chemical to non-toxic levels (Dobson and Tack, 1991; Tulley and Morrissey, 1989). However, the actual lowest levels of pesticides such as dichlorvos that have a physiological or behaviour impact have not been determined for many species (Tulley and Morrissey, 1989).

Sea lice management in B.C. is accomplished largely through non-medicinal approaches such as fallowing and single-year class production and selection of species farmed, as well as by the presentation of ivermectin in feed. The Ministry of Environment, Lands and Parks has never issued a permit for pesticide use on commercial aquaculture operations in B.C. (D. Heath, pers. comm.). Burridge and Haya (1993) report that water-borne exposure to ivermectin was not lethal to shrimp (*Crangon septemspinosa*). This same report, however, showed that ingestion of ivermectin medicated feed was toxic to shrimp. An unpublished study from the Scottish Office's Agriculture and Fisheries Department found that mussels bathed in dilute solutions of ivermectin accumulated significant concentrations of the drug in their tissues (Edwards, 1996). However, studies conducted around fish farms using ivermectin found very low levels of the drug in sediments and mussels (Edwards, 1996). Information regarding the duration and biological activity of these residues was not found although some have claimed that the compound can persist in sediments under net cages. Once again, this illustrates the conflicting results that arise when different studies use different methods to assess the environmental effect of a drug. In a November 1995 investigation conducted by the Health Protection Branch, 15 farmed salmon from New Brunswick were analyzed for residues of ivermectin after treatment. No ivermectin residues were found using confirmatory tests with a limit of quantification of 10ppb (D. Kwok, pers. comm.). Ivermectin also is used in the treatment of parasitic diseases of people and vertebrates with few adverse effects; however, no studies of adverse human health effects due to ingestion of drug residues in fish flesh were found.

Medicated feed

Most of the interest regarding drug use in salmon acquaculture has been associated with medicated feeds in the marine farms. Although medicated feeds have been used to treat hatchery fish for many years, the volume of drugs used by the international salmon farming industry in the early to mid-1980s sparked public and scientific interest. This is reflected in the literature where reports on the environmental fate of drugs in marine environments and on drugs most often used in salmon production predominate. Medicated feeds can either be made by coating feed with a drug or by incorporating the drug into the feed, the latter being the most common practice today in B.C. It has been estimated that 1-5% of feed in land-based salmonid culture (Weston, 1996) and 15-40% in salmonid net-cage culture passes into the environment (Gowen *et al*, 1988; Rosenthal *et al*, 1988; Thorpe *et al*, 1990). As sick fish often have reduced appetites, it is reasonable to assume that medicated feed also enters the environment. However, as feed rates and consumption are adjusted when veterinary prescriptions are written for medicated feed, the amount of waste feed entering the environment may not be higher in pens with sick versus healthy fish. The amount of medicated feed that enters the environment will vary from farm-to-farm depending on feeding methods, medications used, environmental factors, and the medical conditions being treated (AAVBC pers. comm.). A variety of methods are used to reduce fish feed wastes. These include simple management procedures such as hand feeding instead of automatic feeding of sick fish, the use of underwater video equipment to monitor consumption, the use of mechanical devices to collect and remove feed wastes (eg. Ervik *et al*, 1994a) and the adjustment of feeding rates.

Drugs introduced in feed can enter the environment after passage through an animal. While some drugs are metabolized and excreted in biologically inactive forms, other can pass through an animal retaining some biological activity. An example of this is oxytetracycline. It has been estimated that only 7-9% of oxytretacycline ingested by rainbow trout in freshwater is absorbed in the gastrointestinal tract (Cravedi *et al*, 1987). Through poor gut absorption and uneaten feed, a large proportion of oxytetracycline can enter the environment. The importance of unabsorbed or unmetabolized drugs passing through animal and acting as a source of environmental drug varies from drug to drug and with environmental factors that reduce their bioactivity.

The environmental persistence of drugs is an important issue to consider as the development of harmful tissue residues and the acquisition of drug-resistance both require drug exposures of sufficient amount and duration. Persistence of a drug in the environment will vary with the type of product used and the environmental conditions around a farm. Drug-containing feces or medicated feed are either dissolved into the water column, ingested by wild fauna or enter sediment under the farm (Samuelsen, 1994). Environmental factors reduce the persistence of antibacterial agents in the water column. Due to rapid dilution and photodegradation of many drugs, there is little concern regarding the presence of active drugs in the water column around fish farms (Dobson and Tack, 1991; Tulley and Morrissey, 1989; Samuelsen, 1989). Samuelsen (1989) demonstrated that oxytetracycline is much more rapidly degraded in water than in sediments. The rate of degradation was affected by water temperature and light intensity in the water. European studies (Lunestad *et al*, 1995) showed the degradation of oxytetracycline, furazolidone and flumequin in seawater also depended on the intensity of underwater light. This relationship was not seen for other agents, including oxalinic acid.

Feed and feces produced by marine salmon farms generally tend to be distributed within the immediate vicinity of the farm (Johnsen *et al*, 1993). Wild species can be exposed to medicated feed by direct ingestion of waste feed. In land-based facilities, treatment and discharge of waste waters will reduce the exposure of wild species to medicated feed waste. Smith *et al* (1994b) showed that managing effluent water from freshwater hatcheries by sedimentation and filtration will virtually eliminate discharge of oxytetracycline wastes. However, it is more difficult to deal with feed wastes in marine systems. Through field observations and by examining the stomach contents of fish captured outside of net cages in marine and freshwater settings, it has been shown that wild fish will ingest commercial fish feed (Carss, 1990; Phillips *et al*, 1985). Although in some cases, many of the fish captured around farms were thought to be escaped fish that were accustomed to eating pelleted feed, wild fish were also seen to eat waste feed. However, not all species captured around cages were found to eat waste feed (Carrs, 1990; Phillips *et al*, 1985). Experience with raising fish shows it can take several days to get a fish accustomed to eating pelleted or prepared foods. Therefore, the risk of exposure to medicated feed is not likely to be the same for all species that frequent or pass by fish farms. Lack of information regarding the ecology of a sea cage in B.C. makes it difficult to determine which species are at greater risk, yet it is reasonable to assume that fish that have established territories under or near a sea cage or those that have grown dependent on waste commercial feed will be at higher risk of exposure than more transient species.

As dilution, dispersion and degradation remove much of a drug from the water column, more research has focused upon the fate of drugs, particularly antibiotics, in sediments below sea cages. In general the distribution of drugs under marine salmon farms is restricted to areas subjected to the deposition of feed or feces. When compared to predictive models based on sedimentation rates and current flow, Coyne *et al* (1994a) demonstrated that oxytetracycline was distributed to areas subjected to feed depositions, but not in areas subjected only to fecal deposits. Coyne *et al* (1994a) found that the area under treated sea cages that was subjected to sediment deposits of oxytetracycline was an area less than twice that of the cages themselves. The results of Capone *et al* (1996) in Puget Sound support this statement. In that study, residues of oxytetracycline were detected in sediments only immediately under treated pens to a distance of 30m but were absent at 100m. Researchers in Ireland found sediment residues of oxytetracycline to be confined to an area smaller than the extent of the sea cage block itself (Kerry *et al*, 1996). Studies in fresh water fish farms in Europe also demonstrate that the distribution of oxytetracycline delivered by feed follows the distribution of discharged sediments (Smith *et al*, 1994b). Therefore, it appears that most drug wastes will be restricted to the areas immediately under farms in which treatments have been applied.

E. ENVIRONMENTAL FATE OF ANTIBIOTICS

Chemical persistence

Two elements must be considered regarding adverse environmental impacts of aquaculture drugs: (1) the drug must be present long enough to incite effects and (2) it must be present in a biologically active form. The rate at which a chemical degrades is often measured in terms of its half-life. Reports of the half-life of various drugs in marine sediments are present, but variations in methods used to measure this parameter are sufficiently different to make comparisons difficult. The chemical half-life of a drug varies with the particular compound. The sediment half-life of some antibacterial drugs, such as furazolidone, can be measured in hours (Samuelsen, 1991). For others, the half-lives have been measured in months. Reports of 125-144 day half-lives for oxytetracycline (Samuelsen *et al*, 1992b) coupled with its common use by the aquaculture industry has focused much attention on that particular compound. Some authors suggest that for persistent drugs such as oxytetracycline, leaching and redistribution rather than degradation are responsible for depuration of these substances (Hektoen *et al*, 1995). As ivermectin does not degrade under anaerobic conditions, this compound also has the potential to accumulate in anaerobic wastes under net-cages (ICES, 1994). Therefore, a concern has been raised that sediments can act as a prolonged environmental source of some drugs after treatment of fish has ceased.

Fate of drugs in sediment

Studies of marine sediment residues of aquaculture drugs generally reflect the experience of the European community. The tremendous variation in methodologies applied to studies of the fate of drugs in marine sediments complicates efforts to identify their impacts. Lack of attention to the confounding factors and to the principles of casual inference (Appendix A) in the studies that were reviewed weakened their ability to prove or disprove the hypotheses presented. No studies were found that evaluated the fate of drugs under B.C. production and oceanographic conditions. Because the fate of a drug is affected by environmental variables, the direct extrapolation of European data to B.C. must be done cautiously.

The half-life of a drug in sediments is affected by environmental conditions. Natural marine sediments are complex systems subjected to a variety of combinations of oceanographic and biological processes. The intra- and inter-site variability of sediments makes controlled analysis difficult. In attempts to control this variability, a number of the studies determining half-lives were conducted in artificial sediments (Hektoen *et al*, 1995; Jacobsen and Berglind, 1988; Samuelsen *et al*, 1994; Samuelsen *et al*, 1991). The restriction of oceanographic and biological forces in laboratory systems undoubtedly influenced the result of such drug persistence studies.

Although laboratory studies offer the opportunity to control variability of study conditions, they may not reflect what occurs under natural conditions.

The environmental kinetics of a variety of antibiotics in sediments has been studied under field conditions. Once again, variability was seen in the results. An important limitation of many studies conducted under operating fish farms was that little or no information was provided regarding the management practices used and oceanographic conditions of the test sites. The degradation of oxytetracycline was reported to be slowed in waters where sediments buried the drug as it accumulated (Samuelsen, 1989). Anaerobic conditions resulting from accumulations of uneaten feed, the development of anoxic sediments and a lack of bioturbation were associated with a prolonged half-life of oxytetracycline in sediments in one study (Coyne *et al*, 1994b). Hektoen *et al* (1995) found that oxytetracycline, oxolinic acid, flumequin and sarafloxacin depured more rapidly in upper layers than in lower layers of marine sediments. Little effort was spent in sediment studies to convince the reader that control sites selection had taken into account the potential input of drugs from other sources, such as sewage or outfall from terrestrial agriculture operations which act as important sources of chemicals and resistant bacteria in coastal waters (Samuelsen, 1991). As the fate of drugs in sediments is affected by management and environmental conditions, the general lack of information regarding these factors in studies of the environmental fate of drugs in sediments limits the ability to generalize results to B.C. conditions.

More important to consider than the lack of environmental generalizability of studies of drug persistence was the lack of attention to determining the biological activity of sediment residues. Many studies used to determine the half-life of drugs in marine sediments utilized chemical detection methods such as chromatography. Such methods are able to detect chemical fingerprints of a drug, but are unable to determine if the drug is capable of inciting a biological effect. Chemically detected concentrations are not the same as the amount of biologically available active compound. For example, although detectable by chemical means, the biological activity of oxytetracycline was seen to be very significantly reduced in the presence of fresh water sediments (Vaughn and Smith, 1996). The precise mechanism of this antagonism was unclear in fresh water. However, the mechanism for reducing the biological activity of oxytetracycline in seawater is antagonism of the drug by magnesium and calcium (Lunestad and Goksoyr, 1990). The same mechanism works to greatly reduce the bioactivity of other antibacterials such as oxalinic acid, sarafloxacin and flumequin (Barnes *et al*, 1995). However, ionic antagonism does not reduce the bioactivity of drugs such as amoxicillin (Barnes *et al*, 1995). Binding to particulate matter such as feces, sediment and natural humic in nearshore waters will further inhibit the bio-activity of drugs (ICES, 1994). The chemical sensitivity and specificity of current methods used to detect drugs in sediments and other environmental components around fish farms are capable of greatly overestimating the biological significance of the drugs used in aquaculture (ICES,1994).

The instability of some antibacterials used in B.C. results in only short-term sediment residues. For example, ormethoprim and trimethoprin were not detected in sediments after one and two months, and no antibacterial effects of ormethoprim treated sediments could be found after one month (Samuelsen *et al*, 1994). However, prolonged antibacterial activity (180 days) was seen for sulfadiazine. Other work has shown that the residues of the components of Romet-30 (ormethoprim and sulfadimethoxine) could only be found in sediments at levels just above the analytical level of detection two days after treatment of artificial mesocosms was stopped, and could not be found after 22-34 days in artificial mesocosms and 21-62 days in sediments under treated farms (Coyne *et al*, 1994). The extrapolation of these results to natural systems is complicated by methods used to determine antibacterial activity (see discussion on resistance below). Data were not found to adequately describe the duration of possible environmental activity for all drugs used in B.C.

As medicated feed acts as the principal route through which drugs can enter the environment given current practices of salmon aquaculture in B.C., the zone of potential drug deposits will generally be restricted to the zone of sedimentation of food and feces. The duration of possible risk is unknown. Although a variety of drugs can be chemically detected for prolonged periods in sediments under farms, evidence suggests that this does not correspond to prolonged duration of biological activity of the drug.

F. EXPOSURE OF NON-TARGET SPECIES TO DRUGS OF SALMON AQUACULTURE ORIGIN

Fish effects

Although the zone of potential adverse effects of aquaculture drugs appears to be limited in time and space, there exist several reports of wild fauna exposure to aquaculture drug use. The most frequent concerns regarding adverse impacts are direct adverse effects to individual wild species due to drug exposure, the presence of drug residues in food species and the development of bacterial resistance to antibacterial drugs. In general, environmental sources of drugs are unlikely to be harmful to individual wild salmonids. Although all drugs have the potential to induce adverse side-effects, they tend to do so at doses higher than those used therapeutically. Therapeutic doses are likely to be higher than concentrations found in the environment. Different fish species can have idiosyncratic responses to drugs. Controlled exposure of non-salmonid fish or other species to drugs used in B.C. salmon culture settings was not found. Observations by fish farmers, veterinarians and fish health reserachers suggest that fish that frequent net-cages, such as shiner perch, do not appear to suffer in terms of death or illness during drug treatments in salmon sea cages. These observations could not be substantiated as no controlled studies were found that evaluated this claim. In addition, there were no studies found regarding the subclinical effects of drugs on wild stocks. However, experience with medical management of fish held in zoos and aquariums suggests that most wild species will tolerate exposure to antibacterials used in B.C. without untoward effects (Stoskopf, 1993).

Human exposure

There are two principal routes by which humans could potentially be exposed to drugs of salmon aquaculture origin. One is through exposure to residues of drugs in seafoods. This will be discussed in more detail below. The second is by direct contact with the drugs. In the early stages of the B.C. industry, it was not uncommon for farmers to mix medications into feed manually on the farm. This practice has greatly decreased on commercial farms in recent years (J. Brocklebank pers. comm.). Today, medicated feed used in commercial farms tend more often to be prepared by commercial feed mills. Hand delivery or mixing of drugs is more often practiced at enhancement facilities (J. Brocklebank pers. comm.). Proper personal protection is required by workers to decrease occupational exposure to drugs used in aquaculture. Veterinary prescriptions routinely include recommendations regarding the use of personal protective clothing and gear for personnel handling and adminstering drugs (AAVBC, pers. comm.). However, the B.C. Workers Compensation Board does not have established procedures specifically for aquaculturists handling drugs or chemicals. A small proportion of the population has hypersensitivities to antibiotics or will develop them after repeated exposure to a particular drug. Hypersentitivity reactions range from mild (i.e., rashes) to life-threatening, the latter being extremely rare (P. Riben, pers. comm.). Other chemicals, such as malachite green and formalin, have been implicated as potential carcinogens.

Food residues

From a practical standpoint, a drug residue can be defined as traces of a drug in edible portions of fish or other food product. After a fish is exposed to a drug, its body eliminates it through two processes, metabolism and excretion. While the level of drug may quickly decrease below therapeutic levels, it will take longer for the body to rid itself of all of the drug. In recent years, significant public attention has been focused on food residues. The European market has refused to accept beef from North America because of the use of hormone implants for growth promotion. In the mid-1980's, the United States banned the import of Canadian cattle or beef arguing that the use of chloramphenicol in this country presented a human health risk. Like bacterial resistance resulting from the veterinary use of antibiotics, the development of resistance due to drug residues in food has never been clearly shown under field conditions although laboratory evidence supports the possibility (Janzen, 1990). In 1989, the

National Academy of Science concluded that it was not possible to find a body of evidence that conclusively demonstrated a human health hazard arising from the subtherapeutic use of penicillins and tetracyclines in animals feed (Radostits *et al*, 1994). Because of perceived risks, there are increasing demands that food only should be consumed after all chemicals or drugs are eliminated from the product. However, the desire for "zero tolerance" is unlikely to be realistic as analytical methods continue to be able more easily to find smaller and smaller amounts left in tissues (Janzen, 1990).

A large number of papers address the kinetics of drugs in fish. Once again, discussions of tissue residues tend to focus primarily on antibiotics. Many of the papers dealing with the pharmacokinetics of drugs provide information such as proper doses, durations and withdrawal times that can be used to make rational therapeutic decisions (eg., Hsu *et al*, 1994; Inglis *et al*, 1991; Bruno, 1989; Rogstad , 1991). As with studies of the environmental fate of a drug, studies of the fate of a drug in a fish are influenced by how experimental methods affect fish physiology (Horsberg, 1994).

The Inspection Branch of the Department of Fisheries and Oceans is responsible for testing samples of farmed fish flesh for drug residues. All farmed fish must be processed at federally licensed processing facilities. Federal fish processing facilities must participate in a Quality Management Plan. Inspections serve to audit the facilities compliance with this plan. Not all batches of fish processed are sampled. Instead, the Inspection Branch randomly selects lots and fish for sampling (discussions with inspectors suggest that sampling does not follow a formal, systematic random protocol as inspectors may select suspect fish for testing and not randomize their days of inspection). Farmed and wild fish are tested for heavy metals and pesticides residues. To date, no problems with respect to these compounds have been detected in B.C. (S. Schenkeveld, pers. comm.). The Branch also tests fish for the presence of residues of antimicrobial compounds registered for use in food fish. The results of tests from 1991 to November 1996 are presented in Table 14. Health Canada standards classify tissue levels of these drugs > 0.1 micrograms/gm as positive. In the past five years, 0.78% of sampled fish yielded positive results (n=12). Of the 12 positive samples detected in this time period, six equalled 0.1 micrograms/gm, one was 0.12, one was 0.13, one was 0.16, two were 0.2 and one was 0.77. All of the twelve samples were positive for oxytetracycline. The Inspection Branch uses high protein liquid chromatography methods for analyzing fish tissues. As discussed in the section on drug residues in sediments, this method can detect oxytetracycline in a bound or unavailable form. As this compound will deposit in fish bones or scales, contamination of the samples with bone or scale can falsely elevate the level assigned to the flesh. The frequency with which this happens is not known. Despite the finding of some positive samples, the Provincial Fish Veterinarain reports that no exports of B.C. farmed salmon have been rejected by the importing country due to drug residue problems.

Table 14. Summary of domestic drug residue tests for farmed salmon in B.C. from 1991 to November 1996 conducted by the Inspection Branch, Department of Fisheries and Oceans.

	OTC*			**Sulfa drugs****		
Year	**Number sampled**	**Number +ve**	**% +ve**	**Number sampled**	**Number +ve**	**% +ve**
1995/96	241	0	0	85	0	0
1994/95	126	4	3.2	44	0	0
1993/94	114	1	0.9	37	0	0
1992/93	111	0	0	85	0	0
1991/92	182	7	3.8	252***	0	0

OTC = oxytetracycline; ** Sulfa drugs = sulfadimethoxine and sulfadiazine*182 sampled for sulfadiamethoxine and 70 for sulfadiazine*

In a 1995/96 study of quinolones and fluroquinolones use in farmed salmon in B.C. conducted by the Health Protection Branch, none of 50 farmed salmon from New Brunswick and B.C. tested positive for any of six different antimicrobials (D. Kwok, pers .comm.). This survey was conducted as a “spot check” to determine if these compounds were being used in Canada. Unlike in Europe, there is currently no indication that these compounds are being used by fish farmers in B.C. (D, Kwok; M. Sheppard, pers. comms.). The results of tests for ivermectin in farmed fish are discussed elsewhere.

The small sample sizes and limited scope of these surveys for drug residues preclude generalization to the entire industry. Sampling theory would suggest that, given the large number of fish processed in the province each year and the relatively small sample sizes used, estimates of the proportion of fish with positive residue tests will be unstable and have wide margins of error. Typically, samples for drug residue testing in other species are larger than seen in the above salmon data. For example, in B.C., approximately 5,000 hogs are tested annually (C. Enweani, pers. comm.). The Food Production and Inspection Branch of Agriculture and Agri-Food Canada indicates that current levels of compliance with residue limits for terrestrial food species is in the range of 99.6-99.8% (C. Enweani, pers. comm.). While this is comparable to the five-year average for salmon (99.2%), there was year-to-year variation in compliance figures (100-96.2%).

The Inspection Branch also takes a preventive approach to dealing with residues of drugs in fish flesh by inspecting the reports of drug use that are in the possession of the fish processor. Under the terms of their aquaculture licence, fish farmers must keep a record of drug use on their sites. These records include information on the type of drug used, its date of use and withdrawal period. These records must be presented to fish processors at the time of harvest. Processors are not to slaughter fish for which this information is lacking. If a withdrawal period is not specified in the records, a mandatory 105-day withdrawal period must be observed. Processors failing to follow these guidelines can lose their operating licence.

Drug residues in wild species

Residues of antibiotics have been described in wild fish captured near fish farms in Europe (Bjorklund *et al*, 1990; Samuelsen *et al*, 1992a; Lunestad, 1991). In one case, levels of drug residues detected in wild fish exceeded levels tolerated for human consumption. Fish with drug residues in these studies were captured within 400m of the treated sea cages. The ability to detect drug residues in wild fish decreased quickly with none being found within 7-13 days. These studies failed to analyze fish samples collected before treatments were initiated, thus preventing the authors from excluding background sources of antibiotics such as sewage or agricultural run-off. In addition, these studies did not follow the same fish over time, thereby making it impossible to determine how quickly levels of drug decreased in individual fish, if fish with residues moved out of the study area, or if the fish with tissue residues were all removed in early samples. Both pelagic and demersal species of fish were found to have drug residues in one study (Samuelsen *et al*, 1992a; Lunestad, 1991). As bottom-dwelling fish have been seen to ingest waste feeds, this would be a most likely route of exposure to drugs for them. For pelagic species, it is unclear whether the fish are exposed to drugs by consuming waste feed or by consuming escaped or wild fish that contain traces of drugs.

Drugs residues have also been detected in other species, such as crab and mollusks, that were collected around treated fish farms (Capone *et al*, 1996; Samuelsen *et al*, 1992a; Lunestad, 1991). The same study limitations as those above hampered interpretation of these results. A study conducted under treated sea cages in Puget Sound was unable to demonstrate residues of oxytetracyline or Romet-30 in oysters taken mid-way and after treatment of farmed salmon either at the cage or 30m distant (Capone *et al*, 1996). Trace amounts (below violative levels of 0.1 micrograms/gm) of oxytetracycline were found in Dungeness crabs collected below cages, while levels in excess of those recommended for crab flesh by the U.S. Food and Drug Administration (0.8 to 3.8 micrograms/gm) were found in red rock crabs in the midst of treatment and 12 days after its completion. However, samples of red rock crabs taken 41 and 75 days after oxytetracyline was used on a farm failed to show more than trace levels of drug. In another Puget Sound study, Tibbs *et al* (1989) were unable to detect oxytetracycline residues in market-sized oysters and mussels that had been exposed for 10 days to water surrounding salmon net cages. These results heighten methodological concerns regarding alternative sources of drugs and background levels in wild stocks. In an unpublished B.C study, investigators were unable to detect the presence of sulfamerazine in oysters suspended at a fish farm during treatment with that drug (Black *et al*, 1991). These results contrast with other B.C. studies that revealed low levels of sulfadimethoxine and ormethoprim could be found in the flesh of oysters after treatment of salmon (Black *et al*, 1991; Jones, 1990). Studies in shellfish allow for a better estimate of the "zone of exposure". Whereas oxolinic acid residues could be found in mussels taken on a treated farm, they could not be detected in mussels collected at 200 and 400 m from the farm (Samuelsen *et al*, 1992a). In their review of the implications of co-culture of salmon and shellfish, Black *et al* (1991) concluded that shellfish, particularly oysters, will be exposed to antibiotics from salmon farm use through fine particulate feed wastes. These authors also showed that, under laboratory conditions, shellfish cleared drug residues faster than salmon; oxytetracycline and sulfadimethoxine levels fell to undetectable levels within 30 and 13 days respectively. The authors concluded that, based on their and other studies, if contamination of shellfish with antibiotics occurred, the levels of contamination would be very low, and should be detectable only in areas immediately adjacent to the farm. Jones' (1990) B.C. study revealed that oysters with residues of oxytetracycline and Romet-30 in their tissues after treatment of a salmon farm were localized to within 200m of the treated farm site. Jones (1990) concluded that the dispersal of the chemicals in the marine environment was most likely subject to site specific hydrographic conditions This would complicate efforts to generate generic siting guidelines with respect to the miminum distance between a salmon farm and shellfish beds. Jones (1990) further concluded that if shellfish are harvested within 500m of a salmon marine site, a record of treatment of the salmon farm should be consulted to ensure a sufficient time (30 days) for antibiotic clearance from bivalves. However, the Federal Department of Environment, Shellfish and Aquaculture Program, did not express any concerns regarding the current guideline of 125m and were not aware of any shellfish contaminated with antibiotics or pathogens of salmon farm origin (Hal Nelson, pers. comm.).

G. RELATIONSHIP OF ANTIBIOTIC USE IN SALMON AQUACULTURE AND INCREASED ANTIBIOTIC RESISTANCE IN FISH AND HUMAN PATHOGENS

Background

The threat of the emergence of antibacterial resistant strains of bacteria due to the use of drugs in aquaculture has caused some anxiety. In a 1994 ICES report, the potential for a drug to select for resistant strains of bacteria was an important consideration in evaluating the environmental effects of an aquaculture drug. Studies describe antibacterial resistant patterns of bacteria collected from fish or sediments around fish farms (e.g., Aoki *et al*, 1981; Husevag *et al*, 1991; Kerry *et al*, 1994; Kerry *et al*, 1995; Nygaard *et al*, 1992; *Samuelsen et al*, 1992b; Sandaa and Enger, 1996; Spanggaard *et al*, 1993). A high proportion of drug-resistant bacteria has been reported in sediments and water associated with aquaculture facilities (Nygaard *et al*, 1992; Samuelsen *et al*, 1992b; Spanggaard *et al*, 1993). Strains of bacteria that are resistant to antimicrobial agents have also been recovered from farmed fish and wild fish captured near fish farms (Samuelsen *et al*, 1992b; Lunestad, 1991). In their 1991 paper entitled, “Putative public health risk of antibiotic resistance development in aquatic bacteria”, Midtvedt and Lingaas suggest that antimicrobial resistance in the microbial world can develop and spread through pathogens of fish, humans and other animals. These authors concluded that, in order to prevent the spread of resistant pathogens or resistance factors from aquaculture to humans, several of the antibiotics more commonly used in humans should be banned from aquaculture. Yet, in both the record of the discussion that followed the presentation of Midtvedt and Lingaas’ paper and in several other articles, this conclusion was challenged as unreasonable, as was the one-compartment model of sharing resistant pathogens between fish and humans.

The nature of resistance

A strain of bacteria can be considered resistant to an antimicrobial agent if it is able to function, survive and persist in the presence of higher concentrations of the agent than other members of the population from which it emerged (Smith *et al*, 1994a). Resistance is, therefore, a relative term that can only be evaluated by comparison of two strains or species of bacteria. A proportion of any population of bacteria will have an innate resistance to antimicrobial drugs, even in regions that have not been exposed to antibiotics. When a bacterial population is exposed to sufficient levels of an antimicrobial, the sensitive organisms will be replaced by resistant ones that are not effected by the drug. Strains possessing innate characteristics that provide low levels of resistance can be selected for by a variety of factors, including non-drug factors (ICES, 1994). For example, Kapetanaki *et al* (1995) were able to significantly increase the proportion of oxytetracycline resistant bacteria in a drug free mesocosm by overlaying sediments with large amounts of non-medicated fish feed. Similarily, Kerry *et al* (1995) demonstrated that the proportion of resistant organisms in sediments under a sea cage was increased after the use of non-medicated feed. Innate resistance is rarely transferable to other strains. Comparatively few organisms will acquire traits that cause resistance to antibiotics during the course of therapy, although this can occur through transfer of resistance factors between organisms (Rogers and Turck, 1974). These resistance factors are transferred between bacteria on structures known as plasmids. From a public health perspective, it is plasmid-mediated resistance that is of most concern as it may, in theory, be transmitted between different types of bacteria.

The ability of bacteria to transfer resistance characteristics is likely to be very low in the relatively harsh conditions of coastal areas, although it is possible in specific microhabitats, particularly those with high concentrations of organic matter (Baldini and Cabezali, 1991).

In the recent past, significant attention has been placed on the development of antibacterial resistant strains of bacteria in humans, fish and other animals. In humans, the incidence of bacterial resistance to specific antibiotics has closely correlated with the frequency of antibiotic use (Rogers and Turck, 1974). The overuse of antibiotics in hospital settings has been a significant factor in the selection for resistant bacteria that reside there (Hierholzer and Zervos, 1991). In veterinary medicine, more attention has been placed on the sub-therapeutic use of antibiotics as growth promoters, as this is hypothesized to provide low-level, chronic selection against sensitive strains. The emergence of a resistant strain is a straightforward example of how a population adapts to external selective pressures. To maintain these traits in a population, the adaptations must put the resistant bacteria at a survival advantage.

As the bioactivity of antimicrobials is affected by environmental conditions, the species treated, their ability to utilize and metabolize the drug, and the route by which the drug is delivered, these same factors will influence the sensitivity of bacteria to an antibacterial drug. For example, the oral administration of oxolinic acid under commercial farming conditions may not achieve therapeutic levels of the drug in a fish, whereas injections of the same drugs will (Smith *et al*, 1994a). In a therapeutic context, bacteria will be resistant to oxolinic acid if administered to fish orally, but sensitive to the same drug if delivered by injection. As described above, the activity of oxytetracycline can be modified by the presence of magnesium and calcium. The concentration of these ions in a fish's gastrointestinal tract will vary depending on whether or not a fish is in freshwater or saltwater (Stoskopf, 1993). The bioactivity of oxytetracycline against susceptible strains may, therefore, be influenced by whether or not a fish is in a fresh or salt water environment. Because of the modifying effects of host and environmental factors and exposure dose, antibacterial-resistance cannot be viewed as an absolute characteristic, but must be considered a relative feature that is context specific.

Antibacterial resistance in fin-fish aquaculture

There is a large body of information dealing with antibacterial resistance in aquaculture settings: however, there are numerous, significant methodological problems that prevent the comparison of these studies and the development of consensus of opinion. One of the primary problems is the varying criteria used to define and measure bacterial resistance (ICES, 1994). Smith *et al* (1994a) reviewed 23 papers that provided information regarding the sensitivity of fish pathogens. Seven of these papers gave incomplete descriptions of methods. In the remaining 16 papers, 10 different methods were used to measure susceptibility. Six papers gave no definition of a resistant bacterium, and the remaining 17 papers used nine different criteria. Several methods were used to describe resistance patterns in the studies collected for this review. Most utilized laboratory methods. The artificial nature of laboratory methods creates important differences between resistance of a bacterium in the laboratory and their resistance in nature (Gilbert and Brown, 1991). Many of the studies of resistance in fish pathogens were based on laboratory studies alone. The variation in methods and definitions used in previous studies result in disagreements as to whether or not a strain of bacteria should be considered resistant.

Another important limitation in studies of resistance has been the inefficiency of the methods used to culture bacteria. Upon review of previous studies, ICES concluded that none used methods capable of detecting more than 1% of the viable bacterial flora present in environmental samples (ICES, 1994). Variation in the selective qualities of bacterial growth media used further ensures that different studies are unlikely to be examining the same sub-population of flora in environmental samples associated with aquaculture operations. Studies of changes in the pattern of resistance before and after drug treatment generally did not quantify the number of resistance organisms shed. Instead, they compared the proportion of cultured bacteria that showed resistance before and after treatment. In one study of long-range changes in oxytetracycline concentration and bacterial resistance (Samuelsen *et al*, 1992b), the authors concluded that, while the proportion of resistant strains of bacteria changed in response to selection by antimicrobial drug pressure, the change in bacterial number was due to seasonal effects, and not medicinal effects. It is unknown whether or not the absolute environmental load of resistant organisms changes after drug treatment and thus if the probability of human or animal exposure changes.

No study has convincingly demonstrated a relationship between drug levels in sediments as detected by chemical means and the frequency of resistance in microflora (ICES, 1994). In their study of the frequencies of resistant bacteria under treated salmon farms, Kerry *et al* (1996) were unable to correlate the concentration of oxytetracycline in sediment samples with the frequency of resistance in culturable microflora in the samples. Some authors were able to demonstrate that, under controlled conditions, the addition of certain drugs to marine sediments could increase the proportion of resistant organisms recovered from the sediment (Nygaard *et al*, 1992). However, others have demonstrated that the proportion of resistant organisms returned to background or control levels shortly after cessation of antibiotic therapy (Kerry *et al*, 1994). Some studies have shown higher levels of resistant organisms in fish farm effluents than in areas upstream from freshwater farms or in adjacent marine sites distant from farm activity (Spanggaard *et al*, 1993). However, when concluding that the antibacterial resistance developed due to drug use, most studies failed to consider non-drug effects that can influence resistance patterns such as those described by Kerry *et al* (1995) and Kapetanaki *et al* (1995) . A description of the surrounding environment of field studies was never given and thus it was impossible to know if alternative sources of resistant organisms were present. In a study of bacterial resistance in river waters and sediments in Argentina, it was shown that the principal source of antimicrobial drug resistant bacteria (*Escherichia coli*) was non-treated human sewage (Baldini and Cabezali, 1991). As E. coli can transfer resistance to other bacterial strains (Baldini and Cabezali, 1991), the input of untreated sewage from human communities near fish farms may affect patterns of resistance of marine and estuarine bacteria that share the same ecological niche.

In recognition of the deficit of information on background levels of antibiotic resistance in marine bacteria, Smith *et al* (1995) conducted a survey of resistance patterns of bacteria taken from marine sediments uninfluenced by fish farms. Using virtually the same methods as those used to survey sediments under abandoned and operating salmon farm sites in Norway, these authors collected eight sediment samples from locations in Ireland at least 5km from any fish farm or human sewage outfall. The proportion of cultured colonies resistant to oxytetracycline detected in the Irish samples were remarkably similar to those from Norway (mean % resistance in Norway = 0.79% +/- 0.79%; in Ireland = 0.76% +/- 0.30%). A study by Kerry *et al* (1994, cited in Smith *et al*, 1995) examined a larger number of samples (153) from sediments uninfluenced by fish farms and found background resistance in 1.2 +/- 1.8% of colony forming units. Finally, an Irish study demonstrated that in 83 samples collected from sites free of overt human influences, background levels of resistance were 0.4-1.3% depending on the selection concentrations of drug used (Kerry *et al*, 1996). This compared to levels of 0.3—35.1% in samples taken under or within 35m of treated farms in the former study. However, the authors were unable to correlate the proportion of resistant bacteria with sediment concentrations of oxytetracycline and concluded that non-medicinal selection factors were more likely the reasons for elevated frequencies of resistant organisms in the vicinity of treated salmon farms. Although these results may not be universally generalizable, they aid in interpreting the significance of background levels of resistance in bacteria from fish farm sediments.

The inability to completely characterize changes in the resistance patterns of environmental bacteria, uncertainty regarding the environmental and clinical significance of laboratory measures of resistance, and variability in the definitions of resistance used in past research prevent a calculation or quantitative description of the risk of developing antibacterial resistance of ecological significance due to antibacterial therapy in aquaculture.

Resistance to particular drugs does not mean that the bacteria is more able to cause disease or that the disease it does cause will be more severe than susceptible strains. Again, resistance is a relative term. Wild fish, unlike farmed or enhanced fish, are not treated with antimicrobials. Therefore, the presence of resistant organisms would not influence the clinical course of an infection in a wild fish. It is more likely that, in the absence of selective pressure due to antibiotic drugs, resistant strains of bacteria will not be maintained in high proportions. The rapid reduction in the proportion of resistant strains in fish farm effluents or sediments after termination of antibiotic therapy also suggests that resistant strains are at a disadvantage under "normal" environmental conditions. Therefore, the presence of antibacterial drug resistance should not be considered a threat to wild fish.

Implications for humans

Some authors have expressed concerns that antibacterial drugs use in fish farming can select for strains of resistant pathogens and that this resistance could be spread to humans (Midtvedt and Lingaas, 1991; Watanabe *et al*, 1971). This same concern is echoed in discussions of antimicrobials use in terrestrial agriculture. Despite papers that claim to directly link the veterinary use of drugs to resistance in human pathogens (eg. Spika *et al*, 1987; Holmberg *et al*, 1984; Linton *et al*, 1977), this debate remains unresolved. Antibacterial drugs used in aquaculture could hypothetically affect resistance patterns in human medicine via two possible routes. In the first, transferable plasmids coding for resistance are selected for in the aquaculture setting. These plasmids must then enter and spread widely among a population of human pathogens. The transfer of plasmids from animals to humans is controversial. Indirect evidence suggests a link, but critical assessment of published reports fails to rule out other equally or more likely mechanisms of plasmid transfer in human pathogens. This deficit in data is amplified for fish pathogens where less research has been done. The large variety of resistance plasmids in human pathogens would require very large sample sizes to establish an association between fish farming and changes in resistance patterns of human pathogens (O'Brien *et al*, 1993). Such studies have not yet occurred. Ervik *et al* (1994b) argue that available information supports the hypothesis that the use of antimicrobial agents in fish farms selects for plasmids mediated resistance and that transfer of this resistance can occur. Although they suggest that the frequency of such transfers is low, they argue that the size of the aquatic environment compensates, thus allowing ample opportunity for transfer of resistance factors. As plasmids may be transferred between bacterial families the interaction of fish and human pathogens could theoretically allow transfer of resistance factors in either direction. In laboratory experiments, Sandaa and Enger (1996) were able to transfer a plasmid coding for resistance to oxytetracycline from an atypical strain of *Aeromonas salmonicida* to six different bacterial isolates from fish farm sediments. However, as many organisms of fish origin have a limited ability to persist in humans (Smith *et al*, 1994a), it is unlikely that interaction of human and fish pathogens accounts for a large proportion of resistance in human pathogens. It is therefore reasonable to assume that bacteria of fish origin capable of acting as plasmid donors to human pathogens represent a small proportion of plasmid donors available to human pathogens. As discussed above, the majority of resistance in human pathogens is more likely due to interaction between human pathogens. In addition, unless the acquisition of a resistance plasmid confers increased survival capabilities on a bacteria, the characteristics will not be perpetuated or amplified in the bacterial population, thus decreasing opportunity for human exposure. Many studies reveal that the proportion of resistant bacteria decreases within weeks after treatments have been stopped, that the bioactivity of many antimicrobials around fish farms is limited in time and space, and that ecological requirements of most marine and aquatic bacteria are not compatible with persistence in people. Therefore, the likelihood of contact and transfer of resistance factors between fish and human pathogens is low.

In another scenario, humans might acquire resistant strains through direct exposure to fish or fish pathogens. Very few fish pathogens in temperate waters are capable of causing disease in humans. Many of the important human bacterial diseases of fish origin result from improper storage and preparation of fish product and not from direct transfer from fish to man. For example, botulism in B.C. is often associated with the consumption of improperly fermented fish eggs. *Aeromonas hydrophila* has infrequently been associated with disease in farmed salmon or with isolated cases of illness in humans in B.C. This likely reflects shared environmental exposure and not direct transfer from fish to man. Other bacteria that are found in fish and that are capable of causing disease in humans include Salmonella sp., *Vibrio parahemolyticus* and *Pseudomonas aeruginosa* (Smith *et al*, 1994a). Inglis *et al* (1993) concluded that the frequency of fish acting as vectors of human pathogens is low. This frequency will vary between countries and will be more common in temperature waters where aquatic and marine pathogens can tolerate higher temperatures, and in communities where the consumption of raw fish products is common or where fish products are improperly cooked or prepared (Smith *et al*, 1994a). Most of the pathogens associated with disease in both fish and humans are also widely distributed in the environment. No studies were found that quantified the proportion of human illness attributable to pathogens of fish of farm origin; thus the risk of transfer cannot be described. In terms of potential impact of resistance transfer by shared pathogens, most of the pathogenic bacteria shared by fish and man tend to result in self-limiting gastrointestinal disease for which antibiotic therapy is generally not recommended (Snydman and Gorbach, 1991) . Therefore, as for wild fish, this route of resistance transfer does not appear to result in significant impacts on human health.

There are few studies of epidemic spread of antibacterial resistance in human pathogens. Those that are best described have either been organisms restricted to hospital settings or pathogens resistant to drugs used primarily for treating humans (Hierholzer and Zervos, 1991). There are no studies linking the use of antibiotics in fish or other animals to epidemic spread of resistance in human pathogens (Smith *et al*, 1994a). However, it is still hypothetically possible that the use of antimicrobials in animals may influence resistance patterns of human pathogens in localized areas. This likelihood decreases significantly for fish because of considerations such as the lack of shared organisms and reduced opportunity for contact due to different ecological niches.

H. REGULATIONS AND PRACTICES TO REDUCE RISKS ASSOCIATED WITH DRUG USE BY BRITISH COLUMBIA SALMON FARMS.

Federal regulations

The availability and use of chemicals for the management of fish health are regulated by a number of agencies. The ways by which a drug can be made available have been outlined above. Health Canada is responsible for the approval of drugs for aquaculture and act through the *Food and Drug Act* in this capacity. Their primary concern is ensuring that the drugs used in fish (as well as other food animals) are safe and effective and that fish do not contain drug residues harmful to humans. Before a new veterinary drug is introduced in Canada, the manufacturer must submit data to the Bureau of Veterinary Drugs, Health Canada. These data are used to judge the product's safety and efficacy under a specific set of conditions. Once approved, the product receives a drug identification number. A veterinarian may prescribe a product with a drug identification number to a species for which the product was not approved (known as extra-label or off-label use). The drug identification number indicates that the product has been evaluated from a human safety point-of-view but does not specify that the product, if used in a way other than described on the product label, will be effective or safe to the treated animal. Recent moves to recover costs of the drug approval process reduce the likelihood that manufacturers will submit new agents for regulatory evaluation for approval for salmon farming in Canada. Although perceived by some to be a large market, sales of drugs to the aquaculture industry are small compared to sales in other veterinary and human health sectors. Therefore, there is little incentive for pharmaceutical companies to incur additional costs to have new products licensed, and it can be anticipated that extra-label use of drugs will, as seen internationally, remain a part of salmon farming practices in B.C. Health Canada also establishes the maximum safe residue levels in food fish flesh for drugs used in aquaculture. Anything exceeding these levels is classed as a violation. Although they do not require the generation of environmental impact information before licensing a new drug for use in Canada, this Bureau will consider such information generated elsewhere when making licensing decisions (M.S. Yong. pers. comm.).

Agriculture and Agri-Food Canada is responsible for administering the *Feed Act* and *Pesticide Control Act.* The former is intended to control and regulate the sale of feeds to livestock which includes fish. The regulations under this Act serve to ensure that no person can sell, make or import food that may adversely affect animal or human health, and they set standards for feed. This mandate applies to medicated and non-medicated feeds and defines practices and procedures for the addition of therapeutants to feeds. Only drugs with a drug identification number can be used in medicated feed. The "Compendium of Medicating Ingredients Brochures," is published by Agriculture and Agri-Food Canada, lists approved compounds for addition to feeds and sets conditions of use, including withdrawal periods. All medicated feed must be manufactured in accordance with the Compendium with the exception of feed that is manufactured according to a veterinary prescription.

The Department of Fisheries and Oceans Inspection Services is responsible for ensuring that Canada produces fish and fish products that meet minimum standards for identification, quality and safety. Legislation specifies the construction and operating requirements of plants exporting fish products. The Quality Management Program is used as a basis for encouraging and enforcing this legislation. Fish products are inspected in accordance with legislated requirements including checks for drug residues in flesh. The food inspection sections and related animal health services of Agriculture and Agri-Food Canada, Health Canada, and the Department of Fisheries and Oceans are being consolidated into a single Canadian Food Inspection Agency. This agency is expected to begin operation by April, 1997. The Canadian Aquaculture Industry Alliance has proposed that the Fish Health Protection Regulations should also be moved to this new agency as this would allow for more uniform regulation of animal health and food safety issues across species and industries as well as provide the fish farming industry with access to expertise in risk assessment, quality assurance and control, epidemiology, biotechnology, biologics and diagnostics currently not present in the Department of Fisheries and Oceans. This also would link fish health programs with fish inspection and perhaps provide better access to the *Health of Animals Act*. It would also provide for consistency in cost recovery programs across food producing industries. However, at the time of writing this report, government officials indicated that fish health would not come under the jurisdiction of the new agency.

Little attention has been placed in this report on the potential environmental impacts of immunization practices used in salmon farming. No information on adverse effects of vaccines used in salmon farms on wild fish or humans was found in the literature. Side-effects of furunculosis vaccination in the form of internal adhesions in vaccinated fish has been reported, but these do not represent a risk to wild (unvaccinated) stocks. No live vaccines (vaccines containing organisms that have been modified so they can still reproduce, but are not able to incite disease) are licensed for use in salmon aquaculture (J. Thornton and S. Wilson, pers. comms.); thus the risk of introducing a virulent agent is negligible. In addition, the vaccines used in B.C. contain agents such as *Vibrio* spp. that are either ubiquitous environmental organisms or are widespread in nature such as *Aeromonas salmonicida*. Agriculture and Agri-Food Canada has legislative responsibility for ensuring the safety and efficacy of vaccines used in fish farms. When licensing a vaccine, environmental effects are considered (S. Wilson, pers. comm.) This agency is also responsible for regulating aspects of the use of pesticides in food animal systems, including fish farms.

Unlike with drugs, pesticide use requires that a licensed pesticide operator and a pesticide application permit are used. This prevents anyone from applying these compounds in a way other than that explicitly indicated on the permits. Both federal and provincial legislation affect how pesticides can be used and who can use them. Federally, the *Pesticide Control Act* is administered by Agriculture and Agri-Food Canada. The Pest Management Regulatory Agency is involved in reviewing and approving pesticides, disinfectants and some parasiticides. It has an "Alternative Office" which attempts to develop integrated pest management practices. This office is currently working nationally with the salmon aquaculture industry to develop integrated methods for dealing with sea lice.

Provincial regulations

Several provincial regulations affect how chemicals can be used to manage fish health and who can apply them. The *Provincial Veterinarians Act* states that only veterinarians registered under the Act may prescribe or administer a drug or any substance for the cure, treatment or prevention of an animal disease. The owner of an animal or a person who is regularly employed full time by him/her in agricultural or domestic work may administer the drug. A very limited number of medications available for use in fish can be obtained by an owner or employee without veterinary prescription, and drugs can be legally obtained only in limited ways. The Veterinary Drug and Medicated Feed Regulations of the B.C. Pharmacists, *Pharmacy Operations and Drug Scheduling Act* authorizes licences for medicated feed or veterinary drug dispensers. Applications for these licences are reviewed and administered by the province's Chief Veterinarian. These licences allow lay outlets to dispense certain veterinary drugs or medicated feed. Medicated feed licenses allow feed manufacturers to make and sell medicated feeds containing veterinary drugs. These drugs must either be incorporated under veterinary order or in accordance with Schedule A, as outlined in the regulations, which lists agents that can be incorporated without veterinary prescription. These are agents that have been previously approved for use in animals feeds and have associated safety and use instructions. To date, only oxytetracycline at a specified dose can be used in this fashion for food fish. Holders of these licences cannot dispense a drug or medicated feed without the personal supervision of a licensed veterinary drug dispenser. The role of the licensed dispenser is to draw the purchaser's attention to toxicity warnings and precautions to be taken with respect to products intended for human consumption and to ensure that drugs that have exceeded their expiry date are destroyed or returned to the manufacturer. The veterinary prescription with its accompanying instructions fulfills a similar purpose. A licensed drug dispenser must pass an examination set by the Provincial Veterinarian respecting the use, abuse and properties of veterinary drugs. The competency of this person may be checked by later examinations. A holder of a medicated feed licence or veterinary drug licence must keep records of drug or medicated feed purchases and supply these records to the Chief Veterinarian before February 28 each year. In addition, licensees must retain copies of their records for two years. If medicated feeds are made on the written order of a veterinarian, the licensee must retain a copy of this order and forward the original to the Chief Veterinarian. The Chief Veterinarian can also require that the licensee retain copies of all drug sale records. These reports have been reviewed periodically in the past by the provincial Fish Health Veterinarian for the purpose of assessing patterns of drug use in the industry (J. Constantine pers.comm.). Data regarding patterns of medicated feed use in 1995 examined for this review were also derived from these reports. As this information is not stored on a readily accessible computerized database, review of drug use information in B.C. is currently very time-consuming.

The Aquaculture Regulations of the B.C. *Fisheries Act* impose further requirements for drug use to be recorded. A licence holder must keep a record of drugs administered to the holders fin fish. Information in these records must include:

i) the aquaculture licence number and the name of the holder,
ii) the location of the facility,
iii) the species of fin fish cultured and held,
iv) the name of the veterinarian who prescribed any drug, and
v) a log naming the drugs, how they were administered, the treatment schedule including the date treatment began, the date of last treatment and the name and signature of the person responsible for administering each treatment.

These records must be made available to appropriate MAFF enforcement staff. The Provincial Fish Health Veterinarian, however, does not have the authority to request this information. When a person delivers farmed fish to a processing plant, the person must, at the time of delivery, present the above information. The processor must also be provided with the date of harvest, the name of the processing plant to which fish are delivered, and the quantity of fish harvested. The processing plant must retain copies of these reports for one year. These regulations also prevent fish from being harvested for 105 days after administering a drug unless the *Federal Food and Drug Act* or regulations provide standards for withdrawal periods for the drugs used or the drug is prescribed by a veterinarian who has prescribed a mandatory period that must pass before fish are harvested.

The provincial *Pesticide Control Act* specifies similar regulations for pesticide use. These regulations preclude the use of a pesticide on public land unless the person is, or is supervised by, a recognized pesticide applicator. The process of becoming a pesticide dispenser or applicator is similar to that for a licensed drug dispenser and includes a system of knowledge examination. This Act is administered by the Ministry of Environment, Lands and Parks. This Act does not allow for the sale of a pesticide for use in or on a natural body of water except in accordance with the conditions stated on the use permit. To use a pesticide on public land or in or on a natural body of water requires a use permit. An annual summary of sales of reportable pesticides must be prepared by vendors of pesticides to government agents before licences are renewed or current ones expire. For persons using pesticides on Crown lands or for farming purposes a record of use must be kept which records information similar to that required on records of drug use on fish farms. These records must be retained for three years. Copies of use permits and relevant maps must be made available to the public within the vicinity of pesticide use. Some degree of public notification of use can be required.

The B.C. regulations regarding records for drug use in salmon farms contain most of the same elements contained in the Norwegian system for drug use surveillance as described by Bangen *et al* (1994). The principal difference is that, although the elements of a drug use surveillance system are in place in B.C., the information is not routinely collected, analyzed and published. The Norwegian program requires that veterinarians send a copy of all prescriptions of drugs for farmed fish to a central government agency on authorized standard prescription forms. In B.C., the holder of the licence, whether an aquaculture licence or medicated feed licence, rather than the veterinarian must supply this information. Also, unlike B.C., Norway has a central Medicinal Depot that supplies each pharmacy with drugs and records drug sales to authorized feed mills, thus simplifying the task of verifying reports with sales figures. While a record of all drug use in B.C. is available for inspection with slaughtered fish, this data is not routinely stored and analyzed for trends. Instead, it is simply audited as part of federal Quality Management Programs.

Siting regulations may help to reduce public health risk that may be associated with waste discharges from fish farms that contain bacterial and chemical wastes. In the Lands Branch's directives regarding how to process applications for finfish aquaculture for the duration of the "Action Plan for Salmon Aquaculture" project, the guideline for siting a salmon farm near an existing shellfish lease or wild shellfish bed is 125m. The basis for this guideline was not given in the guidelines although the literature tends to report that when found, drug residues in shellfish associated with salmon farms tended to be found in the immediate vicinity of the farm. However, reports did measure residues in food species beyond 125m. In a letter submitted to this review, the B.C. Shellfish Growers Association stated that they did not feel that the safety or quality of their products were threatened by the current system of managing finfish aquaculture in the province. However, representatives of First Nations and other stakeholder groups informed this review of public concerns regarding contamination of invertebrate food sources near salmon farms. Additionally, reports of drug residues in mobile species such as crabs and the possibility that escaped fish may contain residues of drugs may extend the zone of impact. The distance guidelines can be increased if adjacent shellfish farmers express concerns or if recommendations from either the Ministry of Agriculture, Fisheries and Food or Department of Fisheries and Oceans are received. However, these guidelines can also be relaxed if the applicants demonstrate the proposed location is environmentally and socially sound.

The role of the B.C.'s Fish Health Veterinarian includes monitoring the use of drugs on farms. This person reviews treatment records on farms as well as evaluating reports from licensed medicated feed manufacturers. These activities allow for a periodic review of the types of medication being used and the diseases being treated. The Fish Health Veterinarian has also been involved in investigating allegations that unlicensed compounds were used on salmon farms. A review of her 1994/95 Annual Report briefly describes such a case. In response to the allegation, the veterinarian visited the farm, reviewed drug treatment records and sent samples to be screened for drug residues. No problems were detected in this particular case.

Industry

Salmon Health, an industry-led program with the objective of ensuring the availability of safe and effective drugs for fish health management in Canada, is currently working to develop national standards for therapeutant use that can be implemented by regional producer associations. They are attempting to adapt and apply the Hazard and Critical Control Point (HACCP) principles developed for aquaculture in the United States. This program is intended to reduce drug residues in farmed salmon. However, it is still in the development phase and therefore its effectiveness could not be assessed.

Other jurisdictions

Two prominent international activities are relevant to the issue of safe use of chemicals in fish health management in B.C. The first is the draft code of hygienic practice for the products of aquaculture that has been produced by the Codex Alimentarius Commission, a joint commission of the World Health Organization and the Food and Agriculture Organization of the United Nations. B.C. already conforms to the majority of their recommendations regarding dispensing, prescribing and safety requirements. This organization emphasizes the importance of programs designed to prevent disease as the primary means for limiting drug use in aquaculture. This concurs with standard veterinary practices for terrestrial species, which promote preventing disease, drug use and resistance problems by maintaining the health of captive stocks. The organization recommends that Extra-label use of drug products to be undertaken only by veterinarians and that an extended withdrawal time be used. Good practice in the use of veterinary drugs, as defined by the Codex Alimentarius Commission, is the "official recommended or authorized usage including withdrawal periods, approved by national authorities, of veterinary drugs under practice conditions." The primary concerns in these recommendations are toxicological hazards to human health and other public health risks. This commission suggests that the best way to control drug residues in farmed fish flesh is through a program of pre-slaughter control. If the average drug concentration in fish tested prior to slaughter is above the maximum residue limit set by national authorities, then slaughter should be postponed. Such a system requires access to adequate laboratories to ensure rapid and reliable testing of samples. The commission recognizes that although pre-slaughter checks are a good idea, they are not always practical and no good methodologies exist for examining fish flesh for residues in a fashion fast or accurate enough for policing withdrawal policies. Therefore a system of post-slaughter checks, as seen in Canada, is recommended.

The commission recognizes that a proportion of drugs used in aquaculture can enter the environment. They, therefore, recommend that the use of drugs should be limited to the extent possible and that medicinal agents with low toxicity to aquatic organisms and which degrade rapidly in the environment should be encouraged. As occurs in B.C., the commission recommends that the veterinarian and/or fish farmer keep records of drug use and that adverse effects on fish, human or environmental health be reported. In Canada, aquaculture drugs in the environment are considered wastes under the *Canadian Environmental Protection Act*. Therefore, the Bureau of Veterinary Drugs does not have the mandate to evaluate an aquaculture drug's environmental impact when considering approval. However, this agency will request ecotoxicology data from the manufacturers when an approval is being reviewed.

The United States Food and Drug Administration (USFDA) has adapted the HACCP approach to aquaculture drugs. The purpose of this guide is to help regulatory authorities assess the hazard of using an unauthorized or unapproved drugs. The USFDA recognized that, due to the limited number of drugs that are approved for aquaculture, unapproved drugs will be used. The HACCP procedure, now commonly employed in public health and food inspection, allows for the regulatory authority to gauge the potential hazards that the use of an unapproved drug may represent and to identify the critical point at which the hazard can be reduced or eliminated. Hazard control in this case revolves largely around the utilization of FDA approved drugs or drugs that have been prescribed by a veterinarian. In addition, reviews of farm drug use history and residue test are also used to assess hazards generated by drug usage.

Norway prides itself on its current record of no drug residues in exported fish (Armstrong, 1993). The current regulatory system in Norway grew out of a previously complex and confusing system that was in place when the industry first developed. Much of the current system of drug control in Norway is present in Canadian legislation such as the *Food and Drug Act, Feeds Act,* and *Pharmacy Act.* Unlike in Canada, Norwegian veterinarians have a “free right of prescription” in which the state cannot stand in the way of a veterinarian prescribing a pure drug substance for the treatment of an animal disease. In addition, the *Norwegian Animal Welfare Act* dictates that a veterinarian has a responsibility to treat a diseased animal if a treatment is known . This differs from Canada, where a veterinarian can only prescribe, in an extra-label fashion, a drug that is already approved for another species. As more drugs are available for use in salmon in Norway, the primary objective of their regulations is to prevent food residues (Armstrong, 1993). The Norwegians employ a system of pre-slaughter residue screening. A pre-slaughter check must be conducted on any fish from a farm that has been treated with an antimicrobial drug within the preceding 12 months. Thus a condition for licensing an antimicrobial drug in Norway is the availability of a microbiological screening test. Until recently, the Norwegian government held a monopoly on drug distribution. This allowed for centralized supply and monitoring of drug use. Although new conditions of the European community have weakened this monopoly, the Norwegian government requires similar reporting from all drug suppliers. Finally, a notable difference between the prescribing, monitoring and regulating of drugs in Norway and Canada is the much larger number of veterinarians involved in aquaculture in Norway. Up to 200 veterinarians are said to be involved in the Norwegian industry compared to than fewer than a dozen in B.C.

VI. CONCLUSIONS

There is a wide range of opinion regarding the health impacts of commercial salmon farming. While some feel the available evidence indicates that the transmission of diseases to wild stocks and ecotoxicological effects of drug and pesticide use in salmon farming represent significant and unacceptable threats to the environment, others have concluded that the industry generates only minimal environmental effects that are neither significant nor irreversible. The lack of prevalence or incidence data for fish diseases in B.C. prevents accurate description or quantification of the risk of disease interaction between wild and farmed salmon in B.C. The lack of information regarding the ecology of sea cages restricts attempts to identify wild species at high risk of encountering health threats arising from salmon farming. Accurately estimating the risk of disease in wild fish due to the activities of salmon aquaculture in B.C. will require more information than is currently available.

The primary health hazards to wild fish from salmon farming are those outlined in the terms of reference for this review. Public comments identified additional concerns regarding human health, particularly degradation of seafood quality and safety. Ecological and economic costs, both public and private, can result from fish disease outbreaks. It can be concluded that the prevention and reduction of disease in farmed salmon should be a shared goal of advocates, critics and regulators of the industry.

Both advocates and critics of the industy viewed the importation of exotic bacteria, viruses or parasites as extremely undesireable. The introduction of an exotic virulent infectious agent into B.C. could generate new industry costs due to mortality and control efforts as well as the possibility of international trade barriers. It is biologically plausible that the introduction of an exotic pathogen into wild fish populations in B.C. has the potential to negatively impact wild stocks, particularly those compromised by other factors, as well as to generate societal costs due to public efforts to control or eliminate the introduced agent or mitigate its effects. Although preventing the introduction of exotic pathogens into B.C. is a shared fish health goal, there is disagreement as to the extent of regulations that should be employed to meet this goal.

Given the large number of fish or fish products that have been moved throughout the world and the relatively low number of reported serious outbreaks of disease in wild stocks associated with these movement, it follows that the probability of serious disease outbreaks due to importing pathogens to B.C. is low but not zero. The lack of evidence of importation of exotic pathogens into the province during the course of history of salmon farming in B.C. further suggests that, given current policies, there is a very low probability that exotic disease will enter the province and cause measurable negative effects to indigenous fish populations. If a pathogen was imported, farmed fish would be most vulnerable to widespread losses. International examples of significant impact on cultured and wild stocks associated with fish movement remind us of the economic and biological costs that can accompany the importation of exotic pathogens. Thus the risk of importing disease is higher than probability estimated alone would indicate. Although existing importation policies are among the most rigorous in the world, they do not apply risk assessment methods equivalent to those applied to the importation of terrestrial species into Canada or those developed for fish importation in other jurisdictions.

None of the reports uncovered in this review was able to satisfy accepted causal criteria to prove or disprove that salmon farming activities increase the rate of indigenous diseases in wild fishes. Conclusive evidence of indigenous agents transmitted from farmed to wild fish, resulting in negative population effects on wild stocks, could not be found during this review. There was also no conclusive evidence that agents have been transmitted from farmed to wild fish in B.C. Nevertheless, it is reasonable to conclude that wild and farmed fish are exposed to and can be infected by the same organisms in B.C. It is also reasonable to assume that some wild fish can be exposed to pathogens of farm fish origin in B.C. However, it is not possible to confidently reach conclusions as to the ecological importance of such exposure.

The probability of moving infectious agents within the province is higher than for the introduction of an exotic agent. The use of zoning based on the estimated distribution of native diseases and requirements that only fish not exhibiting signs of specific diseases or agents be moved significantly reduce the risk of serious or irreversible effects arising from the movement of indigenous pathogens. However, the current system for approval of transfers of fish within the province is insufficiently standardized or monitored. The lack of explicit methodologies for sampling and testing fish, coupled with the lack of staff available to confirm the health status of transferred fish, provides opportunities for fish with specific diseases or infections to be moved unknowingly throughout the province.

The low level of support for provincial and federal government fish health programs has not allowed for routine, systematic surveillance of disease and thus restricts government's ability to generate and assess fish disease data needed to identify priority health issues and to develop appropriate disease risk reduction programs. By focusing its fish disease surveillance primarily on enhanced salmon, the federal government lacks sufficient data with which to assess changing patterns of disease in wild stocks interacting with farms. The low level of government-sponsored fish disease surveillance, control or prevention programs is inconsistent with the way in which other food-producing industries and animal health disease issues are addressed by Canadian governments and, given the existing scientific uncertainty, is an important limitation of government efforts to identify, prevent or mitigate potential health impacts of salmon farming.

The tremendous variation and methodological limitations of investigations of the fate and effect of drugs used in salmon farming make generalizations regarding their effects difficult. No direct evidence of adverse human or fish health effects of antibiotic use in salmon farming could be found. The transference of antimicrobial drug resistance from marine or aquatic organisms to humans is a hypothetically possible yet unproved concern. International literature coupled with previous reviews of transference of resistance from animals to man suggest that the incremental increase of antimicrobial resistance in human that has been postulated to arise from salmon farming would be very small in comparison to alternative sources of resistant organisms. Some experimental and observational evidence support the contention that pesticide use in marine and aquatic environments can have lethal and sub-lethal effects on individual animals. However, there were no reports available to indicate the extent or duration of population effects that may arise. As B.C. has not allowed the use of pesticides on salmon farms, their negative effects remain a potential yet unrealized risk. There are reports of non-target adverse effects associated with ivermectin use, but no reports were found regarding ecological impacts. Data regarding the extent of use of ivermectin in B.C. were unavailable, thus preventing an evaluation of the risks its use presents in B.C. The reader is referred to the section on waste discharges for a more complete evaluation of ecological effects of pesticide and anti-parasitic drug use in salmon farming.

While a framework for drug use surveillance exists in B.C., inadequate resources coupled with insufficient data collection, storage and retrieval systems prevent timely and regular review by government agencies of drug and pesticide use. The high degree of veterinary involvement and limited number of products that can be used without veterinary prescription are unique in food production and allow for better control and monitoring of patterns of drug use as compared to other agricultural sectors. The risk of human exposure to antimicrobial drug residues in marketed farmed fish appears only slightly higher than for terrestrial species. The probability of human exposure to tissue residues of antimicrobial drug residues in wild species captured near fish farms is low, and exposure will be largely restricted to areas in close proximity to farms and within narrow time frames. However, drugs of aquaculture origin could be moved beyond the immediate vicinity of treated farms if fish escape before the drug withdrawal period expires or if mobile species such as wild fish or crustaceans ingest sufficient drugs to develop harmful tissue residues. The likelihood of a severe adverse human health effect resulting from the ingestion of seafood with residues of antimicrobials used in B.C. is also low. However, consumers should be afforded the opportunity to avoid consumption of food products containing drug residues. This is particularly true for communities with heavily marine-resource dependent diets. This review was unable to find data that farmed salmon in B.C. present human food-borne infectious disease risks greater than those presented by wild fishes.

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APPENDIX A: KEY DEFINITIONS OF DISEASE AND HEALTH

Definition #1: Disease

Changes in the structure or function of a body that present a particular set of signs and symptoms that are distinctly different from what is considered a normal state.

Our lack of understanding of what is considered a normal state for many individual fish and fish populations is one of the major impediments to our understanding of fish disease dynamics. Because of the importance of infectious disease in cultured fish and scientific interest in fish tumours, fish diseases have frequently been studied by individuals with training in microbiology or pathology. The availability of expertise in fish pathology and microbiology, coupled with a dearth of information about clinical fish medicine and epidemiology, have resulted in an emphasis on pathological lesions and microbiological findings in a majority of the published descriptions of fish diseases (Stephen, 1995). However, the presence of a pathological lesion or the isolation of a microorganisms or parasite should not be confused with the diagnosis of a disease.

The development of a disease is not as simple as exposing a fish to a pathogenic organism. In order for a disease to occur, there must exist fish which are susceptible to the organisms or agents that cause the disease. These hosts must be capable of exhibiting the disease response. A disease causing agent must also be present. This agent, whether chemical or biological, must be capable of causing the disease outcome and must be presented in a dose large enough to incite a negative host response. The environment acts as the essential element that often determines whether or not a disease will occur. The importance of the dynamic relationship between host, agent and environment in determining the likelihood of serious or irreversible disease outcomes is illustrated throughout this report.

Definition #2: Health

The extent to which an individual or group is able to satisfy needs and cope with changes in the environment. It is a resource of everyday living that represents a balance between social, biological and societal goals.

This definition is an adaptation of the World Health Organization’s definition of health (Nielsen, 1992). Health is not simply the absence of disease. Therefore, it is important to decide if the outcome of concern in a health risk assessment is the absence of disease, or the presence of health. Just as the presence of a pathogen in an individual should not be confused with a disease, the presence of a diseased individual should not be taken as an indication of an unhealthy population. Disease can decrease the economic or ecological efficiency of a population through decreased growth and reproduction, altered behaviours or increased mortality rates but it does not always cause such negative effects.

The spectrum of health outcomes available for measurement are varied. The outcomes utilized for a risk assessment will depend on the goal of the risk assessor. For programs intended to prevent the entry of new microorganisms into Canada, the disease status of a fish is irrelevant; instead its infections status is of concern. Alternatively, for programs intended to monitor the health of wild stocks of fishes, measures of recruitment, exploitation, growth rate or mortality may be more appropriate. In such cases, the detection a specific pathogens or detection of cases of disease will often provide an incomplete and potentially misleading measure of population health. It is therefore essential that before establishing a fish health program, the goals of the program be identified.

Definition #3: Infection

The colonization of a host with pathogenic replicating microorganisms that incite a host response.

The finding of a potentially pathogenic microorganism is often confused with the diagnosis of a disease. However, there are many ways by which a microorganism can interact with a fish host:

Mutualism: In a mutual relationship, both the host and the microbe population benefit from the relationship. Bacteria that normally inhabit the gastrointestinal tract of vertebrates are examples. The host provides a protected environment and nutrients for the microbe, and the microbes assist the host in digesting food and by out-competing potential pathogens. Microorganisms living in benign coexistence with its host are a fish's normal flaura. Normal flaura can vary between individuals, species and geographic locations.

Infections: In an infection, microorganisms colonize and reproduce in or on a host. Unlike normal flaura, infectious agents incite a host response designed to get rid of the invading organisms. An organism capable of causing disease is a pathogen. Pathogenic organisms are not usually normal flaura. However, under specific circumstances of altered host susceptibility or the movement of normal flaura to unusual body locations (e.g., the contamination of a skin wound with intestinal organisms), normal flaura bacteria can become pathogens. Similarly, environmental organisms that normally do not cause infections can cause infections and disease in immunocompromised hosts. Infections can range from asymptomatic to lethal. When considering macro-parasites such as worms or lice, the term infestation is used instead of infection, yet the principles of interaction with the host are similar.

Asymptomatic infections do not cause signs or symptoms that are readily observed. Fish do not appear ill despite some degree of a host response. An infection can be asymptomatic at the time of initial infection (incubation period), mid-infection or upon recovery. An infection is considered sub-clinical if it does not result in obvious clinical signs, but does reduce the productivity of affected individuals or populations (Thrusfield, 1995). Asymptomatically infected fish present a special challenge to disease control programs as they are capable of shedding infectious organisms, but can easily escape detection. An asymptomatic fish that sheds infectious organisms is termed a carrier.

Definition #4: Pathogen

Any disease producing microorganism

A successful pathogen must be able to attach, enter and multiply within the host organism and must be able to overcome the defence system of the host. There are two types of pathogens: obligate and opportunistic. An obligate pathogen is one that depends on the host for its survival and, when in the host, incites a disease response. An opportunistic pathogen may or may not require the host tissues as part of its normal life cycle. Typically, these organisms are not associated with disease unless they occur in an unusual host or location. A host can be "unusual" in one of two ways. First, it may not be the animal that the microorganism usually lives on or in. For example, the hantavirus that has recently caused deaths in people in B.C. does not produce disease in deer mice, its usual host (Stephen *et al*, 1994). Second, a host can be unusual if its normal defence system is altered. Common examples of this are seen in Acquired Immunodeficiency Syndrome (AIDS) patients. Many AIDS patients die from organisms that usually do not cause disease in people with intact immune systems. Whether or not an organism is a pathogen will depend on characteristics of the organism, where it resides in nature, and features of the host. Pathogen, like many other aspects of disease, is a relative term.

Microorganisms vary in their ability to invade a fish and cause disease. This ability is described in terms of virulence and pathogenicity. Pathogenicity refers to the ability of an organism to induce disease. The ability for an organism to cause disease will vary with differing host and environmental variables. Virulence is the ability of an infectious agent to cause disease in terms of severity (Thrusfield, 1995). A highly virulent organism is one that causes severe disease, and often death. The "cold virus" we have all suffered from is pathogenic but not highly virulent. The hantavirus, which kills approximately 50% of the people it infects (Stephen *et al*, 1994) is a highly virulent pathogen. This is an important distinction to remember later in this paper when considering issues such as the effects of antibacterial resistance. The ability to resist the effects of a drug does not necessarily increase the virulence of a particular strain. In addition, the resistant strain will only be more pathogenic than susceptible strains to the infected host if the host is being treated with antibiotics. Similarly, an organism may be pathogenic in hosts that have no acquired or inherent defence against the organism, but non-pathogenic for individuals with intact defences. The virulence of a pathogen can vary between and within species or strain depending on the host's response to the organism.

Definition #5: Cause of a disease

Cause: that which brings about a condition or produces an effect

A disease is caused by the interaction of the host, the disease causing agent and their shared environment. Disease results when a particular combination of risk factors develop. A risk factor is any host, agent or environmental factor that increase the probability that an adverse health effect will occur. No one single factor is capable of causing a disease on its own (Rothman, 1976). Factors that produce disease under one set of circumstances may not in others. Variability in the fish-agent-environment interactions can complicate efforts to predict the outcome of changes in risk factors. However, certain factors are required to produce a disease. These are known as necessary factors. For example, bacterial kidney disease cannot occur without the presence of sufficient amounts of *Renibacterium salmoninarum,* the bacteria associated with the disease.

Establishing a causal relationship is one of the more difficult tasks of veterinary research. Although laboratory research often provides critical information for understanding the pathology and individual mechanisms of a disease, they are rarely sufficient to determine how a disease outbreak occurs or how a disease is maintained in a population (Susser, 1973). Observational data derived from populations of concern are usually required to understand the role of various risk factors. Appendix B lists criteria that are applied to observational data to determine if a causal relationship exists.

Definition #6: Disease Control

Actions taken to reduce the probability of the occurrence of disease in individuals and to reduce the incidence of disease in populations.

The goal of disease control programs is to identify and manipulate risk factors in order to reduce the probability of disease. It is not necessary to remove the necessary cause to prevent disease from occurring. Diseases can be prevented from occurring by modifying the host, agent or environment. Immunization is an example in which the infectious agent that is the necessary cause of disease is not removed, but the host susceptibility is modified so that disease does not occur. The only way to eliminate all likelihood of a disease occurring is to eliminate the necessary cause from the population. Attempted eradication of pathogenic organisms has often formed the basis of fish disease control programs. However, this has rarely been entirely successful. Efforts to eradicate microorganisms require intense surveillance and testing of all fish at risk. These efforts tend to be very expensive. While often able to greatly reduce the level of a pathogen in a population, eradication schemes are often unable to completely remove the microorganism. The feasibility of a disease eradication program depends on: (Smith, 1995)

- the presence of a reliable diagnostic test for identifying reservoir or carriers
- an effective method for destruction of the agent in reservoirs
- a small host range
- a single or limited number of avenues for spreading the agent that can be readily manipulated
- acceptability of industry or other members of society
- sufficient financial and human resources.

To date only 12 major animal diseases have been eradicated from the United States (Smith, 1995). Eradication of disease is particularly difficult for fish and wildlife as the natural history of the pathogens is rarely completely understood, there may exist several alternative hosts for the microbe, and the re-introduction of indigenous pathogens can be difficult to control. Exceptions to this are found in freshwater, land-based aquaculture situations such as hatcheries where water supplies can be carefully managed, or in the case of exotic pathogens where efforts can be taken to prevent entry of the pathogen.

APPENDIX B

Criteria for Assessing Cause-Effect Relationships from Observational Data

An association between an exposure and a disease does not imply they are causally related. The requirements given by Hill (1965) and by Evans (1976) are often cited as criteria for establishing causal relationships. These criteria act as guidelines. Rarely is there evidence for a specific cause to fulfill all of these requirements. They are presented here to remind the reader of the complexity of trying to prove that a factor leads to disease.

1.1 Hill's Criteria

1. There a clear, measurable, statistically significant association between the exposure and the disease. (Strength of Association)
2. The association between the exposure and the disease has been observed by different persons, in different places, circumstances and times.(Consistency of Association)
3. The exposure always produces the disease. (Specificity of Association)
4. The exposure closely precedes disease. (Temporality)
5. An increase in exposure produce an increased frequency or severity of disease. (Biological Gradient)
6. The hypothesized causal relationship is biologically plausible—what is biologically plausible depends on the knowledge of the day. (Plausibility)
7. The causal relationship is consistent with the known natural history and biology of the disease. (Coherence)
8. There is experimental or semi-experimental evidence from other populations that show the same relationship (Experimental evidence)
9. There is a similar known relationship involving another disease or related type of exposure. (Analogy)

1.2 Evans' Postulates

1. The proportion of currently diseased individuals should be significantly higher in exposed fish than in unexposed fish.
2. The proportion of exposed individuals should be significantly higher in diseased fish than in non-diseased fish.
3. The proportion of new cases of disease should be significantly higher in exposed fish than in unexposed fish.
4. Disease should occur following exposure, with incubation periods showing a bell-shaped (normal) distribution.
5. A spectrum of disease should result from a logical gradient of exposure.
6. Disease should occur consistently following exposure in healthy populations, an increased level of disease should occur consistently following exposure in affected populations, and no disease or increase in disease should occur in fish with no exposure.
7. Experimental evidence should show exposure leads to disease.
8. Removal or modification of the exposure should decrease the incidence of the disease.

9. Prevention of the exposure, or modification of the host's response to the exposure, should decrease the incidence of the disease.

10. The exposure should be biologically and epidemiologically credible as a cause of the disease.

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APPENDIX C: DETAILS OF METHODS OF INFORMATION COLLECTION

1. Computer databases used in literature review

(1) Life Sciences Collection—journal articles and abstracts related to life sciences from 1984 onwards,
(2) WAVES—monographs, technical reports, internal studies, commissioned reports and publications held by the Department of Fisheries and Oceans libraries,
(3) CAB—journal articles, monographs, conference proceedings, theses, technical reports and patents related to science from 1972 onward,
(4) AGRICOLA—journal articles, monographs, theses, patents, audiovisual materials, software and technical reports related to agriculture (including aquaculture) from 1970 onwards.

Items were selected where the title or subject key words included "salmon" and any string of characters of related terms such as "disease," "sample," "diagnosis," "BKD," "renibacteri," "IHN," "aeromonas," "copepods," or "lice." The search identified 2965 titles (Life Sciences = 286; WAVES = 147; CAB = 2295; AGRICOLA = 237). There was significant overlap between the search results from the different databases.

2. Personal Communications

Association of Aquaculture Veterinarians (AAVBC)
G. Bates. Community Liaison, Community Enhancement Projects. Department of Fisheries and Oceans. Port Hardy.
John Brocklebank. Brocklebank Mobile Veterinary Services. Comox.
L. Brown. Research Officer. National Research Council. Institute for Marine Biosciences. Halifax
T. Carey. Senior Program Advisor. Aquaculture and Fish Health. Aquaculture and Ocean Sciences Branch. Department of Fisheries and Oceans. Ottawa.
J. Constantine. Fish Health Veterinarian. B.C. Ministry of Agriculture, Fisheries and Food. Courtney.
L. Copeland. Manager, Food Protection Programs. Public Health Protection. B.C. Ministry of Health. Burnaby.
Cyprian Enweani. Manager Meat Hygiene Program. Agriculture and Agri-Food Canada. B.C. Regional Office. New Westminster.
D. Heath. Regional Manager, Pesticide Management Program. B.C. Ministry of Environment, Lands and Parks. Nanaimo.
Hicks. Vice-President. Pacific Aqua Salmon Farmers Ltd.. Vancouver.
S. Johnson. Research Officer. National Research Council. Institute for Marine Biosciences. Halifax
M. Kent. Head, Fish Health and Parasitology Section. Pacific Biological Station. Department of Fisheries and Oceans. Nanaimo.
D. Kieser. Fish Pathology Section. Pacific Biological Station. Department of Fisheries and Oceans. Nanaimo.
D. Kwok. Laboratory Specialist, Organic Residues Laboratory. Health Protection Branch. Health Canada. Burnaby.
D. Leung. Registrar. B.C. Veterinary Medical Association. Vancouver.
R. Lewis. Assistant Chief Veterinarian. Animal Health Centre. Ministry of Agriculture, Fisheries and Food. Abbotsford.
C. Mercier. General Manager. Canadian Feed Industry Association. Ottawa.
L. Mullens. Fish Health Veterinarian. Province of New Brunswick.
H. Nelson. Shellfish and Aquaculture Program. Pollution Abatement, Environment Canada. North Vancouver.
M. Pearce. Epidemiology Researcher. Epidemiology Services. B.C. Centre for Disease Control. Vancouver.
M. Roth. Technical Director. Pacific National Group Ltd. Vancouver.
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S. Schenkeveld. Inspections Branch. Department of Fisheries and Oceans. Burnaby.

H. Schwantje. Wildlife Veterinarian. Wildlife Branch. B.C. Ministry of Environment, Lands and Parks. Victoria.
Sheppard. Manager, Technical Services. Moore-Clark Canada. Campbell River.
I. Sobol. Medical Health Officer. Nisga'a Valley Health Board. New Aiyanish. Community Medicine Resident. University of British Columbia. Vancouver.
M. Thorburn. Department of Population Medicine. Ontario Veterinary College. University of Guelph. Guelph.
J. Thornton. Director of Research and Product Development. Microtek International Ltd. Saanichton.
M. S. Yong. Food Directorate. Bureau of Veterinary Drugs. Health Canada. Ottawa.
S. Wilson. Biologicals Evaluation Laboratory. Animal Disease Research Institute. Agriculture and Agri-Food Canada. Nepean.

APPENDIX D: ASSESSMENT OF DIAGNOSTIC TESTS

Disease diagnosis and detection play a major role in measuring and assessing health risks. Diseases can be diagnosed in the context of an individual or a population. A diagnosis can be made by using one or more of four criteria: (1) clinical signs and symptoms, (2) detection of specific agents, (3) reactions to diagnostic tests, and (4) identification of lesions (Thrusfield, 1995). A wide variety of information is available to diagnose diseases in individual fish (e.g., Stoskopf, 1993; Kent, 1992). The confirmation of the exact etiology of a specific fish disease often relies upon microscopic examination of tissues, microbiological procedures or serological tests (Stephen 1995; Kent, 1992). For infectious diseases, tests are often assessed by their ability to detect very small amounts of the pathogen and their ability to not "confuse" this agent with other similar organisms. Such measures, however, do not quantify how well a test will be able to determine the **disease or health** status of a patient or population. The outcome of diagnostic procedures can be recorded as observations or interpretations. Events may be recorded as being true, when in fact they are not. These errors can arise from faulty inferences based upon observations, or the inability of the diagnostic test or procedure to accurately classify a patient's or population's true disease status (Thrusfield, 1995). Such errors are associated with all aspects of human and veterinary medicine and are not unique to fish medicine (Sackett *et al*, 1991, Martin *et al*, 1987). Erroneous results may arise from human error, from failures or inadequacies in diagnostic machinery or reagents, or due to other imprecisions in the diagnostic methods applied. More importantly, no two cases of a disease present in exactly the same manner. A case will come to the attention of a diagnostician at any time in the course of a disease; at the initiation of the disease process when the patient may be asymptomatic, mid-disease when signs are expressed, or upon death or recovery. It is unreasonable to expect a single diagnostic test to be capable of recognizing all forms and presentations of a disease. Diagnostic errors can be amplified when the results of tests applied to a sample of a population are used to make inferences about the status of a larger group (Martin *et al*, 1992).

The ability of a test to reflect an individual's true disease status is affected by the frequency (prevalence) of the disease in the test population. As a disease becomes rarer in a population, the likelihood that a negative test result is truly negative increases and the likelihood that a positive test result is truly positive decreases. The opposite effect occurs as a disease becomes more prevalent. In most populations, disease is rare. By selecting certain subsections of a population, one can increase the proportion of fish in a sample that is diseased (Stephen and Ribble, 1994). This approach has been used in some disease monitoring programs (e.g., Amos, 1985). However, lack of knowledge of the prevalence of a disease prevents accurate determination of how well a test or series of tests is able to determine the status of a group. The evaluation of a test's ability to correctly classify the disease status of a population based on a sub-sample has been rarely done for diseases of fish. Sampling errors can modify the ability of samples of populations to be used as indicators of the presence, absence or prevalence of diseases within a larger group (Martin *et al*, 1992). These issues are important when trying to assign a level of certainty to the results of screening or monitoring programs. The development of programs to monitor diseases in population must consider characteristics of the disease, the validity of tests used to detect the disease, and the frequency and distribution of the disease in the populations of concern.

APPENDIX E: MONITORING AND SURVEILLANCE OF DISEASE

Disease monitoring represents an ongoing effort to assess the health and disease status of a population. The activities associated with monitoring are the collection, processing, summarization and dissemination of health information. The most frequently cited reasons for establishing a monitoring program include: (a) estimating the frequency of a disease, (b) certifying that a disease is absent, (c) the early detection of foreign or emerging diseases, and (d) the acquisition of information upon which to base management decisions (Martin *et al*, 1987). Ideally, a program of fish disease monitoring and surveillance should provide a quick response to disease outbreaks, provide information for planning fish health programs, report and evaluate new disease risks and stimulate and support research (Pettijohn *et al*, 1983). The information used in monitoring programs must be accurate and representative of the population of concern. The minimum data requirements for a monitoring program are: (a) enumeration of specific disease with respect to time, location and hosts, (b) characteristics of affected hosts, and (c) characteristics of the population at risk.

Disease monitoring information can be obtained by passive surveillance or active programs. Passive disease monitoring relies upon the voluntary provision of information from individuals or organizations outside of the surveillance agency. Reportable disease programs which rely on veterinarians or other diagnosticians for data on disease occurrence, reviews of submissions to diagnostic laboratories, and voluntary reporting by farmers to private or public organizations are examples of passive surveillance programs. Passive methods have the advantage of being inexpensive, but can suffer from accuracy and delays in reporting. In active surveillance, members of the surveillance agency or their designates generate disease data, usually through special surveys. Active programs are capable of producing more systematic and verifiable information, but are usually expensive in terms of dollars, time and personnel. Wild fish disease information must come from active surveillance as there are generally no alternative sources. Therefore, surveys of wild fish tend to be infrequent and limited in size. Methodological limitations currently prevent the development of a disease monitoring program for wild fish. This creates important limits in our ability to document changing disease risks. In a report of a viral disease outbreak among wild Kokanee, Traxler (1986) noted the current fortuitous nature of outbreak detection in wild salmon.

Several sources of information on diseases of cultured fish can be incorporated into passive monitoring programs. The accessibility of cultured fish for observation and sampling as well as better knowledge of the characteristics of captive populations makes the development of a monitoring program less problematic. In Alaska, a 15-year database of disease examinations in returning sockeye provides a unique chance to look at trends in enhancement stocks (Meyers *et al*, 1990). However, for fish raised as part of stock enhancement programs, only certain life-stages are available for disease monitoring. Once released, monitoring programs for these fish are subject to the same limitations as for wild fish. Neither wild fish nor a large segment of enhanced stocks are readily accessible for disease monitoring programs. Thus, the majority of the Pacific Ocean salmon population cannot be observed for changes in disease risk throughout all stages of their lifecycle.

There are three main sources of disease information for farmed salmon: (1) farm records, (2) veterinary records, and (3) diagnostic laboratory records. As many of the methods for diagnosing salmon diseases require the capture and destruction of a fish (Kent, 1992), random samples of statistically significant size are rarely conducted. Systematic sampling strategies which include a random component are generally required to develop accurate estimates of the prevalence or incidence of a disease (Martin *et al*, 1987). Standard guidelines for disease sampling in cultured fish can be seen in the “Fish Health Blue Book” (Amos, 1985) and Canadian regulations which arose from meetings of fisheries scientists and regulators for the expressed purpose of establishing disease diagnostic and sampling standards. Procedures for sampling to survey for the presence of specific pathogens or conditions generally recommend that the minimum sample size taken be large enough to detect the specific conditions at a 5% or greater prevalence with 95% confidence. For populations of 200 or larger, this strategy requires that at least 60 fish be examined. However, this sample size guideline is often misused or misunderstood. The statistical basis for this guideline assumes that there is an equal non-zero probability of sampling all fish in the population. It is also assumes that the conditions of concern are randomly distributed in the population. Neither of these assumptions is likely to occur in practice (Stephen and Ribble, 1994; Moller and Anders, 1986). Therefore, unless truly random sampling methods are used, these guidelines must be seen as simply that—guidelines, and not rules. The number of sampled fish needed will depend on a variety of factors such as condition being sought, the threshold prevalence of concern and the population dynamics.

In order to increase the likelihood that a disease, if present, will be detected, fish disease monitoring programs often focus on the subsection of the pen population most likely to be diseased. While this can inflate estimates of the magnitude of a disease or pathogen in the general population (Stephen and Ribble, 1994), they can increase the likelihood of finding affected fish. When describing procedures to examine fish for certification, the Manual

Compliance for the federal Fish Health Regulations recommends that moribund fish are first included in samples, with the remainder being made up of samples from the general population. Procedures for monitoring diseases in hatcheries are often biased towards collecting fish that are at the end of the raceways or trough, as these fish are often too weak to keep up with the main group. Previous surveys of the diseases of cage-reared salmon in B.C. have also relied upon moribund fish (Brackett and Newbound, 1990; Brackett *et al*, 1990; Brackett *et al*, 1991a, Brackett *et al*, 1991b). Caution must be used in extrapolating the results of these surveys to the general populations as slow-swimming salmon in net-cages can provide samples that do not reflect the overall proportional mortality ratio of the entire population (Stephen and Ribble, 1994). However, these surveys, particularly when supplemented with the examination of recently dead fish, can detect many of the diseases contributing to clinical illness and mortality in farmed fish. Because of the inherent biases of methods used to sample fish for illness, it is likely that surveys will tend to overestimate the prevalence of common diseases in the general population. However, due to limitations generated by imperfect diagnostic tests and the requirement to sample only portions of the population, the failure to find a pathogen or lesion in a sample does not guarantee that it isn't present, particularly in stocks for which a representative sample cannot be obtained or for which only a single, small sample is examined.

Fish collected at processing have been used to try to estimate population prevalence (St. Hilaire, 1996). This method allows for the application of random sampling methods, but is limited to examining only market age fish. Laboratory submissions are another sought-after source of surveillance data. Samples from diagnostic laboratories are recognized to be subject to selection biases and thus do not accurately reflect the true prevalence of the disease (Martin *et al*, 1987). This is because cases seen by diagnosticians do not necessarily reflect the distribution or frequency of a disease in a population, but are instead influenced by the familiarity of the farmer and veterinarian with the disease, the need for special tests for diagnostics, economic and other factors. Changes in patterns of laboratory use or in the demographics of the industry can influence perceived patterns of disease seen in laboratory data (Stephen and Ribble, 1995) Laboratory data are also limited in use for routine monitoring as they are generally considered by veterinarians and laboratories as confidential information that cannot be released without the expressed consent of the owner. This obstacle can be overcome by legislating that specific disease must be reported to a central authority. In certain countries, veterinarians must report all diagnoses to a central office for the compilation of country-wide statistics. Problems with such systems include large costs, non uniform diagnostic criteria, underreporting of disease not seen by veterinarians and insufficient information on animal characteristics (Henricson, 1975). To limit these problems, most countries, including Canada, require that only a select group of diseases be reported. These diseases are usually selected because of their economic or ecological significance.

Compared to monitoring, disease surveillance is more action-oriented as it is intended to detect changes in disease trends or distribution in order to initiate investigations or control programs. Surveillance can be defined as the continuing scrutiny of the occurrence and spread of a disease that is **relevant to its control**. It involves the collection and analysis of data and the dissemination of results to those that need to know in order to implement control. Whereas monitoring programs emphasize reporting of cases of disease over time, surveillance emphasizes the detection of changes in risk factors. As the goal of surveillance is to prompt actions aimed at controlling the spread, increased frequency or impact of a disease, it uses methods that are rapid and repeatable. Unlike monitoring programs, precision of diagnostic tests may be sacrificed in surveillance programs in order to get timely reports of potential changes in patterns of disease occurrence. The decision as to whether or not to develop a monitoring or surveillance program is dependent on the objectives and goals of disease control programs.

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Many other people contributed to various degrees, particularly the Review Committee, personnel from the EAO office and interested members of the public who participated at meetings. These people have not been listed, but their names are available on the public registry at the B.C. Environmental Assessment Office. In particular, personnel from the EAO office facilitated, assisted, distributed and encouraged beyond the call of duty. I congratulate them on an excellent job. A complete list of contacts and contributors is given in Appendix A.

EXECUTIVE SUMMARY

Waste Discharges

The British Columbia salmon farming industry wants to ensure fish health and optimum production. The Ministries of Environment, Lands and Parks (MELP) and Agriculture, Fisheries and Food (MAFF)want to ensure that the aquaculture industry is sustainable, environmentally responsive and responsible. What is immediately obvious is that there is no conflict in these goals. Reaching and maintaining them is the challenge. In this review, I have defined "impact" as a change in properties of the ecosystem caused by waste discharges from salmonid aquaculture. The word does not, in itself, have a negative connotation.

Net-cage salmon farming operations cause the release of a number of wastes into the aquatic environment. These include uneaten fish food, fish excretory products and organic matter from net-cleaning that enter the water column and/or settle to the bottom. The major components of solid and dissolved waste are various forms of carbon, nitrogen and phosphorus. About 80% of feed carbon and nitrogen ingested by fish becomes waste. Percentage of waste feed estimates for B.C. range from 3% to 17%.

There are a range of estimates for excretion rates for solid and dissolved waste nutrients, as well as for food conversion ratios for farmed fish. Thus, modelling efforts can produce an order of magnitude variation in estimates and fate of output. Nevertheless, evidence indicates that waste output per kilogram of fish produced has declined by about 50% in the past five years, with a concurrent increase in production of about 50%. This reduction in waste output is due to a reduction in food conversion ratios based in improved feed formulations and husbandry practices. Reduction of food waste and conversion ratios will continue to be a priority, as feed represents about 60% of the operating costs of fish farms in B.C.

Other components of direct net-cage output which are of concern include antibiotics, therapeutants, anaesthetics, pesticides, zinc in feeds, net antifoulants and cleansing agents. Other waste discharge issues which are minor in scale but can be locally important include sewage from workers, garbage disposal, offal and morts disposal.

Sedimentation Rate and Extent

The deposition of particles to the ocean floor around salmon net-cages appears to be limited to within 30 m in most cases. Various models, including the MAFF model for particle dispersion, have been used to estimate the extent of sedimentation around marine cage operations.

Predictions of deposition are complicated by lack of information about water column currents, bottom topography, resuspension events by tides and storms; effects of bioturbation and other biological activities; and the rate of chemical and biological oxygen demand versus oxygen exchange rate to sediments, which is related to how fast the benthic ecosystem can break down organic material. There is currently no information on the fate of suspended solid waste which can be carried off-site by currents and end up in intertidal areas.

Sediment Impacts

Total organic carbon (TOC) and related measures of organic matter accumulation in sediments reflect various levels of impact from organic enrichment. The deposition of organic waste products to sediments under salmon net-cages initially results in an increase in aerobic bacterial activity which increases the biological oxygen demand (BOD) of the sediments. If organic material continues to accumulate faster than the biota can break it down, oxygen levels decline, anaerobic bacteria increase, and by-products such as hydrogen sulphide are produced which are toxic to biota. Hydrogen sulphide may in extreme conditions escape into the water column in gas bubbles. The breakdown of organic matter under anoxic conditions is less energy-efficient than in oxic sediments, but will still continue to some extent.

As long as oxygen can be supplied to the sediments by bottom currents and the feeding and burrowing of larger animals, organic wastes will generate microbial breakdown of organics proportionate to the rate of carbon deposition. When carbon deposition exceeds the oxygen assimilation capacity of sediments, deoxygenation and organic buildup occur and are reflected in low redox levels, high organic content and high sulphides in marine sediments. Research indicates that this can occur at deposition rates of >4 g organic carbon/m2 per day. There is some concern that antibiotic residue in sediments from fish food may reduce bacterial populations, thus slowing the organic decay rate.

Any shift in sedimentation or chemical conditions will trigger a shift in benthic fauna composition. Under mild benthic enrichment from farm wastes, abundance and biomass will be enriched, particularly around the perimeter of net-cages, where mobile epifauna and bottom fish species are attracted to feed on the enriched biota and excess feed pellets. As enrichment increases, sediment oxygen declines, and larger macrofauna (particularly deep burrowers) and sensitive epifauna disappear first, followed by organic enrichment tolerant polychaetes (such as *Capitella capitata* complex), organic enrichment meiofauna such as nematodes, and finally all aerobic bacteria. Anoxia is characterized by black, highly reducing sediments with a solid white mat of sulfur bacteria on the surface. The degree of organic enrichment will determine the stage of impact.

Situations in which environmental degradation is occurring in cage-culture can be summarized as being the result of;

a) inappropriate initial siting of the cage operation,
b) over-production (either biomass and/or duration) for the assimilative capacity of the site, and
c) husbandry practices.

The technology (if not all the data) is available to deal with these three factors to prevent further environmental degradation. Environmental degradation from organic fish farm wastes is reversible by natural processes. Because the output from fish farms is almost all biologically available for breakdown, impacts are relatively short-term compared with other, more toxic forms of waste discharged to the marine environment (c.f. urban sewage or stormwater runoff, pulp mill effluent, mine tailings or wood fibre).

There are no clear answers about the effects on benthos from chemicals added to feed or used in operations. Certain fish diseases and pests are controlled with feed using antibiotics and therapeutants. Metabolic metals such as zinc are added to feeds and can accumulate in sediments. Other compounds, such as copper from anti-foulants on nets and cleaning agents for equipment become waste through practices associated with farming.

Based on sediment chemistry and biotic factors, we can tell when sediments under fish farms have recovered to various degrees. What the studies haven't answered is how physical oceanographic and organic water loading factors affect the time it takes to produce various impact levels, and how long it will subsequently take the site to recover when fish are removed. Estimates based on biological recovery and sediment chemistry range from a few months to five years in extreme cases. Estimates from MAFF monitoring data in recent years suggest that most sites will show no visual impact within six to 12 months. In general, the recovery time for fallowed sites will depend on;

1) how long the site has been in production and at what level;

2) bottom topography and currents
3) basin flushing time
4) level or intensity of impact at time recovery begins
5) presence of other sources of enrichment or toxicity

Water Column Effects

Concerns related to the effects of waste discharges from aquaculture on the water column include local build-up of ammonia from fish excretion and sediment remineralization; regional reduction in oxygen from fish metabolism and the breakdown of waste organics; hypernutrification of the water column from organic wastes resulting in increased production of phytoplankton; stimulation of toxic algal blooms; biotic uptake of pharmaceuticals and other chemicals added to feed or used in operations; and flow restrictions from net-cages affection deposition patterns in near-shore areas.

Modelling of water column assimilation capacity for ammonia and dissolved oxygen has been done for the Sechelt area in B.C., for Kyuquot Sound and for inlets and fjords in other jurisdictions. This exercise is very useful in determining the loading capacity feasible for isolated water bodies, and should be pursued in areas of concentrated fish farming (Broughton Archipelago, Clayoquot Sound) if the industry expands significantly from current levels.

The greatest concern about the effects of fish farms in B.C. on the water column is the possibility of hypernutrification which can stimulate algal blooms. This is a concern not only from an environmental viewpoint, but for the fish farmers themselves, since toxic algal blooms can cause significant mortality to caged fish. At the current level of salmonid culture in marine waters of B.C. there is no indication that hypernutrification or algal blooms in the water column can be related to salmon farming. However, hypernutrification has been noted in freshwater hatchery and lake-cage culture areas worldwide and is a particular concern in low productivity coastal lakes of B.C.

Chemical outputs to the water column and bacterial community changes are less well studied than in sediments. Antibiotics degrade quickly in seawater and residues found in nearby oysters are probably related to suspended particulates. There is no evidence of metals contamination in biota in the water column.

Other Impacts

Several categories of smaller scale outputs and impacts include net-cleaning operations, morts disposal, bleeding operations, offal disposal, sewage from farm sites and garbage disposal. Net-cleaning methods vary and the current understanding is that no chemicals are used for this purpose in B.C. The sloughed-off fouling organisms are an additional organic input to sediments, as well as the source of considerable shell debris and attractants to fish and other fauna. In addition, the material may wash up on nearby beaches if net-cleaning is not done appropriately. Fouling biota can contribute considerable ammonia to the water column if not kept under control. Offal disposal from processing and sewage disposal is permitted by MELP. Morts disposal is almost all off-site, by composting and ensiling at three licensed facilities in B.C. Topics for which there is less information are stun and bleed operations and garbage and debris disposal, although there are many anecdotal descriptions and complaints about garbage (see local information committee report for the Broughton Archipelago). There is no indication of sewage type bacteria in marine systems, although some have been found downstream of freshwater hatcheries in various jurisdictions (other sources not considered).

Impacts of Salmon Farms on Freshwater Habitats

There are two lakes in B.C. with lake cage culture and 17 commercial hatcheries. Hypernutrification through addition of phosphorus and nitrogen from salmon farm waste has been noted in freshwater streams from hatcheries and oligotrophic coastal lakes from lake cage culture. This is of particular concern in low productivity British Columbia lakes. Nutrient enrichment effects on lakes must be carefully modelled and controlled to prevent stimulation of algal blooms, oxygen depletion and deleterious changes to productivity.

Sediment impacts in the two lakes currently used for smolt culture are of less concern due to existing high organic carbon and thick organic layers. In addition, the lack of significant commercial or food resources living in sediments or reliant on deep sediment fauna makes the sediment impacts in freshwater of less concern than in the marine. However, remineralization of nitrogen and phosphorus from sediments during lake turnover could affect water column productivity.

Risk Assessment and Current Approaches

Environmental protection related to waste discharges is the responsibility of MELP, but the ministry is obviously under-resourced and hampered by an unwieldy communication flow with the industry and the other major regulatory agency, MAFF. The MELP mandatory monitoring program has proven unsuccessful and has been allowed to lapse. More recently, cooperative monitoring efforts by MELP and MAFF have provided valuable site-specific information which may be used as the partial basis of an industry-wide re-evaluation of siting and site-capacity for existing farming operations. This information, in conjunction with complete site evaluations from existing and proposed farm sites, will be invaluable for ground-truthing the Broughton Archipelago siting and discharge model under development by MAFF. This information needs to be compiled, computerized and analysed in a consistent manner so it is accessible.

Proper risk assessment on a site specific basis can then be performed. A list of risks in order of general importance includes:

Negative

- organic overloading of sediments and sensitive benthic biota
- smothering of important food or commercial species
- biotic and human assimilation of feed and operations chemicals and metals
- increased water column and shoreline turbidity
- eutrophication of freshwater lakes and rivers
- antibiotic resistance in sediment bacteria and non-target organisms
- water column oxygen depletion of poorly flushed water bodies
- benthic and shoreline debris or sewage from workers

Positive (to be weighed against negative)

- increased productivity of biota around salmon farms
- increased productivity of oligotrophic freshwater lakes
- potential for multi-species aquaculture

Currently there are no guidelines or criteria for sediment effects, waste or pharmaceuticals discharge from fish farms in B.C. These are required to effectively regulate the industry. Some examples are given for other jurisdictions or based on data collected in B.C., and include guidelines for TOC, sulphides, redox, % indicator organisms and visual criteria of sediments. Recommendations will be jointly made by the Technical Advisory Team.

Following site-specific evaluations and the development of effective criteria, a plan of remediation needs to be developed for problem sites in consultation with industry, First Nations and concerned government and local organizations.

I. INTRODUCTION

This paper has been prepared in accordance with the terms of reference provided by the Environmental Assessment Office for the B.C. salmon aquaculture review. The paper addresses issues related to waste discharges from commercial salmon aquaculture operations in B.C. and focuses mainly on marine culture of salmonids. Although freshwater culture was laterally included in the terms of reference, it was emphasized that the marine component was of most concern. The problems involved in lake-culture of smolts will be similar in nature to those of trout-rearing operations. Hatcheries operated by government are outside the scope of this review.

The B.C. Salmon Farmers Association reported a total salmonid production of 22,000 tonnes for 1995 and 26,000 tonnes (dressed weight) for 1996. The total production limit on all aquaculture operations in B.C. is about 40,000 tonnes per cycle (18 months to two years—MAFF, August 1996). These values indicate that the industry is close to or exceeding its production capacity at present. The major waste discharges from salmon aquaculture in B.C. include the byproducts from waste food not eaten by fish, as well as the metabolic byproducts of waste excretion from the fish. These wastes contain a concentrated supply of nutrients, notably carbon, nitrogen and phosphorus. In addition, trace amounts of vitamins, some metabolic metals and any medications used in feed can constitute a component of material released into the water column or sedimenting to the bottom. Metabolic byproducts from the fish include solid waste from feces. However, the majority of excretion from fish is in dissolved form, notably carbon dioxide and bicarbonate, ammonia, ammonium and urea. Lesser wastes from salmon farming operations include substances related to auxiliary salmon farm operations, including sewage from human workers, net cleaning operations, morts disposal, bleeding and offal from product preparation, and garbage.

A number of issues of concern have been raised by members of the public or the review committee during the course of the EAO review. These issues will be addressed as possible, or as information permits, within the framework of this paper. Axler et al. (1996) discuss a case study of the freshwater culture of salmonids in abandoned pit mine lakes and emphasize the controversy and public reactions in the U.S. over real and perceived impacts from such intensive aquaculture operations. This emphasizes the need for a thorough review of what is known about salmonid aquaculture in B.C., what information can be extrapolated from other jurisdictions, and what information is lacking. In this way regulatory agencies, the industry and the public can make informed decisions about the salmonid aquaculture industry in B.C.

A. SOURCES OF INFORMATION

Much of the scientific literature from before 1988 was too old to be useful except for historical context and specialized subtopics. Siting parameters (particularly depth), husbandry practices and technology have changed too much in the past 10 years. Even some of the current literature from other jurisdications shows differences in culture practices that must be examined in context. The main focus of this review was salmon aquaculture practices in B.C. Key papers and reviews from other jurisdictions have been cited to serve as examples and to provide insight into mitigation practices used elsewhere. In addition, with the substantial reviews currently present, it was not necessary to re-review literature from other jurisdications. Recent reviews of salmon aquaculture in the primary literature include Iwama (1991), Levings (1994), Gowen et al. (1991), who discuss historical trends.

Several reviews of the industry from consultants have been useful for providing context and sources of data for waste discharge from salmon farming operations (Cross and Kingzett 1994, Hatfield and EVS 1996, ESSA 1993, Terran report—in revision, Ellis 1996). Several more consultant reports are in progress and will hopefully be available before the end of the review. A compilation of data collected by consultants (Thonney and Garnier 1993) for 52 sites in New Brunswick is currently being computerized and will be summarized in this paper.

In addition, there have been a series of consultant's reports and theses based on field surveys of salmonid operations in B.C. (Cross 1988, 1990, 1993, Anderson 1992, 1996; Miller-Retzer 1994; Mahnken 1993; Jones 1990). Monitoring data provided by MAFF and MELP have included sediment metals, organics and geochemistry, invertebrate taxonomy, field notes describing sites and practices, water column nutrients, physical properties and bottom video surveys from 1995 and 1996. Benthic infaunal samples collected from six sites in the Broughton Archipelago in January and July 1995 jointly by MAFF and KTFC, were analysed by Aquametrix Research Ltd. (Cross 1996). In addition, Ed Anderson kindly provided raw data on taxonomy and environmental variables for B.C. salmon farms in electronic form for summary and comparison with other work.

Reviews and updates on industry status by government agencies have provided contextual frameworks for data assimilation and interpretation. These include biophysical and coastal use resource surveys (Ricker et al. 1989, Ricker and Truscott 1989, Ricker and MacDonald 1992, 1995, CRIS 1989).

The aforementioned reports or papers are only a few of the many sources of information which have been utilized in this review. Submissions from the public and review committee members have been used to provide context for certain issues, or to point the direction for further research for information. In some cases, it has highlighted topics which are of public concern but for which there may be insufficient information to answer questions or conclusively respond. Finally, discussions with various government personnel and the public were very informative. A list of contacts and contributors are given in the Acknowledgements and Appendix A.

II. QUANTITY AND COMPOSITION OF WASTE DISCHARGES

Along with domestic sewage, agriculture, and other industries (such as pulp and paper), aquaculture can produce and release to the environment large amounts of carbon, nitrogen and phosphorus (C,N,P).

The nature and quantity of waste discharged from salmon farms is directly related to the nature and quantity of feed fed to caged fish. Dietary factors for 15 different commonly used diets for Atlantic salmon were modelled and reported in ICES (Silvert 1995) session on "Modelling Interactions of Mariculture" in Dartmouth, N.S. An Atlantic salmon diet may contain 45% protein, 30% lipids, 7% carbohydrates, 7% nitrogen and 1% phosphorus (Einen et al. 1995; Rosenthal et al. 1995). A trout diet composition would be similar. Feed P and N concentrations have declined from 1.7 to 0.7% and 7 to 6% respectively (Enell 1995; Persson 1988; Ketola 1982). MacIsaac and Stockner (1995) estimated average P and N content of feed for smolts in Georgie Lake, B.C. at 1.15% and 7.6% respectively. Actual carbon and nitrogen contents ranging from 300-530 (average 360 mg) and 58-84 mg/g dry weight are given respectively for several different salmon feed formulations (Findlay and Watling 1994). ICES (1995) reports 400-470 mg/g C and 8-11 mg/g P for salmonid feeds.

Different feed formulations are utilized as the fish grow. The compositions of the different feeds affect organic matter output. Protein levels may be lower, and pigment concentration may be higher in feed for larger fish. Other components of feed such as antioxidants, vitamins and therapeutic agents may not change in concentration in feed for fish of different sizes. Metabolic rate also declines as the body size increases. This will affect oxygen consumption, carbon dioxide and excretion rates.

A. TOTAL NUTRIENT OUTPUT FROM AQUACULTURE

The total organic output from a salmon farm may be in the order of 2.5 metric tonnes wet weight per tonne live weight fish (Ackefors and Enell 1994). Translating this into dry weight, Weston (1986) estimated about 7 t dry weight organic output per 1 t dry weight of salmon produced, based on the use of pellets with about 35-40% moisture.

Gowen et al. (1991) cite three studies of the flux of carbon through salmonid cage farms. In all three cases the proportion of ingested carbon lost to the environment was 75-80%. Of the carbon lost to the environment, 1/4 is feces, and 3/4 (or 60% of the original organic carbon content of ingested food) is metabolized and discharged as dissolved waste. This does not include waste feed. Enell and Ackefors (1992) indicate that 15-40% of feed N and P is incorporated into fish biomass.

Ackefors and Enell (1990) calculated total P and N loads resulting from Swedish marine fish-farming operations in 1986 of about 35 and 260 t respectively, corresponding to 0.6% and 0.2% of the total Swedish P and N load on the surrounding sea areas. On a broader scale in surrounding seas, this represented 0.05% and 0.02% respectively. Contribution of P and N via precipitation and dry deposition over Sweden is about 100 and 1,100 times greater respectively than from fish farms. Overall loading from fish farms is therefore considered negligible. However, local effects can be important.

Einen et al. (1995) simulated N and P discharge from an Atlantic salmon farm for one year for fish of initial weight of 80 g and found N and P discharge to follow the water temperature patterns over the year. The discharge was approximately 20 g N/kg and 3-4 g P/kg weight gain for fish at 100% ration with no waste feed. This converts to 20 kg N/t and 3-4 kg P/t fish produced. Estimates for Nordic countries and the east coast of Canada have been as high as three times this amount (Cranston 1994; Ackefors and Enell 1994; Enell 1995). More recently, ICES (1996) reports that Norway has reduced their output from fish farms to 35 kg N/t fish and 8 kg P/t fish. DFO (1997) estimates B.C. output of nitrogen at about 1,200 t/yr for 28,000 t fish production (43 kg N/t).

B. SUSPENDED SOLIDS

Food and fecal wastes constitute the majority of the suspended solids output from intensive fish farms. Of the food which enters the cages, some enters the water column as uneaten food, and the rest is consumed by the fish. Part of the eaten food is digested and the rest enters the water as solid fecal waste.

Table (1) shows the estimates for uneaten food for trout cultured in tanks (Warrer-Hansen 1982), salmon cultured in net-cages (Gowen et al. 1991; Findlay and Watling 1994; Braaten et al. 1983) and trout cultured in net-cages (Penczak et al. 1982). Data from Puget Sound (Weston 1986) net-cage operations has suggested that not more than 5% is wasted from introduced feed; however, the method of estimation was not given. Pearson and Gowen (1990) estimated 20% wastage from salmon farms.

The moisture content of the feed will largely affect the ease with which the uneaten pellets will dissolve in water. Rosenthal et al. (1995) indicated that in eastern Canada, up to 35% of moist feeds are wasted, whereas the percentage is only about 3% for dry feed. Weston (1986) states that dry food sinks fastest, but that moist food creates more waste. The salmon farming industry in B.C. uses dry feed of various formulations. Japan and east coast Canadian farms are now using 70% moist, 30% dry versus 70% dry, 30% moist commonly used a few years ago (B. Hargrave, DFO, pers. comm.). Moist food has greater buoyancy and thus fish have a longer time to ingest pellets before they settle to the bottom. However, the greater buoyancy also provides more opportunity for pellets to drift out of the cages or dissolve in the water column. It appears that a wide range in wastage occurs depending on husbandry practices and the type of pellets used. Therefore, the values in Table 1 may not apply to all formulations currently in use.

Table 1. Feed Wastage Estimates for Salmonid Culture.

Type of Feed	% Uneaten trout in tanks	% Uneaten salmon in net-cages	% Uneaten(moisture content) trout in net-cages		
Dry (9 %)	1—5 %	15—20 %	27 %	Moist(30-40%)	5—10 % > 20
%	31 %	Wet (70 %)	10—30 %	variable	

The method of feeding will also affect the percentage of uneaten food. Cross (1988) found that hand feeding resulted in 3.6% wastage or 27 g/m2xday organic matter deposited to the bottom whereas automatic feeders resulted in wastage of 8.8%. Feed pellets were counted in bottom canisters, a method which does not take into account wastage from poorly visible broken up pellets. DFO estimates (submission for EAO review—DFO 1997) suggest that 17% feed wastage is common in B.C. based on the optimum feed conversion ratios measured with new high energy feeds in the laboratory, versus the actual feed conversions estimated for the industry in B.C. (see below). So up to 20% of the food becomes solid waste, which is the first major component of sedimenting waste discharge from salmon net-cages (Beveridge et al. 1991).

Of the feed that is eaten, about 25% to 33% becomes fecal matter (Weston 1986). This is the second major component of suspended solids output from the net-cage. Butz and Vens-Cappell (1982) estimated fecal waste in two ways: by collecting it from the lower intestine of fish; and by collecting actual fecal wastes from the water. They arrived at estimates of 26% and 9-20%, respectively. The latter method always gives lower estimates because of the breakup and dissolution of the fecal matter after it leaves the fish. These are in good agreement with the generally accepted digestibility estimates of about 75-80% for salmon feed.

Simple calculation of output of solids from feed and feces

O = TU + TFW where: O = total output of suspended solids from feed and feces; TU = total uneaten food; TFW = total fecal waste. and:TU = TF X UW TF = total food fed UW = % uneaten food / 100TFW = F X TE F = % fecal waste / 100 TE = total feed eaten = TF—(TF X UW)

Whatever the source of suspended solids might be, one can estimate the load that will be produced from the farm or net-cage by knowing the conversion efficiency of the fish and the total mass of food fed. Estimates of the suspended solids output (O) are therefore dependent on the feed conversion ratios (FCR) chosen.

The FCR is the ratio between the total food fed (kg dry weight feed, which is 90% feed pellet weight for dry pellets) during a given time interval and the amount of wet weight biomass gain (kg) of the fish during the same interval. Management and feeding strategies that minimize uneaten food wastage, or that increase digestibility, thus reducing the FCR, will reduce the suspended solids output.

The research that is currently being conducted on this issue is summarized in the DFO submission to the salmon aquaculture review (DFO 1997). They assume an optimum FCR in the laboratory of 0.9 kg dry feed /kg wet gain of fish (FCR = 0.9:1 for Atlantics based on Johnsen et al. 1993—cited in DFO 1997) with little or no food wastage. However, DFO (1997) suggest that data from the B.C. salmon farming industry shows a FCR 1.15:1 (data source not given) including feed wastage. Assuming that FCRs are similar to laboratory values, this suggests that about 16-17% is unaccounted for and must represent feed wastage. Based on maximum production limits for all farms in B.C. (MAFF, currently 40,000 t per cycle) and reported feed usage for the cycle ending in 1995 (MELP, 43,000 t for 1995 cycle), the B.C. salmon farming industry would have an overall FCR of 1.2:1 including feed wastage if they are producing at 90% of their current maximum limit.

Enell (1995) reports that the trend over the past 20 years has been a decline in feed conversion ratios (reports of 1 to 1.1 from marine farms in Denmark and Norway, minus waste feed). Persson's (1988) treatment of this subject is more detailed, with theoretical considerations of feed conversion ratios in terms of energy content of the feed. Rosenthal et al. (1995) suggested that feed conversion ratios for Atlantic salmon have declined to 1.2 (including waste feed) for dry feed use. Based on estimates from production information for B.C. salmon farms, MAFF has used conservative FCR estimates of 1.4 to 1.5 for Atlantics for their discharge model (MAFF, B. Carswell, pers. comm.). FCRs for Pacific salmon range from 1.7 to 2.0. Both FCR and feed wastage will also depend on husbandry methods such as satiation/starvation patterns, number of feedings per day, and subtle factors such as temperature and weather. The range in FCR and feed wastage estimates emphasize the need to carefully evaluate feed conversion efficiencies and understand the methods of calculation used.

Estimates of the total suspended solids output from intensive net-cage culture of fish range from 5 to about 50 g suspended solids/m2 net area per day for an average Atlantic fish culture operation (Warrer-Hansen 1982; Merican and Phillips 1985; Enell and Löf 1983; Kadowaki et al. 1980). Rosenthal et al. (1995) quote suspended solids loadings of 0.9 to 1.2 g/kg fish each day with levels as high as 7.1 g/kg per day reported by some studies. Table 2 includes a simple calculation of total solids waste from B.C. salmon farms, based on total feed usage for one grow-out cycle, waste feed of 10% average, and digestibility of 80% of feed. This calculation suggests that about 38% of original feed is lost as solid waste. Based on estimates used in the DFO (1997) submission to the review, the estimated feed and fecal waste result in comparable amounts of solid waste (about 37%). The B.C. Salmon Farmers Association (1997) claim that a total of about 24% of solid feed is lost to the environment as waste feed and feces. This would require waste feed estimates of 5% and fecal waste estimates of 10%.

Einen et al. (1995) describe theoretical considerations in calculating the total solids and nutrient discharges from fish farms with a high degree of accuracy, using records of fish production and feed conversion ratios combined with nutrient and component composition of feed and fish. They present a dynamic model for Atlantic salmon which has been incorporated into the MAFF model for farm discharge estimates designed for the Broughton Archipelago (Chandler and Carswell 1995). However, feed conversion ratios are not reported by the industry, so estimates must be used. In addition, production levels are confidential information so that maximum licensed production levels are used in the B.C. model instead. The MAFF model is therefore operating at a conservative level for estimating waste outputs. Estimates of biomass from mortalities are also vital for calculating output. Reported estimates for licences are currently being compiled and summarized by MAFF.

C. SOLID ORGANIC OUTPUT

A detailed review of N and P outputs from aquaculture is given in Iwama (1991). Weston (1986) estimated that 11-22% of nitrogen excreted is in solid form. Merican and Phillips (1985) gave estimates of 35.6, 21.8 and 65.9% output of C, N and P, respectively, as percentages of the feed C,N,P that is lost in solid form to the environment (food and feces). This is corroborated by the fact that there is a 50-70% reduction in C and N in feces over feed (Enell and Ackefors 1992). Similar estimates are given by Einen et al. (1995) and in Table 2.

Silvert (1994) described total amount of organic carbon released in particulate form from Atlantic salmon cage sites in eastern Canada. Of the ingested amount, Silvert (1994) summarized carbon as 20% incorporated into growth (see also Gowen et al. 1991), 20% feces and 60% respired. Whatever is lost as waste feed will be additional. To arrive at these percentages, Silvert estimated surplus feed based on total feed, carbon content of feed at 45%, and estimated carbon content of fish from 10-20% (variable results).

Gowen et al. (1991) calculated that about 10 t of solid organic carbon waste are produced for every 100 t of food fed to the fish. Some of this will stay in suspension and some will be eaten by wild fish. Note that estimates for B.C. for 1995 are about 12 t C, 1.5 t N and 0.7 t P for every t of feed used (Table 2).

A sample calculation of total solids and organic output from the 1995 salmonid production in B.C. is given in Table 2, using one of the currently realistic scenarios:

Table 2. Estimated Solid Nutrient Outputs from Fish Farms in B.C. for Grow-out Cycles Ending in 1995 (about 18 months).

Kg Kg Kg ReferencesTotal Feed
feed eaten digested solid waste per cycle 90% 80% 38%
42936063 38642457 30913965 16315704 Findlay and Watling
1994 Weston 1986
Warrer-Hansen 1982 Butz & Vens-Cappell
1982Estimated solids waste for 1995: 16,315,704 kg dry wtSolid Carbon Nitrogen
Phosphorus ReferencesPercent feed 30-50 6-8 1 Silvert
1994Mean content (mg/g) 400 70 10 Findlay and Watling
1994% lost as feces 20 15 66 Einen et al 1995
Weston, 1986, Silvert 1994kg waste (feed
6011049 644041 300552 and feces)% original nutrients 30 25
76 Gowen et al. 1991, andlost in feed feces
Merican and Phillips 1985 % original feed
12.0 1.8 0.8

Note: The feed usage reported to MELP (data form 1) for the 1995 cycle was 42,936,063 kg.

D. DISSOLVED ORGANIC OUTPUT

There is a substantial loss of dissolved carbon as CO2 and bicarbonate (HCO3—)from respiration. About 60% of food carbon and nitrogen ingested is released as dissolved waste (Gowen et al. 1991). The dissolved forms of carbon are considered inorganic, and add harmlessly to the huge dissolved carbon pool in the oceans. The majority of nitrogen and phosphorus outputs are also released as dissolved organic and inorganic nutrients, and have more profound implications for biota.

Silvert's (1994) salmon growth model indicated that fish in the 3-4 kg range released about 0.1 mmol/day soluble nitrogen wastes. Nitrogen output from the farm comes mainly from the protein in the feed. Approximately 7.5% of the salmon food is N, by weight (Edwards 1978). Weston (1996), Gowen et al. (1991) and Silvert (1994) calculated that 60-85% of N fed to fish is released as dissolved output. Most of the N will be excreted as dissolved ammonia (NH3 or NH4+) through the gills (Gormican 1989) or as urea (Persson 1988; Gowen et al. 1991). Ammonia excretion exhibits a strong diurnal component due to feeding cycles and must therefore be measured over the entire day (Gormican 1989; Iwama 1991). Ammonia excretion peaks shortly after feeding times, and returns to a baseline level between feedings.

Cranston (1994) indicated that for every 1,000 g salmon harvested on the order of 80 g N is excreted as soluble ammonia to the water column (see Hall et al. 1992, Gowen and Bradbury 1987, Levings 1994). Assuming an annual production of 22,000 tonnes in B.C., this would result in the release of about 1,760 tonnes dissolved ammonia by the salmon farming industry in 1995. Other estimates of dissolved N output to the environment (ammonia and urea) are on the order of 5.5 tonnes per day for an annual production of 22,000 tonnes of fish, or about 2,000 tonnes per annum, (see Water Column Impacts section and Appendix 1 of the DFO submission 1997). The estimated N output per kg fish given by Cranston (1994)is about three times the estimate used in calculations by DFO in the main body of their submission (DFO 1997). Therefore, the ammonia output given in the Water Column Impacts section of this paper, and in Appendix 1 of the DFO submission (also written by Forbes and Black) is about 80% higher than the total dissolved plus solid estimate for N output from B.C. salmon farms given by DFO (DFO 1997), and higher than that given as estimated total output by Rosenthal et al. (1995) and other authors citing the European salmon industry (see above).

Brett and Zala (1975) reported baseline and peak N excretion rates of 8.2 and 35 mg N/kg per hr, respectively, for sockeye salmon (*Oncorhynchus nerka*). Peak excretion rates occurred approximately 4 h after the start of feeding. Urea excretion rates remained constant at approximately 2.2 mg N/kg/h. Although these data are old, values of excretion calculated by Cranston (1994) are similar. Both forms of N are important to consider in potential impacts of salmon farming as both can be used by phytoplankton and microbes. Over a 20-year period on carp farms in Hungary, Oláh et al. (1994) reported a total input of 1,246 tonnes of N, and a total release of 686 tonnes N to the environment. This level can be important in freshwater which is partially recycled and where ammonia is allowed to build up.

The dissolved output of P from salmon feed was estimated as approximately 15-35% of the original feed amount (Weston 1986). However, more recently Silvert (1994) suggested that 66-85% P from feed is lost as dissolved waste. Phosphorus is not considered a limiting nutrient for primary production in marine waters and is therefore of less concern than nitrogen, which can be limiting in marine waters. However, cyanobacteria (blue-green algae) can flourish in P-rich marine waters and can produce some nasty toxins (Hobson 1983). This problem has not been noted in the vicinity of marine salmon aquaculture operations. Rosenthal et al. (1995) suggest that recently, improved feed production techniques have reduced the amount of P in feeds to about 1 percent, with N reduced to about 7% with no metabolic cost to cultured fish.

Phosphorus exists in limited quantities in freshwater and is normally fixed to many materials, including particulate matter in suspension. Phosphorus is not found in air, as is nitrogen, nor is it a significant end-product of metabolism, such as carbon. Therefore, P can be an important nutrient input into either freshwater or estuaries. The ratio of N to P is normally about 7:1 in freshwater systems. Therefore, P is the limiting factor in primary productivity and there is better correlation between these two variables than between primary productivity and N. Gowen (1994) observed an approximate doubling of total P concentration (mg P/L) in five Swedish lakes after the establishment of cage fish farms (data from Persson 1991).

In estimating the content of P released into the environment, Ketola (1982) reported approximately 19% retention in the body of trout. In a rainbow trout sea-cage farm in Sweden, Holby and Hall (1991) measured P fluxes, and estimated that of the total P input to the farm, 17-19% was retained in the fish, and 78-82% was lost to the environment. This translates to a general release of much more nitrogen than phosphorus into the water (7/1 by weight).

E. BIOAVAILABILITY

It is important to consider biological availability to microbial flora and fauna in interpreting the results of nutrient output calculations. The average C/N ratio of Atlantic salmon feeds is about 5.3 to 6.7 (Findlay and Watling 1994). At the other end, fecal pellet C/N ratios of about 14-15 have been measured for Atlantic salmon from two sites (Findlay and Watling 1994). Therefore N is much more readily extracted from feed by fish than C. This is true of other organisms as well. In addition, farmed fish excrete dissolved forms of N and P in a similar proportion to the Redfield Ratio (about 14 or 16:1) which makes these nutrients readily usable by algae (see Cross and Kingzett 1994 for references).

About 88% of P in the fish food and 67% of P in feces is biologically available; that is the amount that can be utilized by phytoplankton or autotrophic microbes for growth and reproduction (Persson 1988). Virtually all the dissolved N is biologically available to be utilized by plankton. In fact, ammonium has been shown to be more biologically available to phytoplankton such as *Heterosigma* than nitrate, which is normally the most common form of N in marine waters (Wood and Flynn 1995). Of the total N consumed in food, up to 80% is excreted in dissolved form, and 10% of that may not be biologically available, then up to 72% of the total N fed to fish may be available for primary production by phytoplankton.

F. RELEASE OF DISSOLVED NUTRIENTS FROM SEDIMENTS

Once solids have settled to the bottom they can re-enter the water column in dissolved form. The release of the reactive form of phosphorus from sediments is a concern (for review see Gowen et al. 1991). Nitrogen in the form of ammonium is also released from benthic microbial and invertebrate metabolism. Concern about efflux (re-dissolution) of phosphorus and nitrogen from sediments is most pronounced in freshwater, where 50% of waste phosphorus from fish farms is lost to sediments (see Gowen et al. 1991). In both freshwater and marine anoxic sediments, the rate of release of P is high compared with enriched or unenriched oxidized sediments. Enell and Loff (1983) measured P release rates of 7 vs 1.4-2.6 mmol PO4-P/ m2x d in affected anoxic and oxic marine sediments respectively, compared with rates from undisturbed sediments of 0.01 and 0.15.

Sediment efflux rates and concentrations of nutrients decline rapidly when the input sources from farms is removed. However, it should be noted that the amount of ammonium entering the water column from remineralization in sediments is probably much lower than that entering water from direct dissolved output from fish in cages (ESSA 1993). Estimates of remineralized amounts are 0.02 g NH4-H/d/m2 sediment from Hall and Holby (1986) and Hargrave et. al (1993). Gowen et al. (1991) conclude that the release of nitrogen from sediments is negligible (<1%) compared with the direct water column output and is therefore unlikely to make an important contribution to hypernutrification of the water column.

G. OTHER WASTE COMPONENTS

The components of the effluent from aquaculture operations discussed below might be considered minor in quantity, compared to the suspended solids and release of dissolved material discussed above. Therapeutic drugs, chemicals for the maintenance of the physical structures on the farm, and various additives in the feed are discussed. Another category of chemicals not discussed here are fertilizers. These are used more in the extensive, or semi-intensive culture of non-salmonids, and not in B.C.

Antibiotics and Antimicrobials

The use of prophylactics or therapeutic use of antimicrobial drugs as well as antibiotics are common in salmon farming around the world. ICES (1996) present a review of the use of antibiotic and antimicrobial chemicals used in salmonid culture worldwide. There are eight categories of such antimicrobial agents in use internationally (Weston et al. 1994), of which only some are in use in B.C. (C. Stephen, 1997: EAO discussion paper on fish health). In particular, Mark Sheppard (BCSFA veterinarian) has noted that oxolinic acid, choramphenicol (see also ICES 1996) and furazolidone are not allowed for use in food fish in Canada under any circumstances:

Antibiotics:

- *Tetracylines:* oxytetracycline, chortetracycline, doxycycline
- *Macrolide antibiotics*: erythromycin
- *β-lactam antibiotics*: amoxycillin, penicillin
- *Aminoglycosides*: streptomycin, neomycin, kanamycin
- *Chloramphenicol*

Antimicrobials:

- *Sulphonamides:* sulphamerazine, sulfadiazine, sulfamethylphenazole, sulfisoxazole, sufathiazole, sulfamonomethoxine, sufadimethoxine, sulfaniamide• *Quinilones:* nalidixic acid, piromidic acid, oxolinic acid, flumequine|• *Nitrofurans:* nitrofurazone, furazolidone, nifurprinol, furaltadone

MAFF reports that in 1995, 46% of active salmon farms in B.C. used antibiotics. Numbers for the first quarter of 1996 were 20%. No further breakdown of amounts was given at the time.

The use and extent of regulation for each of the above antimicrobial agents varies widely with each country. At one extreme, there is little or no regulation of their use in developing countries, and at the other extreme in North America the use is limited to two or three of these agents for food fish. Alabaster (1982) and Solbé (1982) report the use of the antibiotics and therapeutants: *auremycin, furazolidone, nitrofurazone, penicillin, oxytetracycline, sulphamerazine,* and *terramycin* on fish farms in the U.K. In general, there is a declining trend in the use of antibiotics in intensive salmonid culture, due to better vaccines and husbandry practices, and the use of other drugs at lower overall volumes.

There was concern about the use of sulphamerazine in B.C., leading to a preliminary study to see if it could be detected in oysters growing adjacent to farmed salmon. MAFF (Aquaculture Information Bulletin No. 24) indicated that no sulphamerazine was detected in samples collected from several days to two weeks after exposure although other studies have found traces of oxytetracycline and Romet 30 in nearby oysters (Black et al. 1991, Jones 1990). In Norway, the use of antibiotics in aquaculture has been decreasing since the peak in 1987 (Grave et al. 1990). The use of antibiotics in Norway was used mainly to control Hitra disease in the early 1980s, and at the peak usage, 48.7 t was used (Grave et al. 1990). In Finland, Mäkinen (1989) reported the annual use of over 1 t of *oxytetracycline.* It is probable that much of the feed-administered antibiotics are going uneaten into the water column, and directly into the sediment (estimates at 70-80%—see Hatfield and EVS 1996). It is not surprising that there is a decline in appetite in sick fish. It is not uncommon to hear that salmon farmers add appetite enhancers, such as krill, into the feed in conjunction with prophylactic or therapeutic treatment. Mark Sheppard, a veterinarian for the B.C. Salmon Farmers Association, has commented that feed rate is considerably reduced for sick fish to reduce wastage of therapeutants in feed. For further discussion of impacts in sediments and the water column, see the following sections.

Some European countries have stipulated zero residues for antibiotics in commercial products (fish and crustaceans) which are checked by microbiological assays (see Rosenthal et al. 1995).

Cravedi et al. (1987) reported that 62-86% of the oxolinic acid ingested by rainbow trout remained in the feces. In contrast, very little (< 1%) of *chloramphenicol* is lost via the feces. Ervik et al. (1994) reported the presence of *oxolinic acid* and *flumequine* in wild fish muscle (mainly saithe) around fish farms in Norway. These authors also found the incidence of bacteria which were resistant to these chemicals to be higher in the intestinal contents of fish after treatment, compared to before treatment. These two quinilones are very persistent in sediments, and residues may be found many months after treatment (Weston et al. 1994). Even though these two quinilones form complexes with divalent cations, they may retain their antimicrobial properties (Hansen et al. 1992; Samuelsen 1994). Samuelsen et al (1992) also found bacteria which were resistant to oxolinic acid in blue mussels, *Mytilus edulis*, collected from the vicinity of fish farms which had just received such treatment. Furazolidone is degraded very quickly and disappears from the sediments within a day (Samuelsen et al. 1991). To date, there are no indications of adverse fish health effects from antibiotic residue uptake.

H. OTHER CHEMICALS

Several reviews document the use of various chemicals around fish farms. Schnick et al. (1986) and Meyer and Schnick (1989) present reviews of chemicals used in fisheries (including aquaculture) and of chemicals used for fish health in the U.S. respectively. Malachite green and formalin have been used in the U.K. for the control of ectoparasites and fungus (Alabaster 1982; Solbé 1982). Mäkinen (1989) reported the annual use of the following chemicals in Finnish salmonid aquaculture: 100 t of NaCl; 4.5 t of *formaldehyde;* 300 kg of *malachite green*; minor amounts of *chloramines* and *benzolconchloride.*

Dichlorvos is an organophosphate pesticide which is the active ingredient in several chemicals used for the control of ectoparasites such as copopods (sea-lice). This chemical is applied in a bath and therefore large quantities can be released into the environment if not handled properly. Infestations of sea lice have been a major problem in the ocean-culture of salmonids such as Atlantic salmon in Europe and the eastern coast of the U.S. and Canada, but have not been as prevalent in B.C. Therefore, *Dichlorvos* is not used in B.C. and little is known of the fate or effects of this chemical on the environment. There is some interest in using Ivermectin (in feeds) to treat sea-lice as this pest may become more prevalent with the increasing use of Atlantic salmon in aquaculture operations in B.C. (see Stephen 1997: EAO discussion paper: Fish Health). Other treatments used globally are discussed in ICES (1996).

I. ANTIFOULANTS AND DISINFECTANTS

Antifoulants are an important part of the proper maintenance net-cages. Clean nets allow the unimpeded flow of water and oxygen through the net-cage, and the flushing of excreted and other waste materials. They also reduce waste discharges due to fouling organisms.

Of all antifoulants, TBT has received the most attention (see Rosenthal et al. 1995) and was of particular concern in B.C. in the late 1980s. *Tributyltin* (TBT) use was once widespread and has been shown to accumulate in the muscle of both finfish (Short and Thrower 1986; Davies and McKie 1987) and mollusks (Davies et al. 1986). Negative effects on fish growth have been demonstrated (Paul and Davies 1986; Davies et al. 1987). Balls (1987) described the leaching kinetics of TBT, and showed very low TBT concentration outside aquaculture structures. Further, concentrations within cages declined exponentially with time after application. The B.C. Salmon Farmers Association voluntarily stopped using the compound and asked members to remove it from nets (most farms had complied by mid 1987—MAFF Aquaculture Information Bulletin No 24). Although it is no longer used directly in B.C. on salmon farms, it is still present in the anti-fouling paint of some boats which may frequent fish farms.

Copper is a component in algaecides (Flexguard, Flexabar trademark) that are used to dip salmon farm nets. The active ingredient in the bath is cuprous oxide (26%). It has a commercial registration with the Commercial Pest Control Products Act. Disposal methods are given by Environmental Protection, Environment Canada. Furthermore, it is not supposed to be applied without the supervision of a certified provincial inspector. Stolt Seafarms have phased in use of this on all nets over the past few years, and have indicated that they only clean the nets once a year as a result.

Copper concentrations inside treated net-cages have not been found to differ from control waters 700 m away (Lewis and Metaxas 1991). Furthermore, copper levels in chinook salmon muscle from copper treated and untreated net-cages were not different (Peterson et al. 1991). The explanation for these findings seems to be due to the high rate of dilution by water flow through the net-cages. Also, free copper complexes with organic and inorganic substances in the water, which precipitates the metal into sediments. Fish probably do not take up significant amounts of copper from the water, as their dietary needs are more than adequately met by the copper levels in the feed (6.5-10 ug Cu/g dry weight feed—Moore Clark and White Crest Feeds, and MELP feed analysis).

Disinfectants are used to clean nets and other equipment. To date, there have been no data found on their marine degradation or ultimate fate. Those which have been reported in use in B.C. in 1995 and 1996 include:

- Bleach• Ovadine (Idophor)• Kilphor• Chloramine T• Formaldehyde• Durueyne• Dustbane

J. HORMONES

Rosenthal et al. (1995) indicate that hormones and growth promoters are used to alter sex, time of maturation, productive viability and growth of cultured organisms around the world. According to the MAFF veterinarian and the B.C. Salmon Farmers Association, hormones are not used in grow-out facilities in B.C. and therefore are not present in cultured fish. Any hormone use in aquaculture is restricted under special MAFF permit and prescription to the hatchery for eggs and alevins to be used for broodstock. Although much work has been done to describe the effects of hormones on target species, little is known of their wider ecological impact. Growth hormone research in salmonids is reviewed in Donaldson et al. (1993).

K. MISCELLANEOUS FEED ADDITIVES

Essential vitamins such as biotin have a short half-life (7 d; Carlucci et al. 1969) and are broken down in sunlight. Therefore, their contribution to the stimulation of plankton may be minor. However, uptake of such elements may occur very rapidly, and thus their effect cannot be discounted. Pigments are added to feed to enhance the colour of the flesh. However, the fate of such pigments has not been studied. Samuelsen et al. (1988) found antioxidants (diphenylamine, and 2,6 bis[1,1 dimethyl ethyl] 4—methylphenol) from feed in the sediments under Norwegian salmon farms.

Zinc is added to salmon feeds to prevent cataracts in Atlantic salmonids and is also an insulin structure and carbonic anhydrase co-factor. It is added to the feeds at about 30-100 mg/kg (Chow and Schell 1978). Samples of EWOS feed pellets analysed by MELP in 1996 indicate that levels as high as 279 ug/g are present in feeds (see also sediment impacts section), part of which is related to skeletal material from ground fish used in feed.

III. SEDIMENTATION RATE AND EXTENT

The potential impact of suspended solids released from salmon farming operations is related to the actual amount of particulates reaching the bottom, and the pattern and magnitude of dispersion of the materials. For instance, Weston (1986) calculated that solids output from salmon farms resulted in sedimentation under salmon farms on the order of 2-10 times greater than in reference areas in Puget Sound.

In order to measure sedimentation rates of feed wastes and fecal pellets it is necessary to put sediment traps under and at various distances down-stream from fish farms. In Maine, some detailed sediment trap measurements made specifically to determine waste feed reaching sediments found that between 5% and 11% of solid farm wastes actually settled (Findlay and Watling 1994). By comparison, the use of a laboratory model based on stagnant conditions overestimated actual sedimentation rates by 2-10 times (Findlay and Watling, op. cit.). Gowen et al. (1991) cite three studies of mass flux of carbon through salmon cage operations. Although the carbon lost to the environment was constant in all cases, the amount ending up in the sediments varied from 7% to 66% of the original output. Saunders (1995) suggested that in the southern Bay of Fundy in Atlantic Canada the extreme tidal amplitude and resulting high flushing rates led to low accumulation of feces or feed beneath farms. Recent observations at selected sites under fish farms in the Western Isles region of the Bay of Fundy have shown that uneaten food pellets do accumulate at sites with low current speeds (Hargrave, pers. comm.). These conflicting observations emphasize the problems inherent in measuring sedimentation rates, and have led to the use of models combining complex effects of environmental factors to provide predictions about the fate of discharges.

Most of the measurements of particle deposition beneath fish farms are short-term, and reflect seasonal conditions during particular growth phases of the salmon. Thus, they are not representative of annual rates. In addition, it is difficult to correct sedimentation rates to account for natural sedimentation (which must also be measured year-round). Estimates range from about 3 to 286 kg solids/m2 x year from various researchers. Data from various sources are listed in chronological order in Table 3. Some examples of data collected in B.C. are included (Cross 1988, 1990, 1993, 1996). However, bottom canisters were used in these studies instead of sediment traps. Different methodologies are not inter-comparable. Cross (1990) estimated that smolt production facilities averaged only 40% of those reported at grow-out production facilities. More recently, Cross (1996) found improved siting and husbandry has reduced these rates by about 50% (see Table 3). However, production limits in B.C. have increased an equivalent amount in B.C. with many farms licensed to produce 1,000 to 1,500 t per year. The sedimentation rates under farms in the upper range of production B.C. (1000-1500 t/y) have not yet been studied.

Table 3. Estimates of Particulate Sedimentation under Salmon Net-cages (kg/m2xyr).

Source under cages reference TOC load Production
at 35% C
TonnesWarrer et al. 1982, Merican&Phillips 1985 39-195 5-50
Gowen and Bradbury 1987, Ireland 10 3
Weston and Gowen 1988, Wash., U.S. 52-110 30
Weston 1990, Wash, U.S. 13.5 Cross 1988,
Sooke, B.C. 30.2 Cross 1990, Georgia Str., B.C.
16-39 1-10 16 133-400Cross 1990, Georgia
Str., B.C. (smolts) 9.12 Cross 1993, B.C. 7-14
5-10 144-332Hargrave 1994, Eastern Canada3-286 1-
100 Findlay and Watling 1994, Maine, U.S. 3-17 1-6
Cross 1996: MAFF, KTFC data, Broughton 7-14 2.5-
4.5 4-5 509-1058 (perimeter
cage)MAFF discharge model estimates: 4-11 <1-4 180-
2700 20 farms in B.C.Range 3-286 *modified
parameters were used based on findings in this report

IV. EXTENT OF SEDIMENTATION

The areal extent of particulate matter deposition under salmon net-cages appears to be fairly limited in most cases, since sedimentation rates drop off with distance from the net-cages. Various researchers have tried to determine the total area affected by particulate waste product sedimenting from fish farms (for reviews see Iwama 1991, Hatfield and EVS 1996).

There are two approaches used to measure the area and rate of sedimentation, both ofwhich are necessary to accurately predict the extent of change in benthos related to fish farm effluent. The first is visual inspection using surficial observations by SCUBA or ROV camera, or within-sediment observations using Sediment Profiling Cameras. The second is some remote measure, such as sampling benthic sedimentation traps or bottom canisters. The remote methods have been criticized as they do not take into account resuspension of bottom material after it has settled. They therefore tend to overestimate long-term sedimentation rates.

Thonney and Garnier (1993) surveyed 52 salmon cage farms concentrated in the Western Isles region (SW corner of New Brunswick) in the Bay of Fundy. They assumed an average 10 m zone of influence around each set of cages and estimated a total benthic zone of impact from cages in the region at 34.6 ha (out of 370 ha leased) of which 8.3 ha was deemed heavily degraded (redox <-315, no epibenthic macrofauna, no infauna, gas bubbles, etc).

Gowen et al. (1991) cited a measurable impact up to 15-50 m from the perimeter of small to moderate fish farms in Europe. At a large farm with annual production of 630 t, gross changes were evident 45-90 m away and subtle changes were apparent at least 150 m away. Weston and Gowen (1988) observed dominance by the opportunistic polychaete *Capitella* and the white-sulphur fixing bacterium *Beggiatoa* (see macrofauna and bacteria under “Sediment Impacts”) up to a maximum of 150 m from net-cages in Puget Sound. Normal conditions occurred at distances greater than 150 m from farms. However, generally, the impact was much less extensive from 25 -150 m from the edge of the farm. At Norwegian farms, Braaten (1991) observed mats of Beggiatoa sp at distances from 20 m to 1.2 km from the perimeter of net-cages, depending on water circulation patterns. Weston (1990) found that reasonable recovery of benthic infauna was evident at distances of 100-150 m from a Puget Sound farm (increase from 9-49 species, biomass about 0.1 to 0.5 kg/m2), but that considerably more taxa (109 species) and biomass of fauna (3 kg/m2) existed up to 450 m away. Brown et al. (1987) showed four zones in studies of a Scottish sea-farm; an azoic zone under sea-cages, an enriched zone with opportunistic fauna from the edge to 8 m out, a slightly enriched transitional zone to 25 m and a clean zone beyond 25 m.

Studies in B.C. by Anderson (1992, 1996) and Cross (1988, 1990, 1993) concluded that benthic impacts were confined to an area in the near vicinity of B.C. fish farms (20-30 m), with no discernible near-shore effects. Visual examinations of benthos under existing or recently fallowed net-cage sites showed the impact in moderate cases to be within 15 m of the actual site (Anderson 1992, 1996). Under heavily impacted sites such as Nanoose Bay the impact area was undetermined, but considerably greater, probably due to frequent relocation of cages within the tenure.

Use of ROV technology is currently allowing researchers and regulators to visually examine the area of effect under and around existing net-cage operations in B.C. where the depth is too great for SCUBA (C. Backman, MAFF). A portion (about six hours) of the video monitoring data for 1996 from MAFF was viewed by the author. The video footage shows variable results with heavy impact observed in one case up to 200 m away from net-cage operations. However, it is not clear if pens had been recently moved from that location. In most cases, the extent of visual impact was much less. Cross (1990) indicated that 500 m from net-cage operations in B.C. should always be a sufficient distance to show “normal” sedimentation conditions.

A. SEDIMENT ACCUMULATION

Sediment accumulation rates are more difficult to measure than sedimentation rates. Accumulation analyses must take the following into consideration: resuspension based on seasonal changes in tidal exchange and storm events;

rate of chemical and biological oxygen demand versus oxygen exchange rate to sediments, which is related to how fast the benthic organisms consume and degrade organic material (see sediment impacts section); effects of bioturbation and other biological activities; and rates of natural sedimentation, which may be seasonally mediated by sedimentation from algal blooms or river runoff. This type of analysis would require directed studies with controlled waste output conditions for a given site throughout a grow-out cycle.

It is possible to determine the history of deposition of different layers in sediments using cores (see also REMOTS benthic sediment profilers, O'Connor et al. 1989). The use of the BOSS (benthic organic seston sampler) for studying dispersion and resuspension of particulates at marine sediments is discussed in ICES (1995).

Benthic accumulation is thickest under the areas where the most feed is deposited, not necessarily under the centre of the cage as assumed by most models (Silvert 1994). Therefore it is difficult to extrapolate extent and thickness of farm-derived wastes from single samples under net-cages. This patchiness is observable visually in videos of bottom sites (C. Backman, MAFF video documentation under B.C. salmon farms) and makes extrapolations difficult. Visually, the moderately to heavily affected areas are evident as patches of white sulfur bacterial mat interspersed with patches of epibenthic organisms.

Empirical attempts to describe conditions which characterize excessive organic accumulation under salmon net-cage operations have been completed. These are discussed in more detail under the section **"Sediment Impacts"** below. For example, in the Bay of Fundy, a comprehensive monitoring program of 52 cage sites (Thonney and Garnier 1993) showed that excessive organic accumulation occurred in the near-vicinity of cages at eight of these sites. Those sites all had silt/clay content of 68% or higher (natural sediments), total organic carbon (TOC) 6% or greater, near-bottom currents less than 5 cm/s, and depth less than 10 m at mean low tide.

An earlier study at a salmon farm in Norway (Braaten et al. 1983) found that there was no benthic accumulation until the third year of culture, at which time accumulation was rapid. Sowles et al. (1994) modelled the relationship between the amount of carbon accumulated in benthos under salmon farms and changes in benthic habitat based on subjective observations (see "sediment impacts" section).

In B.C. short-term studies have made estimates of organic matter accumulation rates in sediments using bottom canisters (c.f. Cross 1990). Based on studies of seven salmon farms rates of 4.8 kg/m2xyr with a decreasing accumulation gradient of 69-74% from the farm perimeters were measured. However, the use of bottom canisters would not have taken resuspension or biotic breakdown into account and may have overestimated sediment accumulation. In addition, canister studies are not directly comparable with sediment trap studies conducted by other researchers. After three years of continual operation, Cross (1993) found minimal impact on the benthos under five B.C. fish farms considered to have been optimally located for husbandry and environmental protection. There have not been any studies in B.C. designed to adequately address the issue of extent of benthic footprint and thickness and temporal accumulation under salmon farms. Nor have attempts been made to relate these to habitat conditions, husbandry and history.

There has been qualitative information collected to suggest conservative characteristics which are optimum for preventing benthic accumulation of organic matter. Cross (1993) considered optimal locations for fish farms for environmental maintenance and production had non-depositional substrates such as rock, stone-boulder or sand/gravel bottoms. Anderson (1992) suggested that the slowest recovery of benthos occurred in fallowed sites which also had the greatest benthic accumulation, the slowest bottom current velocity and high silt/clay sediment. Cross (1993) also stressed that moderate depths (30-35 m) are optimum, and that deeper depths tend to have higher depositional characteristics and lower bottom currents. There was also a discussion of bottom topography and slope effects on sediment accumulation. Anderson (1992) used slope and minimum depth as criteria for selecting farm sites for a fallowing study. However, in some narrow tidal channels, shallower depth is acceptable because the bottom is exposed to high tidal currents (Anderson 1992 gives the example of Sansom Narrows).

Weston (1986) states in his review that benthic accumulation can be expected in any operation in which there is less than 15 m between the bottom of the cage structure and the sea floor.

All five farms studied in Cross (1993) with low deposition rates had moderate (3-5 cm/s) to strong bottom currents, with less than a 2 km fetch for wave action on the surface. The best locations had a net current movement seaward, with the net-cages situated far enough from shore to prevent back-eddying. Some bottom current data for fish farms in B.C. is available from Cross (1988, 1990,1993) and Anderson (1992). However, Anderson (1992, 1996) found measurements of bottom currents using drogues unreliable due to interference from existing moorings or anchoring systems for net-cages.

Anderson (1992) contended that high stability in the water column was also important in contributing to increased depositional characteristics of sediments. Stability can be measured using density stratification of water column, particularly near-bottom, and is affected by currents and tidal action, and by inputs of seasonal freshwater.

Anderson (1992) studied eight fallowed sites in B.C. to determine recovery rates of benthic sediments and infauna. Of the eight sites examined, only the one located behind a shallow sill showed high stability and fine, depositional sediments, with moderate stability at several other locations (near Hardy Island and Village Bay, Broughton area).

B. MODELLING PARTICLE DISPERSION

The second approach to determining sedimentation rates, spatial extent and accumulation under and around fish farms is computer-intensive models of particle dispersion. The field work described above is important in order to ground-truth such models.

The following formula from Gowen and Bradbury (1987) can be applied to describe the dispersion distance of a particle from a net-cage site.

$D = dV/v$where:D = dispersion distance;d = depth of the water under the farm;V = current speed;v = settling velocity of the particle

Using this simplistic approach, a particle of feces or feed falling out of a net-cage with 20 m of water under the farm, with a current speed of 0.035 m/s, and a settling velocity (sedimentation rate) of 0.1 m/s might be found 7 m from the perimeter of the fish farm.

Some simple sinking rate estimates for intact Atlantic salmon fecal pellets have been measured as an average of 2 cm/s under stagnant (lab) conditions (Findlay and Watling 1994) and 7 cm/s (Gowen et al. 1988, Cross 1993). These rates are related to fish size. Findlay and Watling (op. cit.) noted that it was very hard to collect intact fecal pellets as many of them get broken up and become flocculent very quickly in seawater, affecting the performance of settlement models. The settling rate of feed pellets has been measured as an average of 12 cm/s (Gowen et al. 1988) or 5.5 to 15.5 cm/s in the lab (Findlay and Watling 1994), depending on pellet size, but not on moisture content of pellets. Gowen and Bradbury (1987) measured 9-15 cm/s, and Warren-Hansen (1979) suggest 1.7 to 6 cm/s settlement rates for feed. More detailed studies of size fractions of different components of the effluents and refinement of models for dispersion are discussed in ICES (1995) and by Ervik and Kupka-Hansen (ICES 1994).

A number of models have been proposed to examine the extent and quality of benthic sedimentation from salmonid net-cage culture. Older models were reviewed by Silvert (1994) and Gowen et al. (1994). MAFF has developed a modular modelling system designed to utilize the above settling parameters combined with a fish growth model (Iwama and Tautz 1981) and a hydrodynamic barotropic current model using tide data to show the amount and extent of material sedimenting (Chandler and Carswell 1995). The model was originally designed for the Broughton Archipelago. However, in the absence of sufficient bottom current data the model can only estimate deeper currents based on tidal data. This is a problem, as currents throughout the water column are important for modelling sediment particle dispersion. In addition, Black et al. (1991) discuss the effects of cage structure on background flow patterns under net-cages. This factor is rarely incorporated into models of particle settlement.

Silvert (1994) and Gowen et al. (1994) propose, respectively, a general model to look at regional carrying capacity of water column and benthic effects and a site-specific model which may be used to focus in on specific problem areas with detailed depositional information. After determining the amount of particulates output, Silvert (1994) used particle settling speed, water depth, bottom current and direction to determine the footprint or shadow of deposition under the net-cage. Finally, the benthic carbon loading can be calculated using the particulate output based on the ratio of the shadow area to the area of the cage. Researchers in ICES (Silvert 1995) express the importance of cage size, separation and number of rows of cages to modelling dispersion of particulates.

Unfortunately, a uniform settling speed assumed by both the MAFF and Silvert (1994) models is rarely found, since pellets are partially fed upon during descent, and break down to some extent in transit. In addition, there are variations in current speed over the tidal cycle which affect particle displacement from the area. Therefore, the shadow may be underestimated in a whole pellet model, but the total accumulation beneath the nets may be overestimated. In addition, organic flux is not constant over the area of the net since feeding is not uniform.

Particles from unconsumed food pellets and feces may not settle but be retained inside cages, depending on the degree of fouling of nets.

The model discussed by Gowen et al. (1994) contains the same assumptions as that of Silvert (1994), but improves upon it by taking into account fouling of nets, changes in current with depth and bottom bathymetry. However, this model is only usable if bottom sounding data and surface to bottom current measurements are available. In addition, current measurements are needed over at least a full lunar cycle to determine patterns in bottom current direction and speed. The problem with using an average bottom current (even if this data is available) is that it does not take into account the "spreading" capacity of ebb and flood currents, and the "settling" capacity during slack tides. It becomes immediately obvious that this modelling exercise is not an easy one.

C. LIMITATIONS FOR MODELLING BENTHOS IMPACT IN B.C.

The greatest single limiting factor in our ability to model benthic sedimentation rate and extent is the lack of sufficient information on the entire water column currents at fish farm sites or even regionally for areas such as the Broughton Archipelago. It is essential that this type of information be used to ground-truth the existing model used by MAFF and determine the margin of error likely to occur. Although a full lunar cycle current measurement at about the bottom of the nets (15 m depth) is required in permits from the Ministry of Environment, Lands and Parks for fish farms of specific feed tonnage use, a recent evaluation of this information shows that only about 25% of this data is available (L. Erickson, MELP, pers. comm.). More current data has been submitted by fish farms in recent months. This data would only be partially useful at any rate, since many net-cages are now closer to 20 m in depth and the bottom currents will often be considerably lower 15-50 m below the bottom of the net, depending on water column stratification and other oceanographic factors.

V. IMPACT FROM SEDIMENTATION

A. SEDIMENT COMPOSITION

Excessive organic sedimentation at sea-cage operations can result in changes to sediment characters such as particle size, organic content, water content and sediment texture (flocculation—Hargrave 1996, pelletization, etc.).

Changes to sediment particle size can be obvious from grab samples taken under B.C. net-cage operations (MELP field sampling, 1996). Naturally light-coloured, coarse sediments may be overlain by a fine, flocculent layer of organic material, ranging in colour from greenish to black, with loosely held-together feed pellets of varying sizes depending on the size of fish. This flocculent material tends to have a high water content and the surface portion at least is easily resuspended upon disturbance (MAFF video documentation, 1996).

The feed and fecal pellets falling from the cages add an extraordinary source of organic material which is reflected in total organic content of sediments. Total organic carbon (TOC) and percent volatile residues (SVR) are two different measurements designed to determine the organic content of sediments. While TOC measures organic carbon directly (elemental analysis), SVR measures the total organic matter, including nitrogen. This is measured by weighing the ash content of sediments after organic matter is combusted at about 550 C. There is a general linear relationship between TOC and SVR, with some variance, which can be seen in the 1996 B.C. monitoring data from salmon farms (J. Deniseger, MELP 1996, unpublished—see Figure 1). However, data from this source showed a closer linear relationship between percent SVR and total nitrogen (N—Figure 2).

Anderson (1992) suggested that SVR shows a good relationship with visual level of impact under B.C. salmon cage operations even though his data show no correlation of SVR with summary biotic variables such as abundance, species richness or total biomass, or other environmental variables related to sediment condition. As an example, Hargrave et al. (1993) measured TOC 2 x higher under salmon net-cages than at the perimeter of sites in the Bay of Fundy.

However, on their own neither TOC or SVR are reliable as indicators of benthic condition beneath net-cages. Both these values are related to the background sediment particle size of the area and will therefore vary naturally from site to site. Cross (1993) also noted the difficulty in using sediment SVR as an indicator because one farm in his study area had uniformly very high SVR levels throughout the bay, reflecting accumulated wood debris from previous log-booming operations. This point is emphasized in the response document on waste discharges from the B.C. Salmon Farmers Association written by Dr. Ken Brooks (BCSFA December 1996). In Washington state, TOC relative to sediment particle size is used as a trigger or guideline to require further monitoring outside a 100 ft radius from salmon net-cage operations. Several examples are given of the relationship of TOC from fish farms to biotic variables (species richness and abundance—BCSFA 1996).

Figure 1. Relationship (log/log) Between SVR and TOC for MELP Field Monitoring Data.

Note: SVR is approximately twice TOC.

In New Brunswick, Thonney and Garnier (1993) surveyed 52 marine salmon farm sites in the Bay of Fundy. In their data, total organic matter (SVR) was slightly elevated relative to silt/clay percent at the perimeter of net-cages versus reference sites 100 m away (Fig. 3).

There is a GENERAL decline in SVR with species richness in the data from Anderson (1992, 1996) which suggests that the use of cage-site SVR relative to background might provide a tighter relationship to biotic variables (Figure 4—data from Anderson 1992).

Figure 2. Relationship (log/log) Between SVR and Total N for MELP Field Monitoring Data, 1996.

Hargrave (1996) found that TOC was 40% higher on average under salmon net-cages in Atlantic Canada than at reference locations. Results for B.C. monitoring data collected by MELP suggest that for the sites studied in 1996, TOC up to about 4% are normal in reference sediments (generally sandy to silty), with much higher levels evident under net-cage operations (Figure 5). What is curious about this is that in Washington state, TOCs greater than 3.2% are considered to show impact at salmon farms even for very fine sediments, with a good correlation between TOC and grain size (BCSFA—Brooks, 1996). Either methodology used to measure TOC is different between B.C. and Washington state, reference stations selected by MELP for monitoring are not outside some considerable influence from the salmon farms, other anthropogenic sources are influencing measurements, or there may be greater variation in natural productivity of sediments in B.C. than in Washington state. Natural TOC levels in unimpacted sediments on the west coast of Canada have been noted as high as 6% for rich, non-anoxic fjord sediments (Effingham Inlet, D. Hodgins, Seaconsult Ltd, pers. comm.). Sources of organic matter affect "background" levels typical for any given area.

Figure 3. Total Organic Matter (% dry wt.) Versus Percent Silt/Clay for Data from the East Coast.

Note: Comparison at the perimeter of net-cages and 100 m away from net-cages. (note that there is much more variation in total organic matter at cage sites than reference sites.)

Gowen et al. (1991) state that in several cases in their experience sediment organic content was not elevated even though biomass of biota was obviously enriched. This is evident is some data from B.C. (see Anderson 1992 and Cross et al. 1990), where SVR was sometimes higher in reference stations than in those at the perimeter of the farm. Estimates of SVR in Cross (1990) were highly variable, reflecting partially the patchiness in deposition of sediments and partially the fact that samples were homogenized for up to 7 cm from grab samples and thus do not reflect surface sediment values. Despite these problems, TOC and SVR are still considered to be valuable tools for helping to define the extent of organic enrichment under marine salmon cage farms.

Figure 4. Relationship Between Species Richness (number of taxa) and Total Volatile Residue .

Note: From samples taken under fallowed sites by Anderson (1992).

B. SEDIMENT GEOCHEMISTRY (BOD/COD/TEMPERATURE/REDOX)

The accumulation of organic waste products under salmon net-cages initially results in an increase in benthic aerobic bacterial activity which increases the biological oxygen demand (BOD) of the sediments. As oxygen levels decline, chemicals are produced which also have an increased oxygen demand (COD). Hargrave et al. (1993) indicated in an intensive geochemistry survey under a net-cage operation on the east coast of Canada that BOD represents only 20% of total sediment oxygen demand in summer, with COD making up 80%. Oxygen demand was not significantly correlated with temperature, although both were highest in summer. The authors noted a maximum oxygen demand (OD) of 178 mg oxygen/m2 per hr under the cages, which was 4 x higher than the OD 100 m distant from the site. Gowen et al. (1988) measured oxygen consumption of 40 mg/m2 per hr under net-cage operations in Norway.

Figure 5. Relationship of TOC (%) Under Net-Cages to TOC at Reference Stations

Note: From MELP monitoring data, 1996.

Hatfield and EVS (1995) reviewed other studies which suggest that oxygen demand can be 5-15 times higher under net-cages than in normal marine sediments. Enell and Lof (1983) reported a threefold increase of oxygen consumption rates for undisturbed sediments at 16 mg O2/m2 per hr, to 45-55 mg O2/m2 per hr under a salmonid fish farm. Values from 4-56 and as high as 125 ml O2/m2 per hr were measured in the early days of salmon farming by Pamatmat et al. (1973). More recently, Hargrave (1996) measured 15-92 mg/m2 per hr under net-cage operations in eastern Canada, which was 75% higher than at reference sites. Sediment BOD for heavily affected bottom sediments under salmon net-cage operations may be up to 400 mg O2/m2 per hr (Silvert 1994), which is much less than BOD for fish in the water column (see section on water column effects). However, because it is immobile, the sediments have less and slower capacity to replace oxygen than the water column. For comparison, fibre mat beds at pulpmills in Alberni Inlet below the outfall have recently measured ODs of 16-83 mg/m2 per hr, depending on bottom water oxygen levels (D. Stucchi, DFO, D. Hodgins, Seaconsult Ltd., pers. comm.).

In marine systems, recently deposited salmonid farm wastes will generate a sediment oxygen demand proportionate to the rate of carbon deposition (Findlay and Watling 1994). If the sedimentation rate of organics is faster than the ability of the water flowing over the bottom to deliver and assimilate oxygen into the sediments, then progressive deoxygenation and increased CO2 production result. Findlay and Watling (1994) related theoretical maximum aerobic oxidation rates of organic matter for sediments to mean bottom current speed. Based on the empirical model and field studies of four sites (and with a wide margin for error), they were able to predict the occurrence of anoxic sediments and anaerobic bacterial mats based on sedimentation rates of carbon and mean bottom currents.

Sediment redox has been suggested as a quick and simple way to examine the health of the benthos. The redox potential (Eh) is a quantitative measure of the relative reducing or oxidizing intensity of sediments. A positive redox indicates some oxygen is present: a negative value occurs when there is no oxygen. The more negative the redox value the more reducing the sediment and thus degree of oxygen debt.

Redox is strongly correlated with sediment grain size and will usually be higher for coarser sediments than for fine ones, since fine sediments tend to be tightly packed and higher in organics and therefore have a greater oxygen deficit than coarse, well-aerated sediments. Negative redox values indicate poorly aerated sediments, usually high in organics. In normal sediments this would almost always mean very fine, silty sediments. However, under conditions of extraordinary organic enrichment it can occur in coarser sediments (i.e., under fish cages). Redox just above the sediment /water interface goes up fairly rapidly, as evidenced by values in Cross (1990). The method of sample collection is vital for redox measurements, since the redox potential in the surface few cm of the sediments determines the presence or absence of aerobic organisms. The depth of the zero isovolt (aerobic/ anaerobic boundary) gets shallower as enrichment proceeds. Surface sediment redox should be about 300-400 mv in most undisturbed sediments. Iwama (1991) indicated that redox potentials of 200 to -150 mV are typical in the habitat of the polychaete C. capitata and other enrichment opportunists commonly found in impacted sediments beneath fish farms (see also Hargrave et al. 1993). Redox values can change seasonally, in concert with changes in biological activity. The use of redox is often of little use in naturally very fine sediments, where the zero oxygen boundary may already be very close to the surface of the sediments.

Figure 6. Redox Potentials (millivolts) for Sediments at the Perimeter of Net-Cages (circles) Versus Sediments 100 m Distant (triangles).

Note: The figure also shows the lower total organic matter and higher redox in natural marine sediments.

Data from New Brunswick (Thonney and Garnier 1993) illustrate the dichotomy in redox values at the edge of net-cages and 100 m distant (Figure 6). Redox naturally ranges between about 0 and 300 mV regardless of sediment type, whereas organically enriched sediments often have redox values less than zero. There is also a declining trend in redox related to total organic matter. Note that the highest total organic matter (SVR or TOC) values occur in the sediment samples taken at the perimeter of net-cages.

Several studies at marine salmon farms in Europe (Brown et al. 1987 and Enell and Lof 1983) measured redox values of about -150 mV at a depth of 4 cm into the sediment. These values are characteristic of anoxic sediments, which are devoid of animals (see Iwama 1991). Gowen et al. (1991) suggested that carbon loads of greater than 7 kg/m2 per yr can alter sediment redox by as much as -200 mV. References cited in Iwama (1991) suggest that anoxia can occur with carbon loading rates as low as 2 kg/m2 per yr. Hargrave et al. (1994) suggest that carbon sedimentation > 1.5 kg/m2 per yr can lead to anoxia. Average sediment carbon loads in the few B.C. farms measured directly fall between 1 and 7 (Table 3). Revised estimates from the MAFF model for 22 farms in B.C. at varying production levels show a range of carbon sedimentation of <1 to 3.8 kg/m2 per yr.

C. SEDIMENT BIOCHEMISTRY (METHANE, HYDROGEN SULPHIDE, AMMONIA)

Aerobic processes

Chemical and biological processes occurring in sediments under salmon net-cages are different in aerobic versus anaerobic conditions. Under aerobic conditions, heterotrophic bacteria and invertebrate fauna utilize oxygen, producing carbon dioxide and waste products, including ammonia and other forms of nitrogen and phosphorus. The rate of oxygen uptake and carbon dioxide production by bacteria in sediments is greater in the presence of invertebrates. The benthic invertebrate fauna can increase the flux of ammonium from sediments by 50% (Moriarty and Pullin 1987).

Hargrave et al. (1993) measured a maximum ammonia flux of 62 mmol NH4/m2 per dy under cages at a salmon operation on the east coast of Canada. He cited values of 1-14 mmol/m2 per dy as typical of marine sediments not affected by excessive organic enrichment. Ammonia release from sediments was 27 times higher under net-cages than at the perimeter of the site. Hatfield and EVS (1996) cite other salmon farm examples ranging from 12 to 312 mmol/m2 per dy.

Anaerobic processes

When the oxygen demand of sediments exceeds the supply from the overlying water and sediment oxygen levels approach zero, the aerobic heterotrophic bacterial activity declines. Concurrently, anaerobic bacterial activity increases. This process includes three types of bacterial metabolism which will occur in varying degrees depending on habitat conditions. They include nitrate reduction, sulphate reduction and methanogenesis. In most natural marine sediments, a nitrate zone (denitrification by largely aerobic bacteria utilizing nitrate as an alternative electron acceptor to oxygen when the latter has been depleted) occurs on the surface of the sediments. Below this are sulphate (anoxic/oxic interface) and methane zones(completely anoxic). The latter two supply substrates for the sulphate-reducing (hydrogen sulphide—H2S) and methane-producing bacteria via fermentative bacteria. In freshwater sediments the main anaerobic processes are likely denitrification and methanogenesis in varying ratios (Gowen et al. 1991), due to low natural levels of sulphides in sediments.

The turnover of organic carbon by anaerobic processes is as important in anoxic sediments as aerobic processes in undisturbed sediments (Gowen et al. 1991), although it is energetically more expensive and thus slower per unit biomass. Hargrave et al. (1993) measured maximum sulphide concentrations of > 1000 uM S= in sediment pore water under a salmon net-cage operation in eastern Canada. This coincided with the highest oxygen demand and lowest redox potentials in the sediments, as well as maximum summer temperatures. In general, the authors found that H2S production under salmon cages was 10 fold higher than for typical coastal marine sediments. However, after a high summer release, they found that H2S was no longer being released by September from sediments under the net-cages. By 1994, Hargrave(1996) found that the total sulphides had declined in the worst site to <1 mM S=, but were 10-100 times greater than reference values at a series of other sites in eastern Canada (see also Hargrave et al. 1997).

Hydrogen sulphide is quickly broken down by the presence of oxygen in sediments or water. A model developed by Findlay and Watling (1994) in Maine predicted the development of bacterial mats of the sulfur-fixing Beggiatoa sp. under salmon cage operations, based on oxygen supply to the sediments (using bottom current speeds and standard diffusion models), and BOD and COD generated by the waste stream of organic carbon flux to sediments.

Hydrogen sulphide has been measured in sediment pore water under B.C. salmon cage operations (Anderson 1992, 1996). Unfortunately, the data were obtained using a Hach kit, which has relatively low accuracy and is designed for water column measurements. Thus, the values are questionable. The sulphide values ranged from 0 to 10 mg/L in a series of sites recently fallowed. Unfortunately there was no correlation between sulphide values and SVR or other environmental variables, including fallowing time, faunal abundance and species richness.

Qualitative monitoring under B.C. salmon cage operations using grab samples has been done by various contractors (Cross 1988, 1990, 1993; Anderson 1992, 1996) using the strength of smell of H2S and the visual presence of white, sulphur-fixing bacterial mats on the surface of the sediments. These mats are commonly assumed to be the mucous by-products of *Beggiatoa* spp. or other sulphate reducing bacteria which occur at the oxic/anoxic interface because they require H2S from the sediments as well as low levels of oxygen from the overlying water.

What typically happens is that the white mats form in surface patches on sediments under cages, particularly in depressions or pockets where organic material may have collected more quickly and be less influenced by bottom currents. As organic material continues to accumulate, the patches become a more solid mat of white bacterial mucus. In situations where the bottom water becomes anoxic (as may occur in stagnant fjord basins), *Beggiatoa* disappears from the sediments and reappears as a milky cloud at the oxic/anoxic interface in the water column (Burd, unpub.). However, this has not been documented at salmon farms in B.C. and is unlikely to occur except in isolated fjords with shallow sills (such as Saanich Inlet).

In extreme anoxic conditions, outgassing of carbon dioxide, hydrogen sulphide and methane can result from the enhanced activity of sulphate reducing and methanogenic bacteria within sediments (Samuelsen et al. 1988). Gas bubbles containing these compounds erupt from the sediments and rise to the ocean surface around net-cages. This outgassing has been observed at some salmon farms in B.C. (J. Deniseger, MELP, pers. comm.). Samuelsen et al. (1988, 1990) and Cross (1994) indicate that where gas bubbles are released from anoxic sediments under farms, the gas contains about 70% methane, 28% CO2 and 2% H2S. It is not known how much this gaseous mix is harmful to fish. However, methane is not known to be harmful to fish. The presence of hydrogen sulphide in the water column at some marine cage farms has been held responsible for loss of appetite in fish, gill damage and increased mortalities of fish (Braaten et al. 1983), and may partly explain the increase in and persistence of disease. Gowen et al. (1991) also cautions that such bubbles could carry pathogens from sediments up to fish in the water column.

Samuelsen et al. (1988) indicate that the concentration of H2S in gas bubbles at the sediment surface can be as high as 17,000 ppm, but attenuates quickly as the bubbles rise in the water column. By 5 m or so above the bottom, the H2S should be oxidized (removed to SO4=) by the presence of oxygen in the water. This is a good reason to site net-cages with the bottom of the nets at least 5 m shallower than water depth.

Outgassing is only found with high organic loadings. This situation is definitely not in the best interests of the salmon farmer and operations are typically moved when this occurs. The timing and occurrence of gas bubble release is probably related to the physical conditions of the site, including water column stratification, temperature and sediment pH (Cross 1988, Hatfield and EVS 1996).

D. CHEMICAL ACCUMULATION IN SEDIMENTS

Metals

Tributyl tin (TBT) is no longer used at salmon farms in B.C., although some visiting ships (particularly aluminum hulls) may still be coated with it. Copper-based antifoulants on net-cages (Cross 1993; Lewis and Metaxas 1991; Peterson et al. 1991) do not seem to result in adverse environmental effects at the concentrations leaching into the water. High concentrations have not been noted in sediment samples taken in 1996 by MELP, despite its use in feed and antifoulants (MELP monitoring data, 1996). Values in sediments are generally below 75 ug/g.

Because zinc is added to salmonid feeds to protect the fish from cataracts and improve the quality of the product for market, it is not surprising that unusually high levels have been found in sediments under fish farms in B.C. (MELP monitoring data, 1996). Values in sediments have exceeded 800 ug/g. Normal levels for uncontaminated marine sediments in B.C. do not exceed about 100 to 150 ug/g (MacDonald and Crecelius 1994), and anything over 200 ug/g is considered contaminated. Sediment quality objectives for B.C., Washington state and Environment Canada range from about 124-210 ug/g (for summary, see Burd 1996). Because of this, MELP has had feed pellets from EWOS analysed and found levels of about 279 ug/g in feed pellets (recent analysis indicated a range of 105-225 mg/kg1). Feed manufacturers claim that this is partially due to ground up skeletal material from fish meal. It has been suggested that zinc may be useful as a tracer of impact extent around B.C. salmon farms (Figure 7). However, R. MacDonald (DFO) has indicated that zinc is likely to fluctuate to some extent based on silt/clay content of sediments.

Figure 7. Relationship Between Zinc and Organic Carbon in Sediments Under Cages and in Reference Stations.

E. ANTIMICROBIALS (OXYTETRACYCLINE, ROMET 30, TRIBRISSEN)

Gowen et al. (1991) state that at the time of writing the Norwegian State Pollution Control Agency anticipated that 75% of antibiotics used in salmon cage-culture may be lost to the sediment (see also Samuelsen 1989). Some therapeutic compounds persist for months, others break down in a few days (see also C. Stephen's paper: Fish Health). In freshwater cultured rainbow trout, it is estimated that only 7-9% of oxytetracycline gets absorbed by the gut of the fish. The half-life of antibiotics in sediment has been estimated at 9 to over 400 d (Jacobsen and Berglund 1988; Smith and Samuelsen 1996). It is therefore not surprising to find antibiotics in the sediment around fish farms following treatment. Björklund et al. (1990) suggest that the rate of disappearance of antibiotics is more dependent on leaching conditions (leaching and concentration gradients between sediment and water) than on degradation.

Oxytetracycline concentrations >10 mg/kg are commonly found under salmonid net-cages using the antibiotic (see Weston 1994). *Oxytetracycline* concentrations of 1-4 mg/kg have been measured in sediments (0-2cm depth) under a salmon farm shortly after treatment (Capone et al. 1994, 1996, Kerry et al. 1996), with values as high as 11 mg/kg (Coyne et al. 1994) in sediments under farms with heavy TOC usage, and at concentrations up to 285 mg/kg in accumulated piles of waste feed under farms recently using medicated feed. The lower concentrations of TOC generally decline to less than 0.5 mg/kg after two months (Capone et al. 1994; Coyne et al. 1994). Samuelsen et al. (1992), Smith and Samuelsen (1996) and Capone et al. (1996) indicate that oxytetracycline can persist in sediments for up to 500 days after heavy or persistent usage, although its antibiotic activity seems to cease after about one month.

Lunestad and Goksøyr (1990) report that only about 5% of the oxytetracycline found in marine sediments have antibacterial properties, and is mostly complexed with magnesium, calcium, and other divalent cations. The presence of antibiotics and elevated bacterial resistance in sediments also seems to be dependent on anoxia and the presence of invertebrates (Coyne et al. 1994, Kerry et al. 1996). Furazolidone seems to have a very short half life in water and sediments because it is quickly metabolized by microbes. Therefore it is not considered a problem in sediments (see Hatfield and EVS 1996). Romet 30 was not detected in sediments under salmon cages between three days and three weeks after application (Capone et al. 1994, 1996).

The intermittent use, the great dilution of the added antibiotic by the receiving waters, and the susceptibility of some drugs to photo-degradation (e.g., oxytetracycline—Samuelsen 1989; frazolidone—Samuelsen et al. 1991) suggest that drug effluent is minor in quantity under fish farms. However, the persistent use can be additive, and can select for antibiotic-resistant bacteria. Such resistant bacteria have been reported from sediments under fish farms in a pattern which follows the deposition pattern of waste sediments (Björklund et al. 1990; Austin 1985). Results of studies to date are controversial and can be affected by a number of habitat factors. In addition, the resistant bacteria decline quickly in sediments, suggesting that they are not well adapted to compete in normal sediment conditions (for more information see discussion paper on fish health by Craig Stephen).

Smith and Samuelsen (1996) show that the concentration of antibiotics in sediments is strongly affected by the amount of waste feed containing medication accumulating in sediments. This is particularly important for the bacterial communities and invertebrates directly utilizing waste feed pellets. There is little information on the transfer of these chemicals to other species via ingesting waste feed pellets. Capone et al. (1996) examined concentrations of TOC in oysters and crabs near fish farms in Washington State. They found that oysters had very low TOC tissue concentrations, which is not surprising since they feed on particles in the water column rather than detritus on sediments. However, *Cancer productus* (red rock crab), which scavenges on waste feed pellets, had tissue concentrations as high as 3.8 ug/g, well in excess of USFDA limits for solid seafood of 0.1 ug/g. Note that these excessive conditions occurred in several farms with what can only be interpreted as extreme impact conditions in sediments, shallow depth (16-25 m) and heavy usage of antibiotics (up to 450 kg/yr active TOC).

The information presented above on the effects of therapeutic agents is not satisfactory from the perspective of completeness. The amount of data and reliability of reviews very much depends on both the technology that is available to measure the materials in the tissues or sediments, as well as on the funding of programs to determine and/or monitor the materials in question in the biological and physical environments over a sufficient period of time.

F. CHANGES IN BENTHIC ASSEMBLAGES

Any change in sedimentation or chemical conditions (seasonally or with changes in cage operation, fallowing, etc.) will alter benthic flora or fauna community composition to a greater or lesser degree. Burial due to high sedimentation rates tends to alter filter-feeding assemblages to those dominated by deposit feeders. As sediment oxygen declines, larger macrofauna and sensitive epifauna disappear first, followed by organic enrichment tolerant macrofauna, organic enrichment meiofauna and, finally, all aerobic bacteria. When the sediments become completely anoxic, the aerobic bacteria, meiofauna and macrofauna of sediments are eliminated.

G. MACROALGAE, BENTHIC ALGAE

Marine salmon farms in B.C. are generally located at water depths below the photic zone so that there are not significant benthic algal or seaweed mats important to ecosystem structure. This is also true for eelgrass, which tends to occur much shallower than 30-40 m deep. However, bull kelp is found deeper than eelgrass, and can be found adjacent to farms located near sloping rocky shores. The proximity of major kelp beds to salmon net-cages was sometimes noted during visits to salmon farms in Broughton area. As an opportunistic seaweed, kelp may take advantage of increased nutrients in the water column and proliferate near salmon farms (M. Coon, MAFF, pers. comm., see also Black et al. 1991 for discussion of back-eddy effects on kelp).

Tetracycline has been found to be toxic to marine algae in the concentration range of therapeutic use for fish farms, but is probably detoxified by binding with calcium and magnesium in seawater. It is probably more of a problem in freshwater, where this mineral binding would be minimal (Hatfield and EVS 1996).

H. BACTERIAL ASSEMBLAGES

Bacteria may contribute up to 55% of the total turnover of organic carbon in lacustrine sediments (Gowen et al. 1991). Fry (1987) reviewed the functional roles of major bacterial groups associated with detritus, and discussed the complex effects of temperature and deoxygenation on bacterial communities in sediments. Sediment heterotrophic bacteria assimilated organic compounds maximally in summer and minimally in winter. Since there do not seem to be any large seasonal changes in total bacterial numbers, temperature is therefore the main driving force and MUST be considered in models of carbon sedimentation and decomposition beneath net-cages (see below). This seems to apply to anaerobic bacterial decomposition processes as well (Moriarty and Pullen 1987).

The second critical factor in bacterial community composition and growth is food supply. Bacterial biomass is positively correlated with organic carbon and nitrogen content of sediments (Moriarty and Pullin 1987), but also with the "quality" of the organics (C/N ratio, lability or age of carbon and nitrogen). Salmon farm wastes, having a C/N ratio similar to marine algae (the predominant or preferred food resource for heterotrophic bacteria), and generally being "fresh" in terms of age, are very biologically available and of high food quality for bacteria. However, growth rates and production of bacteria are not always correlated with standing stock bacterial biomass or with food (organic detritus) supply. This is because grazing by animals seems to increase bacterial growth rates (Moriarty and Pullin, 1987). Therefore, although bacterial standing stock may be low due to heavy grazing (<5% of detritus organic weight Moriarty and Pullin, op. cit.) gut contents of invertebrates and fish suggest that bacteria are the major food resource for large biomasses of consumers. Therefore, the rate of bacterial production and turnover must be high. Estimates based on oxygen demand in detritus indicate that 1-4 g C can be fixed in bacteria/m2 per dy. Note that this is similar to the suggested maximum organic carbon deposition which can be assimilated by sediments under salmon net-cages (Hargrave 1994 and other authors therein).

A study on the invertebrate opportunistic polychaete *Capitella capitata* showed that the polychaete stimulated bacterial growth when detritus was in low supply, but not when detritus was in high quantities and bacteria were growing very rapidly (see Moriarty and Pullen 1987). Some burrowing infaunal organisms produce mucus tests which actually act as substrates for "farmed" bacteria. The presence of burrowing invertebrates therefore serves to increase the rate of nutrient flux from sediments to overlying water by stimulating bacterial growth and sediment oxidation.

Another critical factor in aerobic bacterial growth and production is oxygen supply to sediments. If the oxygen supply to sediments from bottom currents, diffusion (sediment porosity, compaction) and invertebrate bioturbation is sufficient to provide a continuous supply of oxygen, bacterial production will match the rate of carbon deposition from salmon farm wastes (Findlay and Watling 1994). Oxygen uptake rates in sediments are closely linked to bottom currents and topography and can be modelled. This type of modelling has yet to be incorporated into the MAFF siting model. At present, there is insufficient data available on bottom currents and topography for the majority of salmon cage sites in B.C. However, this information is vital in determining assimilation capacity of sediments for organic waste from farm sites.

There is some concern that antibiotics in sediments may alter the balance of the microbiotic assemblage in breaking down waste, and thereby slow recovery time of sediments from organic enrichment. For example, in lab experiments sulphate reduction in sediments treated with antibiotic was half the rate measured in control sediments—(pers. comm. cited in Gowen et al. 1991). Hansen et al. (1992) found that oxytetracycline, oxalinic acid, flumequine and furazidine reduced bacterial activity in sediments initially (about 10 weeks to full recovery), and that tetracycline showed a delayed response (Hansen et al. 1993). However, no bacterial depression was noted by Capone et al. (1994) for oxytetracycline, Romet 30 or amoxycillin.

In addition, increases in antibiotic resistance of disease bacteria in sediments under salmon farms using medicated feed is a concern. Resistance increases cannot be readily correlated with antibiotic concentrations in sediments under salmon farms, or with prevailing current direction and sediment particle dispersion (Kerry et al. 1996). Resistance increases from background levels of about 1.3% (25 ug/g TOC) to up to 8.8% have been noted under salmon farms (Kerry et al. 1996). However, the ecological significance of these changes has never been determined. The problems involved with measuring antibiotic activity have been considered by Pursell et al. (1996).

I. MEIOFAUNAL ASSEMBLAGES

Meiofauna comprise the invertebrate taxa which fall into the size category between bacteria and the smaller infaunal (within-sediment) and epifaunal (sediment surface) macro-invertebrates (Schwinghamer 1981,1983). They are generally considered to be between 0.01 and 50 ug body mass or 8-500 um body size (Warwick 1987). In highly enriched, low oxygen sediments under salmon cages, opportunistic nematodes tend to make up a very high percentage of invertebrate faunal biomass and respiration (Duplisea and Hargrave 1996, Weston 1990). Organically enriched marine sediments are characterized by smaller meiofauna taxa, including nematodes of the genera *Rhabditis, Diplolaimella* and *Diplolaimelloides* and copepods of the genus *Tisbe* (Warwick 1987). Meiofaunal assemblages in sediments outside the perimeter of net-cages tend to be dominated by larger taxa (Duplisea and Hargrave, op. cit.).

All opportunistic meiofauna have a wide range of food resource capabilities and high potential production and growth rates. Bacterial grazing is a major food supply for many meiofaunal groups, and they enhance bacterial decomposition of organic detritus by the production of fecal pellets, breaking down of bacterial cell walls (release of nutrients) by feeding and by bioturbation. Meiofauna also excrete ammonia, which is readily utilizable by heterotrophic aerobic bacteria. They are therefore a vital part of the breakdown process of organic materials in sediments under salmon farms.

The detritus to nematode biomass conversion efficiency is estimated at about 1% (Warwick 1987), but is probably much higher when enhancement of bacterial communities is considered. Like heterotrophic bacteria, meiofaunal growth and biomass are strongly correlated with the carbon and nitrogen contents of the detrital sources. The lower the C/N ratio of organic matter, the better the growth of nematodes. Gerlach et al. (1985) developed an empirical protocol for translating meiofaunal biomass into organic carbon equivalents and metabolic units for the benthic community. This has ramifications for modelling impacts and field monitoring since meiofauna are much simpler to sample and count than bacteria.

The true concentration of meiofauna is rarely obtained in sediment samples because a screen size for processing sediment samples of 0.5 mm or greater does not capture many of the smaller meiofaunal forms. Generally, the paradigm is that in natural marine sediments a screen size of 0.27mm is required to sample 95% of the animals, whereas a 1 mm mesh will sample 95% of the biomass (for discussion see Burd et al. 1990). However, in situations where nematodes dominate the invertebrate fauna, and organic enrichment coupled with low oxygen has eliminated most of the larger macrofaunal forms (see below), the percentage of total invertebrate biomass in sediments contributed by nematodes and copepods may be substantially higher than in natural sediments. Therefore, in the typical macrofaunal sampling done in sediments under salmon cage operations in B.C. (Cross 1988, 1990, 1993; Anderson 1992, 1996, MAFF data for Broughton 1995) there is no way to know what the true contribution by meiofaunal production and organic turnover is. However, the numbers that are captured on the larger screen are suggestive that this group is extremely important and should not be overlooked in studies on impacted sediments under salmon net-cages.

J. MACROFAUNAL ASSEMBLAGES

Macrofauna are generally the focus in benthic infaunal and epifaunal community studies to document changes related to environmental conditions. These animals can generally be collected in their majority using a 0.5 mm screen. If juveniles are not considered important, adult forms can be readily collected using a 1 mm screen. For this reason, macrofauna are by far the most commonly used biological indicators of environmental stress in benthos (for review see Burd et al. 1990). Certainly, the use of chemical criteria for assessing sediment impacts is of limited value unless there is some known relationship to the biological communities being impacted. Gowen (1990), and Weston and Gowen (1988) maintain that benthic macrofauna are the best indicators of benthic enrichment under salmon farms since changes in abundance and species composition integrate temporal effects. For these to be effective as indicators, it is essential that we understand the basic community structure of the macrofauna inherent to the site before salmon farming begins. The level of impact in sediments can be inferred by characteristics of the benthic infaunal and epifaunal assemblage. Maximum impact occurs when the sediments are completely anoxic and no macrofaunal or meiofaunal species are present. What occurs more commonly under salmon net-cage operations which are not optimally sited is that the bottom will be moderately to heavily impacted, with patches of completely anoxic sediments interspersed with patches of low species richness, low biomass and low abundance of a few classic organic pollution indicator taxa such as the polychaete *Capitella capitata* sp. complex or other deposit-feeding polychates, and certain nematodes (99% or more of total fauna—see Weston 1990). This combination of taxa seems to occur without fail under organic enrichment conditions at salmon farms world-wide (for reviews see Gowen et al. 1991, Levings 1994, Hatfield and EVS 1996). It should be noted that although C. capitata seems to be ubiquitous in temperate climates world-wide and is most often the dominant pollution indicator in the macrofauna under marine fish farms, there are cases where other species have been found to take its place (c.f. K. Brooks, BCSFA 1996).

The difficulty in effectively using these biotic indicators to determine level of impact lies in the wide variations in numbers which may be sampled over a small spatial scale at a salmon farming operation. Gowen et al. (1991) cites examples of varying numbers of C. capitata in the range of 1,000 to 10,000 individuals per square meter of sediment at individual salmon cage operations. In addition, Mahnken (1993) and Cross (1990) warn that the relative abundances of these taxa can vary seasonally in B.C. Hargrave et al. (1993) noted that Capitella capitata at the perimeter of net-cages in eastern Canada in early July numbered 30,000/m2. This was reduced to 2,000/m2 in October and remained low through winter despite no evident changes in output from the farm.

The 1991 data from Anderson (1992) indicate that species richness remained below about 5-15 taxa per sample if the ratio of *C. capitata* to total abundance was .20 (20%) or greater (Figure 8). Data analysed from Thonney and Garnier (1993) from New Brunswick salmon farms indicated that *C. capitata* was present in elevated numbers mainly between redox values of -150 and +100. Below redox potentials of -150 millivolts, all invertebrate fauna disappears (see also Iwama 1991). Hargrave et al. (1997) suggest that sediments with redox < 0 mV will not support macrofauna.

Rather than use total abundance of *C. capitata,* it turns out in re-examining data from Anderson (1992) that the ratio of C. capitata to total abundance provides a good indicator of impact, effectively separating impacted from recovered sites. In Figures 9 and 10 it can be seen that impacted sites show up clearly as a cloud of distinct points with a ratio of C. capitata to total abundance of about 20% or more, despite the percent silt/clay or total volatile residue in sediments. This property of dominance (at varying percentages of the total) by a single opportunistic macro-invertebrate should hold true for any species which may be present in the place of *C. capitata*.

Figure 8. Ratio of Abundance of C. capitata to Total Faunal Abundance, Versus Species Richness for 1991.

Source: Anderson, 1992

As conditions under the cages improve to moderate levels of impact, the faunal compositions become much more site-specific, with higher abundances mainly of *Capitella* and a few other opportunists endemic to the region (quite often the polychaetes *Nephtys cornuta cornuta* or *N. fransiscanum* in B.C. and high-sedimentation tolerant small bivalves such as *Axinopsida serricata*), but biomass and species richness remain depressed.

Figures 9,10. Ratio of C. Capitata/Total Abundance Versus Sediment Characters.

Under mild benthic impact, abundance and biomass will often “overshoot” so that a true enrichment has occurred. Cases have been documented where low enrichment stimulates abundance and biomass and otherwise does not adversely affect benthic communities (Gowen et al. 1988; see also Ervik et al. 1985 and Brown et al. 1987). However, Gowen et al. (1991) caution that macrofaunal biomass does not show a consistent response to organic enrichment under fish farms and depends on the size and density of opportunists. Mild enrichment often includes relatively high or “normal” species richness, but usually will still show high abundances of opportunists such as *Capitella capitata* (c.f. Cross 1990, MAFF 1995 data, unpublished). This type of impact often characterizes a region around the perimeter of net-cages which attracts mobile epifauna and bottom fish species to feed on the enriched biota and excess feed pellets. Several studies have indicated that some large epifaunal species are found in mild to moderately impacted zones under net-cages. These include the anthozoan *Pachycerianthus,* filter-feeding anemones *Metridium senile* and predaceous sun stars *(Pycnopodia helianoides*) which can be found under or at the perimeter of net-cages (Cross 1990, pers. obs. in MAFF videos of Broughton Archipelago and Clayoquot Sound, 1996).

In contrast to the characteristics of enriched conditions, a "natural" or baseline infauna which is not affected by any other unusual form of enrichment will have few if any Capitella capitata or other enrichment opportunists (see Figures 8-10). If the sediments are aerated there may also be large, deep burrowers (such as geoduck).

As an example of the different aforementioned scenarios, Table 4 illustrates changes in mean abundance, biomass and species number for a series of triplicate benthic infaunal samples collected using a ponar grab and 1.0 mm screen by MAFF personnel at four B.C. salmon farm locations in the Broughton Archipelago in January and July of 1995 (C. Backman, MAFF unpublished). This data was analysed by Aquametrix Research Ltd. under contract with MAFF (Cross 1996).

It can be seen from these four examples that the patterns of impact are not always consistent, and that it is most useful to examine all three biotic characters at once (abundance, biomass and species number). As an example, let us focus on the results from July. In the first example, all three faunal factors have been considerably reduced, but the sediments are not totally anoxic. By contrast, in the second example, faunal abundance under the cages is higher than normal, but biomass and species number are not. The high abundance is in small, opportunistic polychaetes (particularly Capitella capitata complex) which do not add much to the biomass. Therefore, although the biota are enriched, impact is low. In the third example, abundance is increased with *Capitella,* but biomass and species numbers have decreased, putting this site between categories for sites 1 and 2. In site 4, the abundance is normal, but biomass is considerably depressed and species number is slightly depressed. This illustrates an early stage of impact in which the larger, rare taxa have been affected more profoundly than the smaller taxa.

Table 4. Examples of Benthic Infaunal Data Collected in Broughton Archipelago Area under Fish Farms and Reference Locations.

No.		Jan 1995			July 1995 1995				
	Mean(st.dev)	reference	farm	Impact	reference	farm	Impact	1	
	abun/0.1m2				164.7(41.5))	38.7(7.2)	heavy		
	biom/0.1m2				2.9(0.65)	0.2(.05)			
	taxa/0.1m2				51.0(2.3)	6.7(1.26)			
		reference	farm	Impact	reference	farm	Impact	2	
	abun/0.1m2	78.3	457	heavy	48.3(12.75)	249.0(45.7)	low		
	biom/0.1m2	0.48	2.98		0.9(0.17)	1.0(0.10)			
	taxa/0.1m2	28.7	3		24.3(6.0)	26.3(2.75)			
		reference	farm	Impact	reference	farm	Impact		3
	abun/0.1m2	93.6	66.3	heavy	95.0(10.0)	188.0(97.7)	moderate-		
					heavy		biom/0.1m2	2.14	0.53
		5.4(1.00)	1.1(0.30)	heavy			taxa/0.1m2	31	1.7
		33.3(2.36)	11.7(3.82)				reference	farm	
	Impact	reference	farm	Impact		4	abun/0.1m2	141	5.3
	extensive	149.0(018.6)	131.3(25.9)		low-			biom/0.1m2	1.36
	.02		3.2(0.40)	0.7(0.10)	moderate	taxa/0.1m2	39.7	1.7	46.0(4.00)
	29.3(3.82)								

Biotoxicity studies were done for MELP on sediments from a number of fish farms in B.C. over 1995 and 1996. They confirm in many cases the toxicity of anoxic marine sediments with high sulphides to various invertebrate species (data provided by L. Erickson, MELP), although Table 4 illustrates variability in effects.

Details of the benthic infaunal community response to organic enrichment from salmon farming in Puget Sound are given in Weston (1990). He describes the classic pollution response of abundance, biomass and species richness (Pearson and Rosenburg (1978).

Decreasing body size of invertebrates can be correlated with proximity to sea-cages, because the rarer, larger forms tend to disappear first during habitat stress. It is hard to spatially quantify this phenomenon with "spot-check" infaunal samplers. This is why visual criteria (SCUBA, video profiles) specifying the presence or absence of large epifauna are important as part of a suite of "health" indicators under salmon net-cage operations. However, within an individual opportunistic species which is well adapted to enrichment conditions, the largest individuals will occur closest to the area of enrichment, further substantiating their ecological superiority under enrichment conditions. Weston (1990) found that C. capitata and other tolerant species may be 3-5 times larger under cages than in undisturbed sites only a few metres distant. In addition, organic enrichment results in the loss of deep, large burrowers in sediments, in favour of smaller species which live close to the sediment/water interface (and hence oxygen source), thus dramatically reducing the vertical distribution of biomass in sediments. Unfortunately, there is not always a good correlation between organic content or chemical changes such as redox potential (particularly in fine sediments) in sediments and benthic communities (see Anderson 1992, 1996; Gowen 1990 and Brown et al. 1987). There have been attempts to correlate biotic and chemical factors. Hargrave et al. (1993) indicated that C. capitata had a maximum tolerance limit of 5,000 umol S= in sediments, with optimum growth conditions at 100 to 1,000 umol S=. Lab experiments were cited which showed survival in the lab of 7-8 days at 1,000 umol S=. Hargrave et al. (1997) also indicated that redox, S=, and biomass of deposit feeders (such as C. capitata and other polychaetes or bivalves) were all sensitive indicators of organic enrichment beneath salmon farms.

K. SEDIMENT ASSIMILATION CAPACITY

One approach to determining assimilation capacity of sediments is to measure the rate of organic carbon breakdown. The organic carbon decay rate constants can be determined in several ways as follows:

1) by measuring the flux of carbon to sediments, the flux of carbon dioxide across the sediment-water interface, and burial of residual organic carbon not degraded;
2) by determining organic carbon remineralization rates using kinetic models of the vertical distribution of sedimentary organic carbon; and
3) indirect determination of organic carbon remineralization from sulphate reduction and oxygen consumption (Findlay and Watling 1994).

In practice, determining the rate of carbon breakdown is only feasible if accurate carbon sedimentation rates can be determined. This is hard to measure with any accuracy due to sediment resuspension. Sediment traps are usually deployed above bottom to avoid confounding data from sediment resuspension. The following discussion of modelling efforts needs to be prefaced with this caution. Recently, a new method has been suggested to accurately measure carbon loading to the sediments taking resuspension into account (BOSS system Silvert 1995). Sediment profiling cameras can also determine sediment layering and contents with considerable accuracy. A modelling workshop on the east coast of Canada (Hargrave 1994) was conducted to examine various methods for determining changes in sediments and water column related to marine salmon farm effluents. A summary of this workshop by the author suggests that short-term benthic carbon loads of <4 g C/m2 per dy has little impact on benthic condition (by expert visual inspection). However, the modelling exercises suggest that long-term accumulation shows problems at levels of 2 or 3 g C/m2 per dy. The carbon output from a cage-site can be predicted based on total feed and feed conversion ratios (see section on discharges in this report). Then bottom depth, topography and current dispersal must be included in estimates of actual settlement to benthos.

Sowles et al. (1994) modelled the relationship between carbon accumulation in benthos and changes in benthic habitat. They used monitoring data collected at 23 net-cage sites averaging 6 m deep in eastern Canada. Note that the cage operations were considerably shallower than those used on the west coast. The model used subjective estimates of benthic impact and related that to measures of sediment chemistry. They found that benthic carbon loading alone was not a good predictor of the subjective benthic impact score. When they included "age" of the site or cumulative carbon loading, they found the relationship between sediment chemistry and benthic index for old and new sites separated out had the same rate of increase, but showed a separation along the benthic impact score axis. Using this model they found that professional observation of benthic index and scoring of sediments correlated very well with predicted TOC and redox, but only for the newer sites. In the older sites, the subjective benthic impact score started out much higher even at the lowest organic sedimentation rates. The aforementioned study points out the fact that it can take time to build up a benthic impact. However, Dr. Brooks (BCSFA 1996) suggests that response and recovery of benthos in Washington state fish farms is very quick.

In general, Sowles et al. (1994) concluded that carbon loading up to 3 or 4 g C/m2 per dy showed little impact at the sites studied. Above this rate of deposition, the decline in benthic condition was much steeper. This is in line with the optimum sedimentary bacterial carbon assimilation rates discussed by Moriarty and Pullen (1987 and see section on bacterial impacts). At the higher levels of deposition the rate of deterioration of benthos is steepest for the first year of operation, after which it starts to slow down as organic sediments get progressively buried by new deposition. This is also true of the accumulated total organic carbon curve.

Using this type of model, it may be possible to predict the period of time for which a farm will have little benthic impact using benthic carbon loading, total feed used and feed conversion ratios.

As a comparison, the rates of carbon deposition for optimally cited fish farms studied in B.C. were measured at 7 to 13 g C/m2 per dy (50-10 kg/m2 per yr) directly under cage operations (Cross 1993). These values were based on an assumed carbon content of 35% of waste sedimenting material. These values were measured in sites where benthic impacts were considered to be low, although the "age" of the site was not considered. In 1996, carbon deposition rates of 10-14 g C/m2 per dy were measured under four salmon farms in the Broughton area (Cross 1996). Impact varied from low to extreme. In both cases, the use of bottom canisters would not take into consideration resuspension and are probably too high. Deposition results for 20 farms of varying sizes using the MAFF discharge model estimate that carbon deposition rates probably range from <1 to 10 g C/m2 per dy, with variable levels of impact in sediments.

Findlay and Watling (1994) estimate the effective bottom current rates required to deliver sufficient oxygen to sediments in order to prevent oxygen depletion based on different carbon loadings. This is theoretical and crude, but the logic is good and it provides a good basis for criteria (Figure 4 from Findlay and Watling 1994). Note also that the model by Findlay and Watling (1994) is standardized to seawater at 20 degrees C and represents the optimum theoretical oxidization rate for organic matter. The model suggests at 20 C with bottom currents of 8 cm/s or greater the maximum theoretical oxidizable carbon input to benthos levels out at about 20 g C/m2 per dy. There is a diminishing rate of oxidizing capacity at bottom currents down to 3-4 cm/s. With a minimum current near zero the sediments can still assimilate up to 5 g C/m2 per dy, which is fairly closely in agreement with the model developed by Sowles et al. (1994).

An example which may be close to the theoretical temperature given in the model by Findlay and Watling (1994) is abstracted in ICES (1995) for a salmon cage operation in the Red Sea. Carbon deposition rates of 4.5 to 12.7 g C/m2/d were matched by bacterial decomposition rates of 1-5 g C/m2/d. However, there was no sediment accumulation, which suggests that invertebrate respiration and resuspension probably took care of the excess carbon.

However, normal temperatures below net-cages in B.C. will be more on the order of 4-8 C, which results in much lower metabolic rates. Holmer and Kristensen (1992) indicate that temperature variations can account for about 40% of seasonal variation in benthic metabolism, with 60% related to the rate of supply of organic matter.

Findlay and Watling (1994) note that oxygen demand by biota and sediments is a dynamic process and instantaneous current speed changes can result in very rapid changes in oxygen availability. Some macrofauna are very susceptible to oxygen depletion even over a short time, so that minimum bottom currents may be a better criterion for sediment organic assimilation than average currents.

Therefore, assuming a non-stagnant water column with bottom current of a few cm/s, a conservative estimate of potential oxygen assimilation and therefore rate of carbon breakdown in sediments under salmon farms in B.C. of about 3-4 g C/m2 per dy or 1.5 kg C/m2 per yr is probably feasible.

Gowen (1994—speaker notes on modeling aquaculture-environment interactions for coastal area management, Victoria, B.C. Sept. 15-16, 1994) described his sedimentation model (with a discussion of limitations) and comparative analyses of fish farm effluents in Scotland and Puget Sound. Model results indicate that redox potential and number of macrofauna species are the most reliable variables for model predictions. He concludes from simulations and regressions of empirical data that a 25% reduction in species richness results from 2 g C/m2 per day; a 50% reduction results from 4.8 g C/m2 per day; and a 75% reduction in species richness results from 7.4 g C/m2 per day. On average, he has found < 4 species at deposition rates of 16 g C/m2 per day, with only two or three species, outgassing is likely to occur. This is still an empirical application of simple models. Note that, using his model, changes in species richness and biomass show a linear (or at least monotonic) relationship to distance from the farms.

Hargrave (1994) took the theoretical modelling a step further, showing empirical correlations between carbon sedimentation rate, organic carbon (TOC) and redox potentials in surface sediments. He came up with a benthic enrichment index (BEI—relationship between sediment redox and TOC—see also Silvert 1995) which declines with sedimentation rates greater than 1 g C/m2 day. However, in examining his data (Figure 1 in Hargrave 1994), it appears as though the BEI doesn't really start to decline in the study areas until sedimentation rate exceeds about 3-4 g C/m2 per day as found by Sowles et al. (1994). At this rate, the BEI falls below 0 due to negative redox values in surface sediments. However, the BEI does decline at sedimentation levels greater than 1 g c/m2 per day in the artificial mesocosm, suggesting that there are factors in the natural system which are not taken into account in the laboratory (i.e., resuspension and invertebrate metabolism). He notes for corroboration that a study of sewage sludge inputs to marine sediments caused anoxia at sedimation rates greater than 1 g C/m2 per day. However, as noted previously, the extrapolation from other industrial organic sources is problematic. Sewage generally contains organic and inorganic toxic material, which may inhibit biotic activity. In addition, the carbon to nitrogen ratios of sewage sludge are different from fish farm waste, resulting in less labile organic material in sewage. The relationship between sedimentation rate of carbon and BEI is not linear, but tapers off above a certain sedimentation level, presumably because burial from on-going sedimentation limits the carbon assimilation problem in surface sediments.

Obviously, the steady state situation in which carbon is broken down at the same rate as it is deposited results in no net extra burial of carbon in sediments. Therefore any burial or accumulation of carbon in sediments indicates that the steady state situation has been exceeded. One of the considerations in examining organic carbon burial under salmon farms is that carbon which is fresh is most readily broken down by bacterial action (labile). Old carbon is less refractory and tends to take longer to decay. Therefore, buried carbon will be broken down progressively slower and slower in sediments (c.f. Hargrave 1994). Cranston (1994) stated that carbon burial rates can be calculated by correlating dissolved ammonium and sulphate profiles in sediment pore water from cores. In this way, he was able to directly measure the accumulated carbon in sediment or carbon burial rate, thereby bypassing the problem of measuring in-situ actual sedimentation rates. Using his model, Cranston (op. cit.) estimated that on average, for every 100 g C added to a fish cage, 10 g gets buried in the sediments.

Modelling the relationship between carbon output and accumulated carbon rate based on different hydrographic and physical conditions in B.C. would be most worthwhile. Most of the aforementioned modelling exercises are relatively straightforward, requiring only the physical, biological, chemical and hydrographic background data to implement them. This lack of baseline data appears to be the major limitation in modelling benthic impacts in B.C. It must also be stressed that modelling will only provide a crude tool for siting and predictions. Field verifications are more reliable for tracking impacts.

L. PATTERNS OF RECOVERY FROM SEDIMENT IMPACTS

Studies of the benthic effects of fish farming have been somewhat reactive and opportunistic in British Columbia. Because there are no commercial-scale "experimental" fish farms in B.C. in typical environments for fish farms, it has not been possible to study specific effects under controlled conditions prior to, during and after culture operations. Therefore, researchers have had to study the effects of fish-farming in "pieces". In addition, any research has had to fit in with existing production and feeding regimes and adapt to whatever changes were occurring in a dynamic, working fish farm. This means that the existing studies have had no real control conditions on which to extrapolate or predict results from other sites and situations. For example, Cross (1990) examined a series of eight farm sites which were expected to have sediment accumulations of organic waste. Sedimentation rates were measured for one month in summer and extrapolated to yearly values, and qualitatively estimated for different stocking densities and life-cycle stages. Other examples include Cross (1988, 1993). Longer-term sedimentations studies and benthic infaunal surveys were conducted in 1995 by MAFF (Cross 1996—problems with data described therein). Other studies have attempted to standardize conditions as much as possible prior to studies (Anderson 1992,1996; Miller-Retzer 1994) but suffer from the inability to determine historical use patterns and thus extrapolate results. It will be seen in this section on recovery of benthic sediments that detailed knowledge of the cumulative deposition and time-series effects of waste deposition from salmon farms is vital in understanding progressive degradation and recovery in benthic sediments under salmon cage operations.

Recovery from benthic impacts must be measured over time at an existing farming operation. However, in the absence of time-series data, the character of that recovery (description of stages of recovery in benthos, etc.) can be inferred from studies of gradients away from existing fish farms. In many cases, it is easier to do the latter. An example of a gradient study of this sort is given in Weston (1990) for a Puget Sound salmon farm.

In addition, the use of a suitable reference station (which is not an easy task because of the many habitat factors that can vary over short spatial distances in marine coastlines) can provide a baseline to determine what full "recovery" should look like. Note that it is important to know where the net-cages have been located in an embayment, as movement of cages within a lease area can confound reference information. Because reference stations are hard to find, the optimum solution is to do baseline surveys of a site which is untouched, subsequently is used for salmon farming, then is closed down to examine recovery.

All the scientific evidence collected so far indicates that given enough time without a fish farm in operation, the benthic habitat beneath will eventually return to a stable and acceptable state. Anderson (1992, 1996) states that there is no evidence of irreversible damage to benthic habitats from salmon farming in B.C. However, it may not return to the same faunal community configuration as before. For example, if a salmon farm has been sited where it will eliminate or seriously reduce a sensitive and spatially-limited or slow-growing food or fisheries resource (generally clams, oysters, geoduck, etc), that particular species may not repopulate the specific region. This is true of any kind of impact sufficiently large in scale, particularly if the impact changes the physical or chemical character of the sediments. The reasons for this are not known but are probably related to chance spatial and temporal settlement patterns of larvae, or subtle changes in sediment chemical or physical conditions which make the species in question less competitive.

There are two important caveats to the discussion above. First of all, such monospecific resources (clam beaches, etc.) can disappear for many different non-anthropogenic reasons, most of which are not understood. Secondly, unlike most other types of industrial benthic impact which include non-degradable or toxic materials or complex organic contaminants, the material settling from fish farms consists with two exceptions almost entirely of labile organic material, which will eventually be broken down and assimilated by consumers in the surface layers of the sediments or buried and remain inert. The two exceptions, which will be discussed separately include:

a) fouling organisms falling from net-cages (particularly high quantities of shell debris which is slowly remineralized)
b) non-food related substances such as antifoulants, metals in feed or antibiotics

Assuming these inorganic substances are kept to a minimum, there is generally no long-term physical or chemical change in marine sediments related to salmon farming. Given normal background sedimentation patterns, the fish food and feces will eventually be completely buried or disappear into the biomass of the ecosystem. This means that rationally sited salmon farms probably have the least probability of effecting long-term changes in benthic habitats of any major existing industry in B.C. including pulp mills, mining, log-booming, sewage outfalls and urban stormwater runoff.

The estimates of recovery time for benthos under salmon farms varies tremendously from several months up to five years (for summary see Hatfield and EVS 1996), and will depend on

1) how long the site has been in production and at what level,
2) bottom topography and currents,
3) basin flushing time,
4) level or intensity of impact at time recovery begins,
5) other potential organic inputs to the area, and
6) what a given researcher will interpret as "recovery".

Ritz et al. (1989) observed major recovery of a benthic community under a Tasmanian salmon farm which was moderately affected, at seven weeks after closure. He concluded that complete recovery had occurred in 14 weeks. He also found that seven weeks after fish were restocked, it had returned to a moderately disturbed (about nine species) condition. He used the ABC method (Warwick 1986. =cumulative abundance and biomass curves), which has had mixed reviews from researchers but nevertheless seemed to work fairly clearly in this case and was corroborated by species richness data. Weston (1986) cites a study in Puget Sound (Clam Bay) where benthic O2 consumption had previously been six times background and returned to normal two months after removal of fish. However, this was not related to recovery of biological flora or fauna assemblages and may have simply reflected a phase of the recovery.

Gowen et al. (1991) suggest that one to two years is more average for benthic recovery under salmonid farms. Cross and Kingzett (1994) state one to five years based on their studies of benthic impacts in B.C. over the years. Ervik and Hansen (1994) indicate that at one Norwegian farm the benthic fauna was still dominated by *Capitella capitata* after five years. These wide variations obviously reflect the effects of the six factors listed above.

There have really only been two studies examining benthic recovery after cessation of fish farming in B.C. (Anderson 1992,1996; Miller-Retzer 1994). In addition, Mahnken (1993) did a seasonal succession study of recovery at an abandoned fish farm in Puget Sound, with descriptions of life history and habits of various stages of invertebrate colonists. None of these studies incorporated the history of the farming operations into their comparisons or estimates of recovery time.

In a three-year study, Anderson (1992, 1996) incorporated and compared the results of the aforementioned three studies as well as some data collected by Cross (1990), in order to examine the recovery of benthos at sites where net-cages had recently been removed. The study included sites with a range of sedimentary, topographic and bottom current conditions. The purpose was to examine the rate and characteristics of recovery under different conditions of enrichment and degrees of impact. Sites had to be freshly abandoned (within 12 months) or have detailed monitoring data from before and after abandonment, with renewed occupation within two years unlikely. Sediment type had to be amenable to benthic grab sampling (fine silt up to coarse sand with deep, rocky sites unsuitable for grab sampling). The net-cages had to have large biomass (grow-out) and be exactly locatable. The study by Andersen is the most intensive and extensive in B.C. to date, and helps to assimilate data collected by other researchers.

Because of patchiness inherent in the impacted sites that could not be accounted for in the study design, Anderson (1992) found difficulties in analysis of the data and suggested that the more sophisticated statistical methods were only useful for gross differentiation between seriously impacted sites and reference sites. He concluded that the most basic measures of sediment sulphides, visual infaunal presence, burrowing activity, sediment colour and character, presence of any high-dominance species (especially *C. capitata* and *nematodes*) were the most feasible for determining ecological stress level. However, the use of a 1 mm screen in the study meant that many nematodes and juvenile macrofauna went through the screen and were not taken into account. Despite this, the data showed some important trends which could be studied further.

Anderson (1996) states that there is a refractory period for sediment chemical and microbial recovery for the most intensely affected sites before benthic invertebrate recovery begins. After this, infaunal numbers increase more quickly, followed by a more gradual return to natural or surrounding conditions.

Anderson used as an index of recovery, a return to 95% of similar infaunal diversity to surrounding benthic communities. The diversity index used (Shannon-Weiner—H') has been shown in the literature to be an unreliable ecological indicator (for review see Burd et al. 1991), is reliant on careful and detailed taxonomic analysis, and only worked adequately at four of the eight stations sampled in the study. However, because faunal impact and recovery beneath net-cages appears to follow a classic pollution response (Pearson and Rosenberg 1978), the assumptions of H' may work quite well in some cases if used properly.

The inclusion of visual and chemical sediment characters mentioned above added consistency and credibility to the results. Three categories of impact were cited as:

1) severely impacted: little or no recovery within 5 mo, complete recovery may take 3-5 yrs (Nanoose Harbour, Tranquil Inlet)
2) moderately impacted: 8-24 mo. (Kanish Bay, Clam Bay, Daniel Point)
3) low impact—two to eight mo. (Sansum Narrows, Village Bay)

In Figure 11 (taken from data from Anderson 1992) it can be seen that in general the ratio of *C. capitata* to total abundance declined to less than 20% within about five months after fallowing, and remained at levels up to 13-15% for up to 20 months. By 30 months the ratio was below 10%, which may be considered more or less recovered. There is considerable variability in recovery results from site to site.

Two other studies summarized and incorporated by Anderson (Miller-Retzer 1994 and Mahnken 1993) both conclude that recovery is not complete until rare (and often biomass dominant species) show up. Miller-Retzer (1994) studied benthic recovery at Village Bay (see also Anderson 1996) and determined that the indicator opportunist *C. capitata* complex was evident from 1.5 to 6 mo. after fallowing, suggestive of the initial recovery phase. From 6-12 mo. species richness approached reference levels but biomass lagged, suggesting the rare, large forms had not recovered. She suggested that biomass was critical to determinations of recovery. Andersen (1996) samples from the same site at 24 mo. showed that there was still some enrichment and differences in biomass, although the sampling was not designed to use biomass as an indicator. Weston (1990) also noted that the biomass profile of sediments changed dramatically with impact under salmon net-cages, due to the loss of the large, deep burrowers which add little to the total abundance but lots to the biomass.

Figure 11. Ratio of C. capitata to Total Abundance Related to Fallowed Time from Previous Salmon Farms in B.C.

Seven cases examined by underwater video by MAFF in 1996 were used to visually describe recovery related to fallowing time at B.C. fish farms (data supplied and interpreted by C. Backman, MAFF). They illustrate that recovery of visual characteristics (sediment colour, texture, epifauna and burrowing) appears to occur in as little as four months, and in all cases between six and 12 months (Figure 12).

Figure 12. Visual Impact Assessment from Seven Fish Farms in B.C. Examined by Underwater Video in 1996 by MAFF.

Note: 0=no impact, 5=extreme impact based on thick white bacterial mat, complete anoxia and no fauna.

Mahnken (1993) studied an abandoned salmon farm at Clam Bay in Washington. The site was in 12 m water depth, which is very shallow compared to sites used for salmon culture in B.C. Mahnken (1993) also showed that C. capitata dominated in the pre-successional recovery phase, and was persistent in low numbers thereafter. Therefore, the presence of this species is not indicative of impact. Rather, its numerical dominance of the assemblage indicates the degree of impact. In this study, the reappearance of rare species was considered the major recovery criterion. Based on this criterion, recovery was still not complete at the termination of the study 20.5 mo. after farm removal.

In summary, return of background levels of abundance, species richness and biomass to values close to those at reference sites is probably adequate to conclude “recovery”, since any fallow site is presumably subject to the same larval dispersal patterns as a nearby reference. In order to do biomass estimates of macrofauna, the sampler size must be adequate to get larger forms. Visual observations tend to be more effective in showing where and when the large biomass dominants and motile species have returned (video monitoring for B.C. salmon farming sites—MAFF). This is important since a fundamental ecological typing of parallel communities from 1910 to the 1960s and even later has relied on the stable, seasonally persistent, long-lived and often larger taxa to show consistency in temperate benthic community structure within specific “healthy” substrate and depth types (see Petersen 1911; Thorson 1957, 1966 for historical precedence; or Burd et al. 1990 for more current review of community concepts).

Based on sediment chemistry and biotic factors described in the previous sections, it ppears that we can tell reasonably effectively when recovery of sediments is more or less complete. What the studies haven't answered is how long at what loading and under what physical conditions it takes to get a site to various impact levels, and how long it will subsequently take the site to recover when fish are removed. Modelling of benthic impacts may be promising for this purpose.

VI. EFFECTS OF DISCHARGES ON THE WATER

A number of questions and concerns have been raised related to the effects of waste discharges from aquaculture on the water column (cf. Ellis 1996; Folke et al. 1994). eseinclude local build-up of ammonia from fish excretion and sediment re-mineralization, and regional effects on oxygen conditions in the water column due to metabolism of waste organics, hypernutrification of the water column resulting in increased production of phytoplankton and stimulation of toxic algal blooms. Less often raised concerns have been voiced about flow restriction from net-cage structures, which may change nearshore patterns of water exchange and affect certain sensitive species or patterns of waste deposition in near-shore areas. Finally, the presence of coliform bacteria such as *E. coli* around net-cage operations has been examined.

A literature review and early field work in Puget Sound by Weston (1986) led to the conclusion that there were no observable effects of mariculture on water quality in B.C. and Washington to that date. He concluded that the amounts of nutrients added by mariculture operations were small compared to ambient levels. The MELP report including data from 1986 to 1990 (Hall and Kangasniemi, in prep) in the Sunshine Coast area concluded that the salmon farms operating there had no effects on the water column. The question of perceived eutrophication of the water column in European marine coastal waters has been discussed by Gowen et al. (1992)

A. WATER FLOW CHANGES

Water flow can be considerably reduced in cages located downstream from the predominant flow direction (Gormican 1989). Therefore, net configuration is important relative to tides and currents (see also ICES 1996). The size, shape, configuration of enclosures, mesh size of nets, net fouling and biomass loading in net-cages can all affect water flow.

Back-eddy effects can prevent offshore transport of wastes in bays where cages are too close to shore (see Cross 1993). Net-cages can create depositional areas where none existed before (see Black 1991). This emphasizes the importance of good oceanographic data for siting and configuration of net-cage operations. The more cages which are placed facing the current, the easier it is to prevent significant decrease in current within “back” cages.

Black et al. (1991) discuss “barrier effects” from net-cages within blocked bays, on the ecology of surrounding flora and fauna—particularly kelp beds. Iwama (1991) and Weston (1986) also discuss reduction in current velocity in the surrounding area of salmon net-cage operations, especially in the down-current direction. However, this is unlikely to be a significant problem except in very restricted areas with intensive culturing. Gormican (1989) showed that 65-80% of the current reduction at net-cages was related to net fouling by mussels and macro-algae. Below fouling depth, currents were within 11% inside and outside the net-cages. Gormican’s predictions of flow restrictions of approximately 50% from net-cage rafts were in general agreement with Weston (1986). One concern is that current reduction behind cages can create depositional zones where none might have been predicted by siting guidelines. This is why a good clearance under nets is required, with adequate current below the nets to disperse waste.

Even the swimming of the fish can alter flow patterns (Hisaoka et al. 1966 in Weston 1986). Gormican (1989) noted that swimming fish can enhance flow during slack tide periods.

B. WATER COLUMN TURBIDITY

Monitoring data collected by MELP in Clayoquot Sound, the Broughton Archipelago and the Sooke basin area often included measurements of water column turbidity from surface to bottom using a nephelometer, which measures light scattering. Values varied considerably from near zero NTU (nephelometer turbidity units) to almost 100 NTU near some farms. Most of the high NTU values were in surface waters. In May and June in particular, these could have been partially related to high phytoplankton biomass. Some very high values in mid-depth ranges (10-50 m) in spring may be related to sinking debris from blooms (Hobson 1983) or to discharges from the farms. However, the nepholometer is only useful for measuring very fine particles in the water, and not the flocculent material which is visible to the divers in and around net-cages. This floc is better measured with a transmissometer, which documents the amount of light blockage of a beam by particulates. The existing data suggests that there may be increased turbidity related to some salmon farms, although more careful measurements are required. This, in turn, could affect nearshore areas in the immediate vicinity, particularly during on-shore current movements (e.g., flood tides).

C. EFFECTS OF AMMONIA DISCHARGE AND OXYGEN CONSUMPTION

Sublethal exposure of salmonids may be induced by long-term exposure to concentrations of >0.025 mg/L ammonia (1.8 umol/L) (see references in Gormican 1989). This level can be important in freshwater which is partially recycled (as in hatcheries) where ammonia is allowed to build up. Gowen and Bradbury (1987) and Ervik et al. (1985) report that ammonia levels may be eight to nine times higher than normal around salmon net-cages. Ammonia and DO levels were modelled for Puget Sound fish farms by Weston (1986), predicting a rise of 0.02 mg/L total ammonia and 0.2 mg/L decrease in DO at a particular site.

Black and Carswell (1986) report no measurable differences in dissolved oxygen or ammonia at active and inactive fish farms and background areas in Sechelt area in B.C. However, a model developed to show oxygen changes and budgets in the Sechelt area was discussed by Black and Carswell (1989) in which they concluded that summer production of 4,000 t would have an oxygen demand about equal to the oxygen available from flushing in upper Sechelt Inlet. They recommended a more intensive monitoring program be initiated in the Sechelt area if production levels were near or greater than that level.

Gormican (1989) indicated that ammonia levels were somewhat elevated over background levels even in near-shore areas at two farms in Sechelt and Jervis Inlet, B.C. This conclusion was based on background levels for the area measured by UBC cruise data up to that time. However, there was no appreciable increase in ammonium beyond background more than 10 m downstream (see also Korman 1989).

Weston (1986) reviewed the literature and industry in Puget Sound and concluded that a flow of at least 10 cm/s outside net-cages is desirable throughout most of the tidal cycle to avoid localized ammonia buildup or oxygen problems. Maximum currents are given as 50-100 cm/s, beyond which mooring systems are not secure.

The biological oxygen demand (BOD) of fish has been measured directly by oxygen consumption and respiration versus estimated carbon uptake. Silvert (1994) indicated that 4 kg Atlantic salmon consume about 20g O2 per day. Given a maximum stocking density used in New Brunswick of 18 kg/m3, with normal cage depths of 5-6 m, the BOD is estimated at 500 g O2/m3 per day. For a 10 m x 10 m cage with 10 t of fish the total oxygen demand would be 48 kg O2/dy.

In his review of Puget Sound finfish culture operations Weston (1986) recommends that dissolved oxygen levels of 6-7 mg/L are the minimum acceptable level for maintaining fish health in cages (see also Caine 1987). Rosenthal et al. (1988) noted that dissolved oxygen concentrations were lowered by as much as 0.5 g/m3 by a single cage stocked at a density of 22 kg/m3 in Usui Bay, Japan despite tidal currents of 3-4 knots. Oxygen levels at the farm site varied tremendously, and were lowest at slack tide and during feeding periods.

Oxygen concentrations below the recommended minimum have been observed (Cross 1990, Anderson 1992) in shallow and/or limited bottom flushing areas of B.C. Gormican (1989) cites examples where net fouling resulted in reduced oxygen concentrations within net-cages due to significant blockage of water flow. This can obviously be avoided with good husbandry practices. During sampling in Broughton Archipelago by MELP and MAFF in September 1996, it was noted at some farms that dissolved oxygen at the bottom of cages was sometimes reported at or below 4 mg/L, probably due to seasonal upwelling of low oxygen dense water in the Strait of Georgia. In some cases where bottom water is isolated from the open ocean circulation (such as deep fjords with shallow sills), low oxygen is natural (Cross 1993, Anderson 1992), but it can nonetheless affect the stress of fish and production of farm sites.

Deoxygenation of bottom water resulting from organic fish farm waste is unlikely to be a serious or long-term problem in marine systems, except in isolated areas where bottom water oxygen depletion is a natural occurrence and may be intensified by high BOD and COD (c.f. Saanich Inlet, B.C., and Anderson 1992). Gowen et al. (1991) suggest that farms located in such fjords should only be sited over the well-flushed, shallow inshore margins or over sills. Brown et al. (1987) reported a depletion in bottom water with low flow and high organic input below a fish farm. Aure et al. (1988) observed a maximum 30% decrease in oxygen overlying sediments near Norwegian salmonid net-cages compared with undisturbed sites. Weston and Gowen (1988) did not observe any depletions in high current areas in Ireland.

D. NUTRIENT ENRICHMENT

Dissolved nitrogen and phosphorus output to the water column in current waste loadings of fish farms in B.C. is considered negligible overall compared to other inputs (Taylor et al. 1994, Taylor and Horner 1994, Hatfield and EVS 1996, and see Table 4). Taylor et al. (1991) in a study of Sechelt Inlet from 1988-1990 concluded that salmon farms could not be shown to impact nutrient regime or algal blooms in the inlet (which usually originated outside the inlet).

Phosphorus can be a concern due to remineralization in anoxic sediments and release of the dissolved reactive form into the water column (for review see Gowen et al. 1991). However, this generally occurs in deep water where it can’t affect phytoplankton. In turnover or upwelling conditions it can come to the surface, but these usually occur in winter according to Taylor (in Hatfield and EVS 1996). However, in Saanich Inlet and other areas affected by Georgia Strait, upwelling of cold, dense water occurs in fall, when late plankton blooms (particularly *Heterosigma)* may occur. Nevertheless, phosphorus is not considered to be limiting in marine waters and is a concern mainly in estuarine and freshwater locations, where it can be a limiting nutrient (see section on Freshwater, this report).

E. EFFECTS OF ELEVATED NUTRIENTS FROM FISH FARM WASTES ON PHYTOPLANKTON PRODUCTIVITY

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This review considers approaches to evaluating the impact that wastes from fish farms may have on biological production of the nearby area. Concern has been expressed that enhanced phytoplankton production from nutrients included in these wastes could have deleterious effects. Such effects could include changes in the stimulation of harmful blooms (Pridmore and Rutherford 1992), changes in the marine food web and, on decomposition, stimulation of secondary oxygen production leading to oxygen depletion (Persson 1991).

Nitrogen is generally considered the limiting nutrient for marine plant growth and for this review discussions will focus on the role and effect fish farm wastes have in elevating background levels of nitrogen. In low salinity estuarine systems phosphorus is occasionally the growth-limiting nutrient, as it is in freshwater. Because many fjordic estuarine environments experience considerable temporal variation in salinity and repeated occurrences of such variations constitute considerable physiological stress on husbanded salmon, few salmon farms, if any, will locate in this type of environment.

Eutrophication, in the sense considered here, is the measurable increase of primary productivity associated with enhanced nutrients associated with human intervention. In discussing eutrophication, it is important to clarify that the botanical utilization of nutrient concentrations associated with fish farms is affected by whether the plants are attached to a fixed substrate or are part of the phytoplankton drifting through the farm site. Plants attached to or in close proximity (within 30 m) to cage structures can also, and perhaps better, utilize the nutrient wastes excreted by the fishes (Persson 1991) than the phytoplankton. Further, as will be illustrated below, the kinetics of nutrient uptake and farm waste dispersion make it necessary to consider fish farms a diffuse rather than a point source of nutrients.

There are basically four approaches which may be used to evaluating the probable impact fish farm nutrients might have on marine phytoplankton growth.

• Nutrient uptake rates and their role in utilization of nitrogenous farm wastes.

Nitrogen limitation of algal growth in B.C. coastal waters is primarily a phenomenon associated with the stratified waters of late spring, summer and early fall months. During this period the uptake kinetics of the algae and the length of exposure the algae have to increased nutrient levels determine whether the algae could utilize any local increase in nutrient concentrations.

Uptake of ionic nutrients by phytoplankton involves active transfer across the cell membrane. This involves both time and energy. Generally phytoplankton appear to take up recycled nutrients (ammonia and urea) differently from new N nutrients (nitrate and nitrite). The recycled nutrients are often the products of bacterial metabolisms, while most of the nitrogen excreted from fish is ammonia with a small contribution of urea.

For example, Collos (1980) demonstrated that when the pennate diatom *Phaeodactylum tricornutum* is in a nitrogen limited environment for periods between one and five days the lag in nitrogen uptake mobilization increases from 30 minutes to over 60 minutes. However for shorter periods of starvation (2-4 hrs.) there is no lag in mobilization of the uptake mechanism.

It seems that at most fish farms it is unlikely algae like *Phaeodactylum* would be able to utilize any localized increase in nutrients. Typical salmon cages are 15 metres across and experience currents in the order of 5 to 10 cm/sec (three to six metres/minute) for most of the tidal cycle. In the few instances where plumes of nitrogenous wastes have been detected outside of a cage they seldom extend as far as 30 metres beyond the cage. In those currents it would take a phytoplankton cell 15 minutes to pass through the plume of nutrients.

In contrast algae utilizing ammonia may respond as the microflagellate *Micromonas pusilla*. In these species there is a short-lived enhancement of NH4+ uptake (Cochlan and Harrison 1991). However, the amount of nitrogen that could potentially be taken up in 15 minutes would contribute relatively little to the cell's internal pool of nitrogen (10-15%). Unless the same cells passed through the plume repeatedly this is unlikely to result in a measurable increase in phytoplankton abundance.

• The relative contribution fish farms make to available nitrogenous stocks and fluxes of a water body.

Another approach is to assume that over time there may be a gradual but significant increase in the total nutrient budget of a water body due to nutrient inputs from salmon farms. There are two concerns with this. First, does the overall production of salmon farms affect nutrient loading over a broad geographic scale? Second, are there localized areas that may be sensitive to increased loading?

One way to look for the potential scale of impact would be to take a hypothetical worst case scenario—for example, taking the entire production of the salmon farming industry and pretending that it all occurred in the waters of the Strait of Georgia. This waterbody has a mean residence time of 1.3 years (LaBlonde 1983), which is greater than that found in most of the fjordic system in B.C.

Table 5. Sources of Nitrogen to the Strait of Georgia and Puget Sound and Estimate of Current Input from B.C. Salmon Farms

Source	Estimated total N input (tonnes N day-1)	Proportion of total
Oceanic (Juan de Fuca Strait)	~ 2,000	92.2 %
Riverine (Fraser + others, includes some sewage & agricultural)	~ 100	4.6 %
Sewage (Seattle, Vancouver, Victoria)	~ 70	3.2 %
Current B.C. salmon farm production	~ 6 (22,000 tonnes salmon / yr; dissolved component)	

Note: data extracted from Harrison et al. 1994, based on data from Brett and Zala 1975 and Cranston 1994

Harrison et al. (1994) have assessed the inputs of nitrogen from natural and anthropogenic sources to the Strait of Georgia and Puget Sound (Table 5). The majority of nitrogen enters this system naturally by entrainment of oceanic waters through estuarine circulation driven principally by freshwater from the Fraser River. They suggest that input to the Strait of Georgia through Johnstone Strait and Discovery Passage accounts for 10-15% of natural input. Approximately 75% of the nitrogen inputs are exported via surface outflow the Juan de Fuca Strait, with the remainder supporting biological production within the system. Annual primary production within the Strait of Georgia is approximately 300g C.m-2.yr-1, equivalent to around 82g N.m-2.yr-1, or about 1,500 tonnes nitrogen per day overall in the strait.

Calculations of dissolved nitrogen output from B.C. salmon farms, based on 22,000 tonnes production per year, would yield 2,464 tonnes N.yr-1 (~7 tonnes per day) as potentially entering the environment. This is based on a feed conversion ratio of approximately 1.4 and a total nitrogen content in the feed of 8% (Kiaerskou 1991). Clearly, the contribution of current salmon farm production to overall marine productivity in our coastal waters is small in comparison to natural and other anthropogenic sources. On a smaller scale, the concern is that individual or closely spaced farms might elevate nutrients sufficiently to cause locally enhanced production. The potential for this depends on the production of the individual farms, local current patterns around the farm and the exchange or flushing rates of the receiving waters.

- **The maximum phytoplankton biomass that could be realized from fish farm nitrogenous wastes, and what effects that biomass would have on the phytoplankton biomass of the receiving waters.**

As a simplification, if it is assumed that all nitrogenous wastes from fish farms are converted to phytoplankton biomass, the upper limit of the contribution to production can be estimated. As an example, four farms are located in Kyuquot Sound on the west coast of Vancouver Island, with a potential annual maximum production of salmon of 2,340 tonnes. Kyuquot Sound has an area of approximately 460 km2. If it is assumed that these farms produce nitrogenous wastes in amounts indicated in the section above and all is converted to phytoplankton biomass, they would produce around 188 tonnes nitrogen per year. With typical C:N ratios of 7.1 (Bodungen et al. 1981), this would translate into 1,330 tonnes phytoplankton carbon biomass per year assuming all of it was present when there is enough light to utilize it. Distributed evenly throughout the sound, this would yield 2.9 gC.m-2.yr-1.

Kyuquot Sound is probably typical of most coastal B.C. waters in having a spring bloom of high phytoplankton production, followed by generally low productivity through the summer, due to stratification and depletion of nutrients in the surface mixed layer. In winter, nutrients would be replenished but productivity low due to low light levels. Typical summertime baseline nitrogen concentrations in Kyuquot Sound are <1Tmol.L-1. However, occasional upwelling events on the continental shelf off the entrance of the sound can elevate levels to as much as 5Tmol.L-1 (Ianson and Timothy 1994). This would be equivalent to adding 276 tonnes nitrogen in the upper 10m. Data from Ianson and Timothy show that response of the phytoplankton community to such an injection of nutrients is enhanced production ranging from 2-15Tg.L-1 chlorophyll a in the upper 10m. Taking as representative an increase of 5 Tg.L-1, and a typical C:chl ratio of 35 (Bodungen et al. 1981), such an event yields production of 54 tonnes chlorophyll or 805 tonnes carbon overall in the sound (1.8 gC.m-2). If this conversion ratio of nitrogen to carbon were typical for fish farm nitrogen output, the annual contribution to production by the farms would be 684 rather than 1,300 tonnes carbon, resulting in an enhancement of areal production by 1.4 gC.m-2.yr-1. It should be recognized, however, that much of the fish farm waste is released during winter months when there is insufficient light to allow full utilization by the phytoplankton.

- **Ecologically resolved phytoplankton production from nitrogen**

As seen above, the potential production from injection of new nitrogen into the system is not met, due to a variety of factors, including biochemical processes, such as algal growth response to form of nitrogen (Levasseur et al. 1993), biological factors, such as physiological response by the phytoplankton cells (Collos 1980), grazing (Gowen et al. 1992), and competition with bacteria (Horstmann and Hoppe 1981) and a broad range of physical processes, including diffusion, dilution, mixing, stratification and light-related effects (Gowen 1994). A practical approach to estimating the likely yield rather than upper bound is to carry out field experiments to examine the relationship between nitrogen depletion and chlorophyll or carbon production. Tett et al. (1985) conducted such experiments in Loch Creran, Scotland, during a spring bloom, and established a yield, q, of 1.56 mg chl.(mmol N)-1 for particulate organic nitrogen, and 1.96 for phytoplankton particulate carbon.

In order to broaden the application of this as a tool to estimate impacts on a wider geographic scale, Gowen et al. (1992) used data from synoptic surveys of waters of the west coast of Scotland. Two-thirds of the 60 data sets they examined showed a significant inverse relationship between chlorophyll and nitrate concentration. This result was interpreted as representing variation in time, with nitrate decreasing as a result of its assimilation by phytoplankton. The median value for q was 1.05 mg chl.(mmol N)-1, with the range from 0.25 to 4.4 comprising 95% of the values. The variation in q was considered resulting from factors such as chemical-analytical and sampling errors, seasonal trends, species composition, nutrient limitation status and partitioning of nitrogen between autotrophic and heterotrophic components. As the value of q takes into account a range of ecosystem effects, it can provide a useful device for predicting the typical response of phytoplankton to nitrogen input. Gowen et al. (1992) hold that the precautionary principle suggests that a value of q greater than the median should be applied to encompass the upper limit of ecosystem response. They propose that the upper 95th percentile, 4.4 mg chl.(mmol N)-1 is appropriate for their region.

Although Gowen (1994) cautions that q should properly be determined for individual inlets, it is useful as an illustration to apply Gowen et al.'s results to Kyuquot Sound. Applying the upper limit of 4.4 mg chl.(mmol N)-1 to Kyuquot Sound indicates that the 200 tonnes nitrogen input from fish farms could yield 63 tonnes chlorophyll, or 2,200 tonnes carbon annually. Distributed throughout the inlet, this would be approximately 4.8gC m-2.yr-1. At the median value of 1.05 mg chl.(mmol N)-1, the yield in the sound would be 15 tonnes chlorophyll, 525 tonnes carbon and 1.2 gC.m-2.yr-1, which approximates the yield of 1.4 gC.m-2.yr-1 calculated above.

In conclusion, the estimates calculated above, both for overall dissolved waste nitrogen produced by the B.C. industry, and for a more local example in Kyuquot Sound, indicate that the impact of these wastes is small in comparison to natural and other anthropogenic sources of nitrogen input. The total dissolved waste nitrogen produced by the industry is less than 0.3% of nitrogen input to the Strait of Georgia. In Kyuquot Sound, the nitrogen introduced annually by the industry is of the same order as that injected during a single summer upwelling event that would last for a week or so. As the system is light-limited rather than nutrient-limited for much of the year, the actual yield in Kyuquot from farm wastes would be less.

Documented examples of eutrophying effects of farms are sparse. Although Gowen and Ezzi (1992) were able to demonstrate that intensive cage culture can cause measurable nutrient enrichment in tidally energetic, fjordic estuaries, they concluded that large scale eutrophication in such situations was unlikely. Persson (1991) suggests that there is evidence of enhanced productivity from aquaculture activities in the archipelago of southwest Finland, where there is strong summer stratification and minimal tidal mixing. However, in the Baltic input from aquaculture represents only a small proportion of the total anthropogenic loading (Ackefors and Enell 1990). In modelling a Big Glory Bay, a small coastal embayment in southern New Zealand, Pridmore and Rutherford (1992) were able to simulate phytoplankton biomass. They suggested that salmon aquaculture increased nitrogen concentrations in Big Glory Bay by 30%, with a corresponding increase in production. However, the data on hydraulic exchange did not rule out incursions of high nutrient oceanic water. In addition, the food conversion ratio of farms in the bay was 2.7, which is substantially higher than current practice in the B.C. industry.

These results suggest that the industry in B.C. is unlikely to have a significant impact at current production levels, although the potential for local effects in areas of poor circulation or where farms interfere with local current patterns should not be discounted. Some further evaluation of these areas could consider whether, at the increased concentrations, there would be sufficient to stimulate harmful blooms or, through changing the nutrient ratios, there could be shifts, for example, from diatom to flagellate-dominated systems. There may be value in considering Gowen’s (1994) proposal that scientifically based standards be established to which predicted impacts could be related, prior to development. Such evaluations would require quantification of the amounts of wastes generated, use of numerical models to predict impact, and the establishment of specific ecological standards or targets.

F. TOXIC ALGAL BLOOMS

Hatfield and EVS (1996) summarized the main types of algae which are of concern in terms of toxicity to fish or humans, and their modes of action. Factors which are important in the triggering and promotion of toxic algal blooms include light, nutrients, temperature and salinity. There is some question that micro-nutrients or vitamins may also be important. The obvious potential factor which may be affected by waste discharges from salmon farms is in localized nutrient enrichment.

The main period of concern for stimulation of toxic blooms in marine systems by extra nutrients is late summer and early fall, when N can be limiting in surface waters after spring blooms. This is particularly true for the migrating dinoflagellates, which can move down in the water column to take advantage of extra nutrients at depth. At that time, an increase in N input in local areas could theoretically stimulate the opportunistic (quick multiplying) algae such as *Heterosigma.* In winter, light is limiting and blooms are unlikely to occur. An extreme example is given for Great Glory Bay on South Island of New Zealand, in which a small, shallow, semi-enclosed bay developed a major kill of farmed salmon by *Heterosigma* in 1989. The salmonid farms were estimated to have increased the ambient load in this isolated location by 30%. However, no clear link between the nutrients output and the bloom was established—Pridmore and Rutherford (1992).

There is no evidence that aquaculture causes toxic blooms (Hatfield and EVS 1996; Haigh et al. 1990; Taylor et al. 1994; Taylor and Horner 1994; Gowen et al. 1988; Aure and Stigebrand 1990). The concern is generally the other way around. Caged finfish mortalities due to blooms have caused losses on average of $3 million annually. Wild fish can escape blooms, whereas caged fish are vulnerable. In the ICES (1996) working group on Environmental Interactions with Mariculture it was noted that toxic Heterosigma blooms appeared for the first time in France in 1994.

One question which has not been addressed is whether or not problems may occur with respect to disposal of dead fish from farming operations which have been toxified by algae.

Another issue of some concern is the seeding of new blooms from cysts of *Hetersigma* in sediments. There is sampling and anecdotal evidence of cysts occurring in some sediment areas of B.C. (Maurice, R., Royal Roads, Victoria, B.C.; Max Taylor, UBC, pers. comm.). If cysts persist for long periods, it is possible that they may be deriving sustenance heterotrophically (i.e., feeding on bacteria or nutrients) in sediments in the absence of sunlight. Obviously, this is an area which requires considerably more research.

G. BACTERIAL ENRICHMENT

Rosenthal et al. (1995) point out that the effects of mariculture on natural microbial communities is poorly understood. It is not known if and how mariculture changes bacterial communities in the water column and how these affect other invertebrate and fish species. Hall and Cuell (1994) and Gormican (1989) found elevated numbers of coliform bacteria adjacent to marine salmon cages in B.C., whereas earlier studies (Austin and Allen-Austin 1985) found only marginal quantitative changes in bacterial concentrations at two salmon farms. Methods of bacterial culture are difficult and must be carefully scrutinized (Moriarty and Pullen 1987). Gormican (1989) points out that

E. coli may be elevated by fecal material from birds roosting nearby, or from leaky septic systems. In B.C. the septic systems for salmon farms require a waste management permit and are monitored (MELP). The presence of coliform bacteria near fish farms has not been raised as a major concern in B.C.

H. ZOOPLANKTON ENRICHMENT

There is currently no information on the effects of intensive salmonid culture on zooplankton. It stands to reason that any zooplankton drifting through or attracted to lights on net-cages may be fed upon by the fish in the cages, but there are no descriptions of this. In most studies, the stomach contents are being examined for other fish species (see Report to the EAO on Aquatic Mammals and Other Species, G. Iwama). In well-flushed areas, this should have no impact on the local zooplankton communities. As with other potential problems related to water column impacts from salmon culture, zooplankton are only likely to be measurably affected in very small, isolated or poorly flushed water bodies. Modelling exercises (Ross et al. 1993) examining the combined effects of changes in light conditions, nutrient enrichment and zooplankton grazing on fjords indicate that the most dangerous scenario for promotion of photoplankton blooms is a reduction in zooplankton grazing, which can result in high phytoplankton biomass for a longer portion of the year. In systems in which phytoplankton production is nutrient limited (isolated from outside ocean and tidal exchange), the worst combination is reduction in grazing rate combined with an unusual increase in nutrient loading.

I. CHEMICALS AND METALS

The effects of therapeutant discharges from salmon farms is described more thoroughly in Craig Stephen’s paper on fish health. The main concern for environmental contamination is from “baths” of chemicals used as prophylactics, such as the pesticide Dichlorvos (used for sea-lice). However, this product is not currently used in B.C. The effects of the pesticide Dichlorvos on the environment are unknown. However, because it is a crustacean toxin, large quantities of Dichlorvos released into the water column could potentially poison other zooplankton crustacean adults or larvae in the near vicinity of the net-cages. There are equivocal study results on this chemical, but some potential danger is indicated in its use. Munro (1990) suggests a 2,000-fold dilution is necessary to eliminate Dichlorvos in the water column. This latter condition is easily met in most net-cage operations in the ocean, and there is evidence that it dissipates quickly with no accumulation around the point of use (Tulley and Morrisey 1989). However, the toxicity (LC50 values) of the Dichlorvos to larvae of lobster, *Homarus gammarus,* and herring (*Clupea harengus*) have been reported (McHenery et al. 1991; see also Alderman et al. 1994). While the crustacean was more susceptible to the toxic effects, recovery was possible. Gillibrand and Turrell (1995) actually modelled the concentration and retention of dichlorvos for the water column in a Scottish sea-loch. A proposed acceptable annual mean was given as 40 ng/L and compared with the estimated amount of dichlorvos in use in the area in 1989 (0.292 kg/t consented production). No conclusions were given.

Antibiotics in general are quickly diluted, photo-degraded in surface waters or complexed with calcium and magnesium in marine waters and therefore deactivated. In general, the biological activity of Oxytetracycline is only about 10% as much in seawater as it is in lab media, because of complexing with Ca and Mg (Lambert and O'Grady 1992). Tetracycline has been shown to be highly toxic to marine algae at therapeutic concentrations used for fish (Petersen et al. 1993), although at the rapid dilution and deactivation rates in seawater, this toxic effect is probably not realized in net-cages. Romet 30 and oxytetracycline can be taken up by long-line oysters at ambient concentrations of 40 ppm over time, probably in particulate form in feed waste rather than from dissolved form in the water column (Black et al. 1991; Jones 1990). Depuration is mostly accomplished within 24 hours and the antibiotics are undetectable within 30 days.

There has been some concern about "out-washing" of antibiotics from sediments to the water column by redissolution. This was modelled by Smith and Samuelsen (1996), who concluded that quantities returning to the water column were extremely low and unlikely to have any biological significance. By far the majority of waste antibiotics settle and remain in the sediments from solid feed and fecal waste.

Chloramines (chlorines) used to control bacteria and parasitic infections of the gills and bodies of fish are used in low concentrations in order to avoid harming fish and therefore are not considered harmful to zooplankton (Kaniewska-Prus 1982). However, chlorines are very toxic to all aquatic organisms. Therefore, they are seldom used, and are neutralized with sodium thiosulphate before discharge.

There have been questions about the possible effects of vitamin discharge (e.g., biotin) from uneaten food on water column biota (see Gowen and Bradbury 1987; Hatfield and EVS 1996), but since it is broken down by sunlight, its effect on phytoplankton growth may be minor (see "Discharges" section). There is currently insufficient research to draw any conclusions on this issue. This is probably more of a concern in freshwater (Hatfield and EVS 1996).

The effects on marine biota from the use of copper antifoulants on nets is of some concern. Although copper is a micronutrient, and vital in the blood chemistry of most invertebrates, it is toxic at higher concentrations than those required metabolically. It is particularly toxic to marine algae. The active ingredient, cuprous oxide (26% or more) is coated on nets using a bath. The U.S. EPA marine chronic water quality criteria for copper is about 3 ug/L. Lewis and Metaxis (1991) measured dissolved copper concentrations immediately adjacent to newly installed, copper-treated nets in B.C. Maximum levels of 0.54 ug/L were measured inside cages immediately after and one month after application. Peterson et al (1991) examined chinook salmon tissues from treated cages and concluded that the salmon do not bioaccumulate copper.

There has been no detailed study of the fate or accumulation of copper in fouling organisms which are then washed into the water and sediment to bottom. Brooks (BCSFA 1996) concluded that there can be heavy sediment accumulation of fouling organisms on the benthos in areas where nets are being washed, and that prevention of that fouling may be more environmentally sound than dumping built-up organic and shell debris on the sediments.

In addition, Dale Blackburn of Stolt Seafarms has suggested that seals don't like the treated nets, possibly because they are stiffer. With the deterrent to predators and considerably reduced handling of nets, they have noted fewer tears and breaks and thus less opportunity for escapes.

VII. OTHER IMPACTS

Several categories of smaller scale outputs and impacts are discussed under the terms of reference for the EAO review. These include net-cleaning operations, morts disposal, bleeding operations, offal disposal, sewage from farm sites and garbage disposal.

A. NET-CLEANING OPERATIONS

The natural growth of epifauna and flora on net-cages and structures will ultimately slough off or be cleaned off and become a 'discharge' to the environment. The fouling organisms include attached forms such as barnacles, mussels, algae and tunicates. These constitute an additional organic metabolic output to the water column, as well as being the source of considerable shell debris and an attractant to birds, zooplankton, fish and other fauna in the water column.

The material from nets that sloughs off and falls to the sediments tends to add to the organic debris at the periphery of nets. This benthic debris attracts fish, crabs and starfish to feed near the edges of farms. Shell debris is common in video transects under and around salmonid net-cages (MAFF video documentation and MELP grab samples). The total proportion of sedimenting organic material that is contributed by net fouling organisms will depend on when and where net-cleaning occurs and how often. However, there is no data on net-fouling outfall available for salmon net-cage culture in B.C. Brooks (BCSFA 1996) cites an example where in-situ net cleaning at a salmon farm in Washington state produced a layer of mussel debris to a distance greater than 6 m down-current nearly 30 cm deep in some samples, with undoubted impacts on sediment benthos.

There are concerns from First Nations that in-situ net cleaning at inappropriate times in the tidal cycle can cause considerable solid detritus to wash up on beaches in the vicinity of net-cage operations. This could potentially affect sensitive stocks of food or commercial shellfish and other species in intertidal and near-shore areas.

Net fouling biota can contribute considerable ammonia to the water column if not kept under control. Black and Carswell (1986) found similar ammonia downstream from unused, fouled net-cages and active fish farms, making it difficult to assess whether fish-farms themselves or fouling are more of an issue with respect to dissolved nutrient discharge (see also Gormican 1989). Note also that nets provide a substrate for epiphytic or attached macro and micro algae (E. Black, MAFF, pers. comm.).

Net-cleaning methods vary from site to site. A description of different methods is given in Hatfield and EVS (1996). The two methods used most commonly in B.C. are mechanical net washers and off-site pressure washing. Other methods include in-situ pressure washing, submarine pressure washing by SCUBA, air-drying followed by hand washing (which is labour intensive), and dropping the nets to the sea floor to allow predators to remove the organisms. Hatfield and EVS (1996) suggest that this latter method is not commonly used in B.C. except when a very heavy shellfish set occurs (e.g., footage from KTFC, Broughton Archipelago).

Hatfield and EVS (1996) indicated that no chemicals are used to wash nets in B.C. However, antifoulants containing cuprous oxide are occasionally used to discourage net growth (see previous section). Some of the chemicals in use are discussed in other appropriate sections in this paper.

B. MORTS AND OFFAL DISPOSAL

Morts disposal is reported to MELP as part of the aquaculture permit. A summary of this data indicates that almost all morts disposal occurs off-site, by composting and ensiling at three licensed facilities in B.C. Documented methods range from on site landfill operations to off-site rendering for compost. Contractors are hired to remove morts from the farm site on a regular basis. Virtually all morts are taken to one of two self-sustaining commercial composting facilities æ one operated with UBC by a company at Oyster River near Nanaimo, and Bio-Waste located at Black Creek, B.C. A new facility near Port McNeill was opened in 1995. The Oyster River facility apparently has its compost tested regularly for heavy metals (Hatfield and EVS 1996). One or two very small salmon farming operations use off-site landfills; one uses on-site ensiling for pig food. There used to be a facility in Port Alberni called Super Marine Soils operated by Pacific National Group aquaculture company, but this operation was shut down.

Ensiling and composting of morts has the advantage of reducing odor, storage volume (about 15%), long-term costs of storage, and eliminates the need for a waste management permit (Rosenthal et al. 1995, see also Carswell et al. 1992). A summary description of these methods is given in Hatfield and EVS (1996). Composting and ensiling are described in more detail by Carswell et al. (1992). Current facilities seem to be adequate for the mort disposal from fish farms, but any increases in the industry may require more composting facility capacity and possibly more local availability (particularly for the west coast).

Actual numbers of morts (versus production) data is being compiled by MELP at the present time and will hopefully be available before the end of this review. A table of estimated quantities of fish mortalities for 1994 is given in Hatfield and EVS (1996). They estimate total morts at 20% for all species and all causes for 1994. Mortality rates are apparently lower for Atlantic salmon than for chinook and coho.

Rosenthal et al. (1995) describe the current practice of ocean-disposal of morts (and blood water) in New Brunswick. Currently, a voluntary code of practice for processing morts and offal is used by producers, feed companies and processors, and includes a procedural manual for disposal of morts, offal and blood water. Ocean dumping permits will likely be terminated in the near future and a task force (federal/provincial) has been established to develop an obligatory waste management policy for the salmon industry in the Bay of Fundy, partly as a result of the increasing incidence of Hitra disease, which may be carried in blood products of fish. For further information on potential disease vectors in blood-water, see the paper on fish health for this review (by Craig Stephen).

Offal disposal from processing is permitted by MELP at licensed facilities. The composting facilities described under “morts disposal” also receive offal from processing plants.

C. GARBAGE DISPOSAL

Regular garbage clean-up is necessary to a viable operation, to avoid safety hazards, attracting birds and other animals. A major concern that has been raised with respect to garbage disposal is the practice of leaving net-cage structures, moorings, leftover rope and other debris at sites which have been vacated. In many cases, these sites will be used again in the future. However, in the meantime, the debris can be a hazard to prawn trap-lines, boaters, etc. Some of the KTFC video footage shows an underwater net-cleaning operation with considerable bottom area covered by nets, floats, and other debris. The Broughton Archipelago subcommittee report had a number of responses related to garbage left from fish farm sites.

Local comments in the Broughton Archipelago subcommittee report suggest that floating garbage and plastics washed up on beaches (particularly feed bags) can be a problem. Oil pumped from bilges from fish farm barges has also been described.

D. SEWAGE FROM WORKERS

All fish farms require a Waste Management Permit for sewage disposal. MELP summarizes and keeps track of methods of sewage disposal and initially has technicians inspect and approve permits based on the following criteria. If there is to be a minimum discharge (<2.5 cubic m per day) the operation is required to have a two day retention time in septic systems and discharge > 15 m depth at greater than 125 m from recreational or food fishery resources (e.g. clam beaches).

Fecal coliform counts have been elevated near netpens, possibly because of inadequate on-site septic systems (see Gormical 1989; Hall and Cuell 1994). However, there is no specific data relating to the issue of septic systems. No complaints about sewage have been documented specifically by MELP to date.

VIII. FRESHWATER CULTURE OF SALMON

Government operated hatcheries and lake-cage sites are outside the scope of this review. Only commercial operations will be discussed. Some of the concerns related to freshwater intensive culture of salmon smolts include water quality and cost of treating drinking water (Axler et al. 1996). For example, harmful chlorination byproducts increase in water which is heavily chlorine-treated due to high organic loads. Therefore freshwater culture facilities should not be located near a drinking water source. Another concern with respect to water quality is the potential eutrophication of lakes from additional nutrients, leading to excessive algal blooms, or blooms of noxious blue-green algae. In Norway, expansion of fish farming in freshwater is not permitted under the LENKA program (see jurisdictional paper by Ann Hillyer).

Hatcheries

There are currently 17 commercial salmon hatcheries in B.C. MELP is responsible for administering waste discharge permits (see below) and has collected some monitoring data from hatcheries.

Hatcheries are land-based operations utilizing tanks, raceways or ponds for the hatching of eggs and/or the entire freshwater cycle of the fish. The water sources and requirements for land-based freshwater systems and methods of culture are reviewed and described in Dube and Mason (1995). Hatchery systems can be water intensive (flow-through) or conservative (recirculated). Water flow into a discharge stream can be greatly increased over ambient levels if the source for the aquaculture operation is from groundwater. Discharges from hatcheries will be similar in character and quantity to those from lake-cage operations, but will be more definitely a point source discharge like an outfall, often into moving water (rivers or streams). Seven commercial hatcheries in B.C. discharge into groundwater or ponds/marshes instead of moving water. Wetlands have been used extensively in recent applications of organic wastewater treatment from greenhouses and other sources (B.C. Science Council). Two hatcheries discharge into coastal marine waters.

Taylor and Perrin (1989) note that land-based recirculation systems as used in some hatchery operations have been known to reduce suspended solids and BOD by up to 85%, with a tenfold increase in fish production. These systems often use treatment methods such as filtration of solids or separation ponds. Effluent levels can temporarily increase tremendously during cleaning of such systems.

Lake-cage culture

The S1 and S2 smolts (first and second year) can be raised in lake cages rather than hatcheries. In cage culture in lakes all effluent goes directly into the lake. Because the culture medium is similar to that which smolts will encounter in the wild, and there are no pumping costs, lake-cage rearing of salmon smolts is attractive financially to fish farmers. ESSA (1993) describe feasibility studies in Scotland which suggest that lake-cage rearing of smolts is about 13% more economical than land-based operations. However, this doesn’t take into account the economy of scale for the larger operations possible in a lake.

Axler et al (1996) describe feasibility studies in the late 1980s on the potential for aquaculture of salmonids in mine pit lakes near Minnesota. These operations generate an estimated $44 million/yr in primary and secondary revenues. The feasibility study focused on four pit-mine lakes which had been used to raise salmon and trout or been connected to lakes with aquaculture operations. One advantage of using pit mine lakes is that there are no indigenous fish stocks to worry about. It may be noted that a similar lake is in the process of being formed at Island Copper Mine at Port Hardy, B.C. It is 2.5 km deep with a stable water column and surface freshwater layer, and may therefore provide a promising location for lake culture operations.

At present, there are three commercial freshwater net-cage operations in B.C. The five lakes which have been approved for such culture include Lois, Georgie, Ewart, Viola and Kennedy. Kennedy Lake has since been removed from consideration due to public opposition. No applications are currently being considered for Ewart or Viola by MELP because of potential conflicts or environmental concerns. Criteria for siting in B.C. currently state that only oligotrophic lakes (low nutrient and productivity) will be used for smolt rearing. However, there are no criteria for approving more lakes or considering proposals for new operations.

Only Georgie and Lois lakes are currently in use for commercial cage-culture. Ward Griffioen of West Coast Fishculture Ltd. has 60 net-cages for salmon smolts at Lois Lake near Powell River, B.C. The Lake is 24 km long and was dammed in 1930 for hydro. Lois Lake is low nutrient, typical of B.C. coastal lakes. Logging is also occurring around the lake. The Georgie Lake operation has been the focus of a fairly intensive environmental monitoring program and study by the Department of Fisheries and Oceans (MacIsaac and Stockner 1995). Some monitoring and video work were also done by MELP in the spring of 1994. The latter study included Georgie, Quatse (control) and O'Connor lakes near Port Hardy. All three lakes are softwater, slightly acidic, typical B.C. coastal lakes. O'Connor Lake was included because it has a federal government net-cage operation. Georgie and O'Connor are 40 m deep and the water column in each can be totally mixed once or twice a year. Georgie Lake is about 8.5 km long, whereas O'Connor is only 1.5 km long (about 1/10 surface area of Georgie). Quatse Lake has a mean area about three times larger than O'Connor. MacIsaac and Stockner (1995) concluded that Quatse lake is too unique to be used as a control for studying Georgie and O'Connor lakes. In fact, lakes are so varied and isolated from each other that it is unlikely that a suitable control lake can be found for environmental monitoring of another lake. In the end, the detailed environmental monitoring concentrated on Georgie Lake because of differences between lakes and seasonal complications masking localized effects of nutrients discharge near net-cage operations (MacIsaac and Stockner 1995).

A. WASTE DISCHARGES

The waste discharge issues related to land-based and lake-cage culture of salmonids are similar to those discussed for marine systems, and the modelling of outputs has been discussed for all life-cycle stages in the section on solid and dissolved discharges in this report. In addition, considerable work has been done on trout culture operations, which will have the same discharge characteristics as any freshwater intensive culture (for review in Atlantic Canada see Dube and Mason 1995). Taylor and Perrin (1989) did a bibliography on freshwater aquaculture activities; they conclude that mass balance models examining the input of nutrients into lake and river systems had been the focus of most of the literature up to the time of writing (c.f. Beveridge 1984 and other references cited therein).

The major waste discharges of interest are the same as for the marine, including: dissolved ammonia and urea, soluble phosphorus, solid food waste and fecal nutrients (C,N,P), remineralized ammonia and phosphorus from sediments into the water column, therapeurants and metabolic metals in the water column and sediments. The emphasis or importance of these various factors is somewhat different in freshwater than in the marine.

Hatcheries are regulated under the MELP Land-based Finfish Waste Control Regulation, which is part of the Waste Management Act. The Act requires that the owner submit a receiving water quality report before construction of the facility, which must include an analysis of proposed discharge and predicted eutrophication of the receiving waters. If the dilution ratio for discharge is greater than 20 to 1, the initial report is not required. The Act further prohibits discharging solids in excess of 10 mg/L if the dilution ratio is less than 20 to 1, or in excess of 20 mg/L with a dilution ratio of 20 to 1 or greater. Phosphorus concentrations in effluents of the same dilutions as above are not allowed over 0.1 mg/L or 0.2 mg/L. There are no standards for ammonia or nitrogen discharge levels. No detectable chlorine is allowed in discharges. The operator cannot discharge any detergents, disinfecting agents or chemicals which do not pass a 96-hour LC20 (20% lethality from concentration) for rainbow trout. Finally, no dead fish, blood or processing wastes can be discharged to freshwater.

Hatchery flowrates are monitored and reported weekly for hatcheries. Typical land-based flow rates for salmon smolt (35-70 g weight) culture are about 50 L per minute per metric tonne of fish (Dube and Mason 1995). Rates for adult culture of salmonids on land are more in the order of 350-500 L per minute. Quarterly discharge and water column concentrations of nutrients and solids are reported, although data is not available for all hatcheries (L. Erickson, MELP). Data reported includes BOD (mg/L), ammonia, nitrate, phosphate and total suspended solids. L. Erickson (MELP) has indicated that monitoring data he has reviewed shows solids discharge rates of around 5 mg/L or less. Problems with monitoring data from hatcheries is similar in nature to that experienced with marine operations (see Current Approaches section). It is evident from some of the data examined that phosphate levels exceed the limit of 0.1 or 0.2 mg/L specified for total Phosphorus. Although a few high values have been noted, generally ammonia levels are around 0.03 mg/L or less, within B.C. Water Quality Objectives issued by MELP. Although some enrichment of downstream areas has been noted relative to hatcheries, most of the operations do not discharge directly into streams or rivers and siting seems to be appropriate (L. Erickson, MELP).

Some monitoring of smolt-rearing operations in lakes has been done by MELP and Fisheries and Oceans, Canada. Sampling at Georgie and O'Connor Lakes was done by MELP in the spring of 1994, along with video footage of the bottom sediments under net-cage operations at Georgie and O'Connor Lakes. MELP has not provided data reports for the sampling, although video footage was examined. The remarkable characteristic of sediments of both lakes was that they were extremely flocculent, water-filled and loose to a depth greater than 1 m. Considerable cedar wood debris was present on the bottom near one of the operations in Georgie Lake. The thick, fine ooze in both lakes suggests relatively little bottom water movement below the depth of the thermocline. The video footage for both lakes also showed distinct fuzzy matting and food pellets in depressions under net-cages. The matting is presumably bacterial, but is different in texture and character from that found in marine sediments (which generally contain high amounts of sulphides). Due to the lack of large epifauna in lakes it is difficult to assess the health of benthic fauna without access to sediment samples.

In Georgie Lake, the work done by DFO (MacIsaac and Stockner 1995) estimated that on average P and N content of feed for smolts was 1.15% and 7.6% respectively. Attempts are continuing by feed companies and researchers to reduce dietary P levels. A total of 614 kg P and 4,349 kg N were output as waste from the eastern net-cage operations over the 5.5 years of operations. This translates to a total areal output of 23.8 and 168 mg P and N respectively /m2 per yr. The output of nutrients from smolt cage culture to the sediments was estimated at approximately 13.8 mg P/m2 per yr and 50.4 mg N/m2 per yr (MacIsaac and Stockner 1995). This is below the routine fertilization loads for coastal sockeye salmon nursery lakes in B.C. (40-150 mg P/m2 per yr).

The effects of these discharges on lake systems will be different from the marine in magnitude and character, because of the different physical characteristics of the freshwater environment and because of the more isolated nature of lakes. The problems involved in lake-culture of smolts will be similar in nature to those of trout-rearing operations, if of a different scale. For a comprehensive review of cage culture methods and potential impacts see Beveridge (1984). Phillips (1987) described environmental changes caused by freshwater salmonid cage farming and carrying capacity models for Scottish sea lochs. Axler et al. (1996) describe the use of abandoned mine pit lakes in Minnesota for salmonid freshwater culture. The pits, however, are typically small (2-100 ha) 20 m to >200 m deep.

Whereas most marine operations are located in highly productive coastal waters, the coastal lakes of B.C. are very low nutrient and low production (oligotrophic) and therefore extremely sensitive to even minor changes in nutrient regime (Stockner 1981). Add to this the temporally limited (usually winter) flushing and mixing conditions of lakes with strong stratification, and there is limited capacity to eliminate wastes. Since B.C. coastal lakes tend to be oligotrophic, the addition of P can change them into mesotrophic (moderately productive) or eutrophic (highly productive) lakes. Sensitivity is highest in lowest production lakes with the lowest flushing rates (from rainfall). Flushing and dilution capacity of lakes is much less than that of the ocean. Therefore the water column has less capacity to absorb nutrients and there is less dispersion of wastes in benthos due to lack of tidal flushing and bottom flow.

Benthic biota are much less diverse in freshwater systems than in the marine, and may therefore be more susceptible to subtle changes in the environment. Unlike marine systems which may become N limited in late summer, freshwater systems tend to be P limited, or both N and P limited. Therefore, the amount of P entering the lake, and the ability of the lake to flush out that soluble P is vital.

Mine pit lakes studied in Minnesota (Axler et al. 1996) have naturally high nitrate and low phosphorus, high alkalinity, high calcium and magnesium. Algal productivity is likely limited by P during the growing season, hence the pit lakes are considered oligotrophic. Some pits do not mix to the bottom in winter due to high depth/surface area ratios. Some are therefore anoxic in bottom water.

B. PRODUCTIVITY, PHYTO AND PERI-PHYTON ENHANCEMENT

A literature database and summary (Taylor and Perrin 1989) notes the growing concern over potential and real eutrophication effects from nutrient output from freshwater aquaculture. Weston (1986) states that in freshwater operations, eutrophication is a distinct possibility with high phosphorus loading from fish farms and high N/P ratios. Weston states the need to substantially reduce phosphorus in feeds, which Rosenthal et al. (1995) note has been accomplished in the past few years with no apparent adverse effects on fish nutrition.

Rosenthal (1995) summarized studies worldwide in which the nutrient discharges from land-based fish farms have caused eutrophication to freshwater and increases in local phytoplankton blooms (see also Persson 1991). Taylor and Perrin (1989) also note that stimulation of phytoplankton production in freshwater has been shown to occur as a result of nutrient additions from fish farm effluents (see also Penczak et al. 1982). Effluent discharges to rivers have the same effect on periphyton (attached algae) production (5-7 fold increases below outfall of a hatchery). Degree of impact is related to backgound nutrient levels as well as effluent nutrient levels. Phillips (1987) noted that algal growth can be stimulated by intensive freshwater culture in Scotland, beneficially increasing production of zooplankton and fish as long as there is no stimulation of blue-green algal blooms. Algal blooms are not beneficial to the aquaculture operations, since they can lead to toxicity, oxygen depletion due to light reduction in surface waters, increased BOD as the algae decay, and off-flavour fish. Phillips (1987) recommend that the most useful monitoring of eutrophication effects for freshwater cage culture is algal biomass, along with levels of N and P for productivity checks in lakes. Axler et al. (1996) found that algal concentrations in pit mine lakes with intensive smolt aquaculture were reduced considerably by artificial mixing and circulation methods commonly used in trout ponds.

It has been suggested that the nutrients added to low productivity lakes from salmon smolt culture may beneficially enhance productivity of wild fish in these lakes. The DFO Salmonid Enhancement Program fertilizes some sockeye rearing lakes to increase production of the entire trophic system and thereby enhance growth and early marine survival of smolts (see Stephens and Stockner 1983, Stockner 1981, 1987). However, MacIsaac and Stockner (1995) indicate that this practice is not always successful because unwanted competitor species and inedible algae can also be encouraged, with the danger of blue-green algal blooms if N/P ratios are not kept within a very narrow acceptable range (ESSA 1993, Taylor and Perrin 1989). They further caution that such fertilization procedures must be based on careful study of the hydrographic and chemical factors controlling the dynamics of the lake. Without such knowledge, fertilization practices would be “shots in the dark”. It is unlikely that lakes used for SEP programs would also be approved for intensive commercial cage culture due to conflicts in usage and the uncontrolled nature of the nutrient input from fish cage operations.

The study of the Georgie Lake smolt-rearing operation in B.C. showed that periphyton growth experienced a 10-fold increase both at the net-cage operation and 150 m downshore compared to mid-lake control levels, in the second year of study following intensive use of the site. This periphyton enhancement was not found at the government operation in O’Connor Lake. Periphyton growth in both Georgie and O’Connor lakes in B.C. is P limited (MacIsaac and Stockner 1995). Taylor and Perrin (1989) conclude that soluble P is more important than solid P (see also Phillips 1987), except when bottom oxygen levels are low, causing remineralization from sediments. Axler et al. (1996) note that in both lake cage culture and land-based systems, bottom anoxia and near-bottom water column anoxia have been noted. This results in the release of ammonium and methane from sediments. In addition, MacIsaac and Stockner (1995) indicate that considerable ammonia and phosphorus can be remineralized from freshwater sediments depending on pH and temperature conditions. Phosphorus can be resuspended during lake turn-over or other mixing events. Axler et al. (1996) estimate that in the pit mine lake in Minnesota with the worst eutrophication, 91% of the waste P from aquaculture was deposited in sediments. By 1992, water column P in the lake had increased 10-fold from pre-aquaculture levels. In addition, ammonium levels became relatively high in aquaculture lakes relative to the controls (~500 ug N/L), due to accumulation during times of low oxygen or low mixing.

Taylor and Perrin (1989) concluded that ammonia was important because of its dual nature, that of an inorganic toxicant (NH_3) and a nutrient (NH_4^+). The various forms are affected by pH and temperature. There are few references to the toxic effects of NH_3. The authors note that in some lakes in B.C. which are N limited, the addition of N alone can increase production an order of magnitude, but both N and P addition can increase production by two or more orders of magnitude. They describe the effects of different forms of N and P on freshwater productivity.

Phillips (1987) stated that fish grown in intensive cage culture in more biologically productive waters are more susceptible to bacterial and fungal infections. Therefore, significant long-term increases to productivity in lakes where salmon smolts are reared is harmful. He suggests choosing a low productivity site for intensive culture, with detailed modelling of the effects on algal production. He further suggests limiting the concentration of P to 10-20 mg/m3 in the water column.

Total P in water type of water body(mg/m3)

<10 oligotrophic- good for salmonid culture10-20 mesotrophic—some risk of algal

blooms>20 eutrophic—high risk for salmonid culture

Some peaty (highly acidic) waters can withstand higher levels of fertilization than clear waters because of light limitations on growth of algae.

C. OXYGEN DEPLETION

There is a greater risk of deoxygenation of bottom waters in organically enriched lakes. This is because there is a limited oxygen supply below the thermocline most of the year especially if there is strong seasonal stratification (Gowen et al. 1991). Gowen et al. (1991) measured O_2 consumption in sediments in the vicinity of fish farms of between 45 and 55 mg/m2 per hr. MacIsaac and Stockner (1995) measured oxygen consumption 2-4 times higher in sediments under cages in Georgie Lake, B.C. than at mid-lake control stations. No measurements of redox in sediments were taken. Stagnation in deep water has negative implications for the productivity of a lake.

Taylor and Perrin (1989) suggest that significant reduction of oxygen appears to be relatively unusual except during cleaning operations (particularly in hatcheries). MacIsaac and Stockner (1996) found that dissolved oxygen in the water column was adequate at Georgie, O’Connor and Quatse lakes throughout the several years of the study period. However, Axler et al. (1996) concluded that oxygen depletion sets the practical limit for aquaculture in mine-pit lakes. Most oxygen depletion is from fish respiration, feces, and waste food, but can be enhanced by the breakdown of algal cells following a bloom.

D. SEDIMENT RATE AND CHEMISTRY

Weston (1986) estimated that sedimentation rates beneath freshwater net-cages in some lakes in Washington State were 100-200 times the rates for reference areas (low deposition lakes). Weston (1986) also estimated nutrient and BOD loadings from freshwater salmonid hatcheries and net pen aquaculture. Variations due to temperature, type of feed, quantity and frequency of feeding, fish size and proportion of suspended solids in effluent have made it very difficult to predict the nutrient and BOD loading from any given facility.

MacIsaac and Stockner (1995) describe sediment sampling done in the latter part of the monitoring program at Georgie Lake in B.C. Modified cores suited to the loose, soft sediments were collected to examine sediment accumulation, organic C, N and P, metals and surface microbial communities, and to measure sediment oxygen consumption rates. MacIsaac and Stockner (1995) estimated sediment accumulation of solids at 6.6 g dry wt/cm2 for a total deposited sediment dry weight of 1.62 x 105 kg over the 5 year study. They estimated total deposition of nutrients in sediments under the net-cages over the 5.5 years of operation as 356 kg P and 1,296 kg N, which is equivalent to 58% and 30% respectively of waste output loads from the operation. A total of 3-11 cm solids has sedimented under and near the cage operations over the 5.5 years of operation, but no anoxia or H2S were detected in any cores. This is not surprising since the loose, almost neutrally buoyant sediments would have high water content and be easily aerated by overlying waters. In addition, sulphides tend to be low in lakes (compared with marine systems), so that any bacterial growth would be more likely to be methane producing in anoxic conditions, and CO2 producing in aerobic conditions. However, sediment N and P levels were about double at net-cages than at mid-lake, with organic C levels very little different between sites. This combination suggests that total organic matter (TOM) measurements are not particularly useful for lake cage operations, since total organic carbon (TOC) is so high already compared with the marine (about 20% versus 4%). O'Connor lake sediments showed similar elevated N and P but not C levels. Rates of N and P release from sediments were much higher near net-cages than in mid-lake samples with a low N/P ratio.

E. CHEMICALS AND METALS

The feed supplements zinc and calcium showed a clear elevation under net-cages in Georgie Lake, B.C. (MacIsaac and Stockner 1995). Surface sediment zinc levels were 2-6 times higher than in natural lake sediments, whereas deep sediment core values were normal. Copper ranged from 55-80 ug/g, which is within acceptable guidelines for both freshwater and marine sediments in B.C. Copper and zinc levels in the water column were not measured, but Dube and Mason (1995) cite the tolerance level of salmonids in freshwater as .006 to .03 mg/L cu and .004 to .04 mg/L zn respectively.

Chloramines are sometimes used in freshwater for treating parasistic infections of gills and bodies. This treatment must be done on land and chemicals neutralized before disposal, since the Waste Management Act allows no detectable chlorine to be discharged to freshwater.

F. IMPACTS ON BIOTA

Bacteria

Taylor and Perrin (1989) have indicated that most of the work on bacterial effects from salmonid wastes in freshwater has focused on disease transmission via fecal coliforms and streptococci. Levels of these sewage bacteria have been found to increase at several freshwater fish cage operations (see Niemi and Taipalinen 1982—in Taylor and Perrin 1989). In addition, increased coliforms have been reported downstream of hatcheries in the U.S. (Hinshaw 1973), although they have not been noted at other operations (see Rosenthal 1995). In most cases, this is probably due to the presence of mammals, nearby human sewage or bird droppings. Austin and Allen-Austin (1985) found no significant change in the bacterial populations of two salmon farms. Counts were generally higher in effluent than influent water, but were within the range normally associated with freshwater.

It is in the bacterial decomposition of organic materials that there are important differences between freshwater and marine sediments due to different chemical makeup of sediments (see above). These differences have an important bearing on the consequences of organic enrichment over the long-term (Gowen et al. 1991). In contrast to marine systems, enrichment of sediments beneath freshwater cages farms is less likely to affect the long-term production potential of a site (Gowen et al. 1991—see below). Compared to marine sediments, the amount of sulphate is relatively low in freshwater sediments, so that sulphate reduction (hydrogen sulphide production) accounts for only between 2-5% of the breakdown of organics. Most of the anaerobic production is methane, which is not considered toxic to fish.

Organic waste stimulates the concentration and production of bacteria in freshwater sediments. There has been little work done on the effects of fish farm wastes on water column and sediment microbiology. Some of this work is currently being done by a visiting scientist at Fisheries and Oceans (see MacIsaac and Stockner 1995) and will hopefully be published soon.

Sediment organic accumulations under fish cages in freshwater lakes in Poland have been partly responsible for enhanced mineralization and increased levels of nutrients caused by the proliferation of heterotrophic and proteolytic bacteria, with the resulting increase in local phytoplankton blooms (Penczak et al. 1982). *Beggiatoa* (sp. such as *alba)* have been noted to cover anaerobic sludge in freshwater systems impacted from trout farm wastes (Iwama 1991). The studies in Georgie Lake showed that standing stock abundance or biomass are not useful measures of bacterial effects. However, carbon production rates from heterotrophic bacteria show a much more distinct increase in the water column near net-cages than mid-lake (MacIsaac and Stockner 1995). The effects of fish farm effluent on bacterial communities in marine habitats are similar (Moriarty and Pullen 1987).

The effects of antibiotics on freshwater bacteria should be similar in character to marine systems, though little work is available (ESSA 1993). Taylor and Perrin (1989) conclude that chemical food additives are too diluted to be a problem in proximity to cage culture operations. Axler et al. (1996) also concluded that therapeutant use was minimal in pit-mine lakes with levels at all times far below the Minnesota Department of Health drinking water standards.

Invertebrates

There seems to be very little information on the direct effects on zooplankton of effluents from salmon smolt culture. Presumably, the effects trickle through the food chain, as would be expected during enrichment of any sort in freshwater systems.

Measurements on the responses of protozoa to fish farm effluents in sediments were done at Georgie Lake (MacIsaac and Stockner 1995). Protozoa feed on bacteria, and are a vital link in the food chain to zooplankton and larger carnivores. As in the bacteria, the researchers found that standing stock measurements of protozoa did not show any effects from fish farm effluents, whereas production (carbon uptake) rates were considerably higher at the cage site than mid-lake.

Taylor and Perrin (1989) indicate that invertebrate reactions to enrichment in freshwater sediments are similar to marine in character, ranging from mild enhancement to increased abundance of organic pollution indicators to loss of invertebrate fauna (abundance and species richness) due to sediment anoxia. Organic enrichment opportunists in freshwater include tubificid oligochaetes, certain leeches, water lice, midges and chironomids. There is generally a decline in the “clean-water” taxa such as plecoptera, ephemeroptera and tricoptera downstream of trout farms (Iwama 1991). Because the benthic infauna is less species rich and abundant than in normal marine systems, subtle effects on one or two species can change the benthic faunal balance considerably.

Other fish

Phillips (1987) indicates that sediment degradation in freshwater is less harmful to fish than in the marine environment. Taylor and Perrin (1989) conclude that there is little indication of impact on fish from salmonid culture in freshwater. Some enhancement is evident and there is definitely an attraction of fish to cages to consume uneaten food. In freshwater finfish operations wild fish are frequently observed in high densities around cages containing cultured fish (references in Weston 1986; Rosenthal et al. 1995; Iwama 1991). Culture activities have been shown to increase number and biomass of native fish in lakes and reservoirs by beneficial enrichment (limited and managed). In the Philippines, pen culture of milkfish and *Tilapia* has altered density and species composition of the wild fish community in a particular lake (Ackefors et al. 1984 in Weston 1986), which is not surprising since one third of the surface area of the lake has pens.

IX. CURRENT APPROACHES

In this section, the current state of monitoring, compliance and regulations or guidelines for salmonid aquaculture in B.C. are discussed in relation to waste discharges. At present, a four-year old moratorium on new fish farm sites is in effect.

A. GUIDELINES

Fairly detailed guidelines have been developed in B.C. for initial salmon farm siting (see “Siting” paper, by Catherine Berris). These siting factors are guidelines rather than criteria, and in many cases have not been followed in the siting of fish farms. In addition, an extensive referral process is in place to determine the effects and responses of interested parties to the placement of new farm sites. This process has worked with varying success. However, older farms were sited before many of these guidelines and referral processes were developed. The referral process is described in more detail in the paper on jurisdictional issues for this review by Ann Hillyer.

Perhaps what is most surprising is that there has been no requirement to examine the environmental characteristics of a proposed site before operations begin. Some questions are asked about biophysical conditions, but there has been no follow-up or checking of information before permitting and no information gathered during the referral process.

The detailed guidelines and referral process for initial licensing are not in place for production quota changes. It is not clear what process is used to determine that production can be increased at specific sites. In addition, if a company sells a lease, the new owner needs to reapply for the lease, but does not go through the full approval process. Therefore, despite the moratorium over the past four years on the granting of new salmon aquaculture licences, marine production limits for salmonids in B.C. have increased considerably, and annual production by the industry has increased by 44% (MAFF production information, summer 1996). Increases in production quotas can be granted at the time of license renewal (see Ann Hillyer’s paper for details on licensing). MAFF also allows some flexibility for good agricultural methods, shifting fish around, holding for marketability, etc. to a total of about 20% flexibility in maximum production levels for short periods of time.

In other jurisdictions, the onus has been on fish farms to prove that the existing farm production limits were not causing environmental damage directly beneath cages (eastern Canada) or outside the allowed boundary of impact (Washington state), before any consideration was given to increasing production (see Monitoring below).

In summary, salmonid production has increased substantially in the past four years without concurrent understanding of the effects of waste discharges and no mechanism in place to effectively regulate the industry. However, it should be noted that studies such as Cross (1996—and see Table 2) suggest that the increased production does not necessarily result in a concurrent increase in waste discharges over that experienced five or more years ago. Improved husbandry practices have probably reduced waste discharges per tonne of fish over the past five years. The point is that we didn’t know the extent of impacts before the moratorium, and we don’t know the effects now. Before any further expansion of this industry, it is imperative that we understand the present effects and plan for future effects.

B. MONITORING/COMPLIANCE

It is just within the past two years that MAFF and MELP have been monitoring to help determine how existing production levels at farms in B.C. are affecting the habitat. As yet, this data has provided no definitive answers. The monitoring program has never been clearly defined or designed to answer specific questions. In addition, there are gaps in data, background information and manpower within government which have made it difficult to interpret and use this monitoring information.

The public and aquaculture industry require three different results from monitoring, including evaluation/feedback on environmental changes; measures of site assimilation capacity; and data to enhance and improve siting decisions. The distribution of responsibilities in regulating, monitoring and reporting requirements for the B.C. salmon farming industry are summarized in the jurisdictional paper for this review by Ann Hillyer.

C. WHAT SHOULD BE MONITORED

Monitoring of waste discharges can include water column and sediment physical oceanography (temperature, salinity, dissolved oxygen, currents, sediment particle size, particle settling rates and accumulation), chemical oceanography (nutrients such as nitrites, nitrates, ammonia, ammonium and total organic carbon; hydrogen sulphide, methane, redox, chemical oxygen demand), and biological oceanography (fish, invertebrates, bacteria, biological oxygen demand, chlorophylls, phaeopigments and biotoxicity assays). In addition, a range of husbandry factors, historical events (plankton blooms, disease outbreaks, etc.) and visual effects (video footage of cage structures or sediments) can also be monitored. All of these have been measured in the vicinity of some marine salmon net-cages either in B.C. or abroad and have been discussed in more detail in the body of this discussion paper.

The question remains; what should be monitored to best indicate the impact of the operation on the water column and bottom habitats? There have been numerous attempts to use simple chemical indices. Gowen et al. (1991) state their opinion that sediment chemistry is a poor substitute for biological measures, since in several cases in their experience sediment chemistry appears normal when biota are obviously affected. This is also evident in Anderson (1992, 1996). Hargrave (1994) and Hargrave et al. (1993, 1997) concluded from a series of studies that sediment sulphides (S=), total organic carbon, chemical CO2 release from sediments and oxygen uptake were sensitive variables for detecting organic enrichment under salmon farms in eastern Canada. In addition, he advocates the use of a Benthic Enrichment Index (BEI) combining redox potentials and total organic carbon (TOC) in sediments, which provides a sensitive measure of enrichment. Finally, he states that total macrofauna biomass and deposit feeder biomass are good indicators or enrichment.

Based on the consensus of information acquired during the writing of this discussion paper, it appears that the chemistry measures of most value for monitoring sediments include some measure of organic content (total organic nitrogen, total volatile residue or total organic carbon), redox potential and sediment particle size. Sediment oxygen demand is also useful, but more complex to measure. Of more concern is the fate of antibiotics and metals in sediments, water column and benthic organisms. This issue requires further study and the development of standard practices and monitoring protocols at the time of usage. Zinc is particularly important in monitoring of sediments.

Biotic measures of most value in sediments include total abundance, biomass and species richness of invertebrate infauna. Bacterial production measurements and BOD are also useful, but may be more difficult in terms of sampling, and costly for measurement. The ratio of the indicator taxa such as Capitella capitata relative to total abundance appears to provide a useful measure of organic enrichment. Finally, visual reconnaissance of sediments is very useful for a trained observer.

Water column effects seem to be of less concern locally, with minor changes in nutrients downstream from operations if husbandry practices are efficient. Furthermore, salmonids are one of the most sensitive indicators of oxygen or ammonia problems, so that on-site monitoring of temperature, salinity and dissolved oxygen by farm operators seems to be sufficient for measuring water quality and ensuring health of their stock. Water column particulate loadings have not been examined in a systematic way, although turbidity readings have been taken by MELP during monitoring at some sites in B.C. Particulates in the water column could cause outwashing on beaches or intertidal areas nearby on flood tides.

D. MONITORING IN BRITISH COLUMBIA

MELP initiated mandatory monitoring by the industry in 1988 through the Aquaculture Waste Control Regulations. Cross (1994) summarized monitoring requirements from the industry, compliance and response by the provincial government in terms of follow-up, data evaluation and reporting back to the industry. Monitoring requirements from the Ministry of Environment, Lands and Parks are scaled into three categories based on the amount of feed used each year. Schedule A is <120 t/y; schedule B is 120-630 t/y and schedule C is >630 t/y. Schedule C also requires a waste management permit for disposal of feed and feces. The Waste Management permit is fairly general in terms of requirements and basically calls for "good practices", which means that there are no regulatable criteria for waste discharges.

The monitoring requirements for all schedules are laid out in the "Environmental Monitoring Program for Marine Fish Farms" guidelines from MELP (1988), with field sampling methods and analytical requirements contained in the "Field Criteria for Sampling Effluents and Receiving Waters" and "A Laboratory Manual for the Chemical Analysis of Waters, Wastewaters, Sediments and Biological Materials" (1976 edition updated April 1989) both issued by MELP. The fish farmer must buy the latter two manuals from Victoria, B.C. The first one is free but must be obtained from the Vancouver Island Environmental Protection Office. MELP published and distributed an Environmental Monitoring program guideline, but this was not mentioned in the aquaculture regulations, instead it was expected that each farm would be made aware by phone call of the guidelines. Therefore not all farms may be aware of what is actually required.

Monitoring requirements for all categories require quarterly information on materials accounting, feed and other substances used, fish production and waste handling. Schedule B farms are further required to provide monthly temperature and salinity profiles for the first year of operation, current measurements at a depth of 15 m (bottom of net-cages for a duration of one month, one time), vertical profiles of temperature and dissolved oxygen (DO) taken monthly during summer months; annual qualitative diver survey of bottom sediments and benthic communities in vicinity of cages. Schedule C farms must provide in addition, monthly ammonia, nitrite and nitrate profiles for the water column. The program was supposed to run for three years, but has not been revised and has lapsed.

All fish farm operations currently require an effluent treatment permit for sewage from dwellings for worker. During the first two years of the required monitoring program, data was submitted to Victoria for Hypercard computer database information system entry on a MacIntosh based program (Murray Sexton).

The MELP monitoring program was reviewed (Cross and Kingzett 1994) and found inadequate. The information returned via data forms from the industry to MELP was incomplete, with questionable data quality (L. Erickson, MELP, pers. comm.). There had been less than 50% response in all categories. Most farms were originally in the middle category Schedule B with 120-630 tonnes feed usage annually. Data for this category is largely incomplete both for one-time environmental reports (current, temp/salin) and for on-going reporting. Benthic sedimentation data and surveys were least often reported. Major restructuring of the industry during the period of the monitoring program and large numbers of receiverships, consolidations and relocations of original farms have undoubtedly caused some confusion in records keeping.

On the other hand, MELP did not process all monitoring submissions, was not aware of non-compliance and did not acknowledge receipt of submitted monitoring information or respond to failures to comply. In addition, the data were not being analyzed by MELP and returned to the fish farmers so that any problems could be traced and acted upon when necessary. In other words, the program was not working. Cross and Kingzett (1994) recommended consolidation of all existing monitoring data of reliable quality, and revision of the monitoring program. This has not been done to date.

MELP is apparently considering depermitting of sewage treatment for fish farms. In addition, depermitting for food and feces discharge from fish farms is being considered mainly because of limitations in manpower and problems with the actual functioning of the permitting process. Instead, ALL fish farms would be subject to the aquaculture regulations. There is some question about whether this has any enforceability.

A further problem with monitoring and regulation of the industry is inefficient communication between MAFF and MELP, so that when production increases are given by MAFF, information on the new production levels often doesn't reach MELP for some time. Amendments to production limits by MAFF are not automatically forwarded to appropriate persons in MELP. This was evident in the MELP monitoring data field sheets for 1996. In addition, several farms examined at the time of the Cross and Kingzett (1994) study had reported an increase in production and feed usage which would change them to category C, but had not been issued waste management permits by MELP. In a number of cases, the farms themselves have applied for the Waste Management Permits required to change their status from Schedule B to Schedule C. Thirty to forty such Permits are in progress at MELP, and will take up to two years to process. Cross and Kingzett (1994) indicated that the main concern of MELP's waste management branch is the permitted farms (Schedule C—11 currently), particularly sewage, morts disposal and bleeding.

Within the past two years, MAFF have tried to check the environmental status of fish farms in B.C. with the intent to visit every farm site at least once, and those with potential problems several times. This process is not complete. Some auditing of the monitoring program and additional work has been done in conjunction with the Kwakiutl Tribal Fisheries Commission. MAFF personnel have used a small remotely operated vehicle (ROV) with camera system which is capable of working to a maximum of about 35 m depth. About 35-40 hours of video footage from this work is currently being edited and analysed by MAFF personnel. Video has been taken of sediments, along with fisheries inspections at all farms within the past two years to help identify environmental problems. There are several enforcement options, the use of which have not been documented: a) ticketing or fines for minor infractions; b) closure of operations; c) court cases.

A summary of the video information from MAFF for 40 B.C. farms in 1996 categorizes the farm waste discharge impacts to sediments under cages as follows:

- zero—no visible impact, feed waste, bacterial mats, etc.
- low—light sedimentation, no bacterial mats, lots of invertebrate burrowing and fauna present
- medium/low to medium—higher sedimentation, patchy bacterial mats, some burrowing activity
- medium/high to extensive—extensive sedimentation and feed pellets, sizable patches to solid sheets of thick white bacterial mats, no evidence of benthic fauna or burrowing.

Based on this scheme, 15 farms were rated as zero-low; 18 as medium/low to medium; 7 as medium high to extensive (C. Backman, MAFF). At least six of these farms had been fallow for three or more months. Figure 13 shows the comparison of 22 of the video results with the MAFF model carbon sedimentation loads for the biomass noted in the cages at the time of survey. There is a rough exponential increase in sediment carbon load relative to impact score, but the scatter in data illustrate the difficulty in using such simplistic comparisons. In particular, the relationship does not take into account the stage of production cycle, or the history of discharge leading up to the time the video footage was taken. As well, site-specific capacities will depend on variety of hydrographic conditions. Therefore, it is necessary to obtain information on impacts and sediment carbon loads from all B.C. farms before any conclusions can be made about patterns.

Figure 13. Estimated Carbon Load from 22 Farms in B.C. Which Had Bottom Sediments Videotaped by B.C. MAFF in 1996.

Note: Impact scores up to 2 show no signs of anoxia and have moderate infauna and burrowing evident. Scores of 3 or more show increasing patches of anoxia, reduced to no invertebrate fauna and progressive degradation of sediment quality.

Personnel from MELP have also conducted surveys of fish farms in the Broughton area, Clayoquot Sound and Sooke Inlet near Victoria in 1996, some of it in concert with MAFF survey trips. These surveys were not always consistent in their procedures or sample collection, but nevertheless provide the most extensive set of monitoring information currently available on the status and environmental effects of marine fish farms in B.C. This data has been examined and discussed in the appropriate information sections of this report. Site selection for sampling was determined in an attempt to examine the differences between effects under cages, at the cage perimeter and at some reference location in similar substrates 50-200 m away from the operation. In some cases, reference samples could not be collected or could not be considered similar enough in terms of substrate. Generally, fallowed or unused sites were not sampled.

Quantitative sampling by MELP has included water column nitrates and ammonia, dissolved oxygen and temperature; sediment total organic carbon, total organic nitrogen, sediment volatile residue, particle size, particulate metals; biotoxicity tests on sea urchin eggs and other organisms. Qualitative sampling included descriptions of sediment colour, texture, strength of hydrogen sulphide smell and presence or absence of feed pellets. Included on field sheets was information on current net-cage biomass, feed usage and method, size or age of fish, and if possible some information on historical usage and fallowing practices (this was very sketchy), recent disease outbreaks, predator problems, or other pertinent observations.

A study of the benthic infauna and sedimentation rates over at least one year at four fish farms and two pre-operational sites in the Broughton Archipelago area has recently been completed by MAFF and the Kwakiutl Tribal Fisheries Commission (for report see Cross 1996).

The MAFF Siting and Discharge Model

A biophysical model for farm siting and estimating waste loading and distribution was developed by MAFF. The modelling approach was first conceived by Caine et al. (1987) and has recently been modularized and expanded by Chandler and Carswell (1995) based on loading models developed by Einen et al. (1995) and Iwama and Tautz (1981). The interface of this model with GIS systems and databases is a potential advantage over existing models since it allows upgrading and improving of the model with relative ease and efficiency (see Rosenthal et al. 1995). It also allows the digital integration of existing benthic video footage collected by MAFF in the last two years. The model is currently limited by lack of enough data on total water column currents, bottom topography and slope at all sites, and by incomplete records on food conversion ratios and production at farms. A barotropic tidal model is used to predict bottom currents, and an industry-wide average food conversion ratio of 1.5 or 1.4 is used for the model. Verification of model results from MAFF and MELP environmental monitoring data is currently underway (C. Backman, MAFF, pers. comm.), but data are still incomplete and model assumptions are simplistic for accurate predictions.

The MAFF model has been assessed for its applicability in the Broughton Archipelago (Chandler and Carswell 1995). Based on the findings of this discussion paper (see solids and dissolved outputs), there is considerable variation in estimates of quantity of discharge depending on certain assumptions about food conversion ratio at the farm (rather than in the lab), amount of waste feed, attraction of zooplankton and small fish to the site (which can reduce waste feed falling through nets to the bottom, or may contribute to the diet of the fish themselves).

In addition, the model needs to be ground-truthed or verified based on field measurements, to determine how accurately the projections match reality. There is currently insufficient data to do this. Data that is required to predict the temporal and spatial extent of effect, severity of impact and fallowing schemes can be modelled on a site by site basis using:

1) Natural, site-specific physical factors need to be incorporated into the model, based on other recent modelling exercises for aquaculture. Baseline hydrographic data such as temperature, salinity, currents at surface (which can be estimated using a tidal or barotropic model), currents at the bottom of nets (data required for MELP) and maximum water depth over an entire lunar tidal cycle in spring and fall. Also, bottom topography and slope, sediment particle size and the presence of large epifaunal species observed by diver or ROV survey). Much of this work needs to be done only at the beginning of the tenure.
2) Farm-related factors such as net-cage numbers, size and configuration, sediment TOC and redox, solids accumulation over time (suggest the use of transect lines with flags to measure ACTUAL settlement of solids over time æ this takes into account resuspension and natural breakdown and assimilation of carbon by biota). This type of information needs to be taken on a regular basis and used to continuously update the model parameters. Monitoring should be done at the beginning and climax of each grow-out cycle (i.e., minimum at start of cycle and maximum stocking density just before marketing of fish) along with a set of benthic grab or core samples below, at edge, 30 m and 100 m downstream from cages for total counts and weights of benthic infauna and counts of *Capitella capitata* or other dominant opportunists.
3) a component describing estimates of water column suspended solids distribution should be incorporated into the model and tested with field research.

E. MONITORING IN OTHER JURISDICTIONS

Monitoring guidelines for other jurisdictions are summarized by Hatfield and EVS (1996) and Cross (1994). Levings (1994) also summarizes approaches for Washington state, Scotland and Norway.

Cook and Simpson (1995) describe the roles of government agencies in aquaculture development in Atlantic Canada. In 1992 the New Brunswick Department of Environment completed a baseline study of 52 marine salmon-cage sites in the province (Thonney and Garnier 1993). The field data of sediments, biota and oceanographic data provided site-specific recommendations for minimizing the effects of sedimentation. Sites prone to excessive organic accumulation (progressive deterioration of sediment quality under and around cages) were generally less than 10 m deep at mean low tide, had currents less than 5 cm/s, and a sediment total organic carbon (TOC) content of greater than 6%. This data was examined in some detail for the current report (see appropriate sections in the main body of this report).

There is a responsiveness summary (173-204-412 WAC) related to marine finfish rearing sediment standards for Washington state (WSDE 1995) which discusses responses to the proposed impact zone guidelines (which have now been adopted) for benthic effects around net-cage facilities. Responses from a range of interest groups and the public were mixed. Washington state allows an acceptable impact zone “with substantial reduction in benthic population within an authorized net pen mixing zone of 100 ft from perimeter of the footprint of the farm operation”. A further description of this approach and philosophy is given in the BCSFA (1996) response document for this review, in the section on Waste Discharges by Dr. Ken Brooks. Sediment management standards for Washington state (dept. Natural Resources) indicate that increased monitoring of sediments will have to be done if TOC levels statistically exceed those listed below outside the 100 ft boundary:

Percent silt/clay	**Total organic carbon (% dry wt)**		
0-20		0.520-50	1.750-80
	3.280-100	2.6	

Note that the upper limit of TOC which triggers further monitoring is 3.2%, compared with a maximum of about 4% noted in reference areas in B.C. (MELP 1996 monitoring data and see Figure 5). Three percent is considered average for northern east coast marine sediments (Cranston 1994). The Washington state guidelines imply that any impacts to benthos within 100’ of the net-cages are acceptable. Dr. Ken Brooks (see BCSFA 1996 and pers. comm.) has suggested that siting in Washington state should be in low production or naturally impoverished benthic sediment areas as these have low inherent ecological or economic value. The Washington state approach is endorsed and recommended as the approach to take in B.C. by B.C. Salmon Farmers Association and MAFF. However, if Washington state were faced with substantial increases in aquaculture sites in Puget Sound, the criteria adopted to date not prove to be suitable.

F. MODELLING REGIONAL CARRYING CAPACITY

For projecting what the environment can handle in terms of waste discharges from aquaculture, it is useful to make estimates of the carrying capacity or assimilation capacity of regions, particularly for the water column. Data requirements are dependent on the region to be modelled, but include year-round water column temperature, salinity, oxygen, tidal current characteristics, total basin volume, dissolved N and P, and chlorophylls.

Silvert (1994) notes in his review of aquaculture operations on the east coast of Canada that some areas are already at “flushing capacity” from other organic sources (natural or anthropogenic). These areas would not be suitable for aquaculture in case the existing steady state should become unbalanced, or because the area already may have compromised water quality making it too risky for husbandry.

Some of the models for dispersion and organics loading to sediments and the water column have been discussed in previous sections. Modelling efforts for sedimentation and dispersal of fish farm wastes are reviewed up to 1990 by Levings (1994). He notes that models to that date had not been applied to B.C. Levings (1994) also discussed some models for carrying capacity for fjord water bodies. In particular, 30 Norwegian fjords were “classified” according to their capacity to consume excess organic material arising from fish farm wastes (Aure and Stigebrandt 1989, 1990). They found sill and related basin depth most important in calculations, since these factors determine the flushing capacity and time for fjords.

Silvert (1994) and Cranston (1994—see also ICES 1995) modelled cumulative effects of aquaculture dissolved output based on a simple calculation of water volume in region, flushing time, and total input of nutrients to the region. By adding typical summer values for N for the area one can get a crude estimate of additional loading. Then, increased uptake and thus removal by phytoplankton must be taken into account. This method, although crude, gives some method for estimating water column carrying capacity for a region based on the availability of some basic oceanographic data. In a steady state, input equals flushing out.

Cranston (1994) did estimates of carrying capacity of sediments for east coast inlets based on dissolved ammonium and sulphate profiles in sediment pore water from cores. In this way, he was able to directly measure the accumulated carbon in sediment (carbon burial rate), while extracting all other potential carbon removal processes. He used these data to calculate benthic carrying capacity based on doubling of current carbon burial rates in basins. For specific areas on the east coast of Canada, Cranston (1994) estimated that sediments could “carry” production ranges from 225 t/a to 94,000 t/a depending on the area, with similar values for the water column. The only real decreases in water column capacity occurred where water depth was greater than 20 m. He calculated for L'Etang Inlet that at maximum current licensed production, the salmon in the inlet are producing approximately 60% of the carrying capacity (= 5,000 t/y). Estimates of carrying capacity by Cranston (1994) for the 20 inlets in eastern Canada were in very close agreement with those determined by Silvert (1994), despite the use of very different methods.

A summary table listing results from Silvert (1994) and Hargrave (1994) shows estimated holding capacity for 141 sites on the east coast of Canada. Values range from almost no capacity to over one million tonnes per area (based strictly on water column nitrates).

The B.C. case: Broughton Archipelago as model

The type of oceanographic data required to do the simple modelling such as that outlined above is currently available for some areas in B.C. More sophisticated regional flow models are in the process of being developed in B.C. by researchers at the Department of Fisheries and Oceans and by oceanographic consultants. The output and distribution model being developed by MAFF has been set up to estimate waste loading and dispersion in the Broughton Archipelago (Caine et al. 1987; Chandler and Carswell 1995). The model is still under development and basic oceanographic data for the area is somewhat limited. The carrying capacity model for Sechelt Inlet showed that extensive calibration (ground-truthing) was required for the nutrient dispersal model (C. Levings, pers. comm.). The same would be true for a model for the Broughton.

Other areas for which there is an interest in examining assimilation capacity for salmonid aquaculture include: Barkley Sound, Kyuquot Sound, Clayoquot Sound, and Northern Georgia Strait.

There is considerable oceanographic data for the Sechelt area, Barkley Sound, Georgia Strait (considerable nutrients modelling has already been done—see Mackas and Harrison 1997), and little for Clayoquot Sound. Clayoquot may be particularly important to study since it seems to have a somewhat restricted entrance (shallow sill) and may have slow flushing. It is also an important area for fish-farming. A simple flushing model for Kyuquot Sound was developed and has been used to estimate nutrient loading capacity (see water column impact section on nutrients).

In the Sechelt area, nutrients and oxygen demand versus flushing ability of the inlet have been modelled (see Black and Carswell 1989). They indicate that only oxygen demand may be an issue at greater than 4,000 t production in mid-summer when flushing is at a minimum. This is mainly because the inlet has low oxygen concentration in deeper waters.

Recommendations about monitoring protocols and responsibilities will be included in the jointly developed section on "Recommendations" to be completed by the TAT.

G. DATA ACCESS

Any monitoring data collected on a large scale in B.C. needs to be centrally available for regulators and the industry. To date, such data collected from the industry and within government has not been adequately processed or computerized for easy access, summary and assimilation into the MAFF siting and discharge model. Prompt analysis of this data would also assist greatly in real-time responses to problems, in feedback requirements from the industry, and to drive necessary research into issues of importance.

H. MITIGATION AND PREVENTION

Cross and Kingzett (1994) recommended an obligatory set of operating standards for industry which they state will fulfill both industry and government agency goals and provide reassurance to the public about the environmental practices of fish farms. Topics include:

• net-cage structure, • site buildings,• therapeutants,• bleeding an doffal disposal options,• mort
disposal options,• antifoulants, and • enforcement.

These practices would have to be flexible and revised regularly to allow for site-specific modifications and technological improvements. Methods for compliance monitoring would have to be determined. They further recommend a complaint system to go first through the BCSFA for internal handling with a time limit on response and mitigation, with a secondary channel if this is not satisfactory to go to the regional Environmental Protection Officer for more serious response. They suggest that the government regulators consider fines, cancellation of licences, etc. depending on the seriousness of the offence.

I. HUSBANDRY

Stocking densities of 8-18 kg/m3 are used for Atlantic salmon in B.C. (B.C. Salmon Farmers Association). Anything over 20 kg/m3 stresses fish. Initial stocking of smolts is usually more like 5-8 kg/m3. Densities of 5-10 kg/m3 are more common for chinook salmon. Nets are usually 15 m deep or more and up to 15-30 m square or in diameter. Round cages have much greater volume and generally have a maximum stocking density of 10 kg/m3, which is healthier for the fish. The structural features of the round cages would therefore seem to be the best for use in culturing chinook salmon. Round cages also tend to be less tightly packed together and can be deployed in higher current and wind areas. Therefore, the use of the larger, circular cages serves to spread the benthic deposition of nutrients over a broader area than the square cages, which theoretically causes less stress to the assimilation capacity of sediments, but affects a greater area to a lesser degree.

In New Brunswick salmonid farms were initially limited to a maximum stocking of 30,000 fish annually on a lease no larger than 2 ha for a maximum annual production of 75-100 t annually. This limitation was lifted in 1986 for economic reasons (economy of scale), leading to some serious overstocking problems. Currently, New Brunswick site potential guidelines are limited by depth at the centre of the site, minimum site area, and recommended average current speed. A table with these site size and stocking densities is given in Rosenthal et al. (1995). The maximum site potential production is given as 320 t, with a maximum cage capacity of 80,000 fish and a minimum site spacing of 300 m. However, it should be noted that net-cages in New Brunswick are not as deep as in B.C. so that maximum stocking density may be prorated accordingly. Increases in stocking levels at a site are conditional upon there being no adverse effects as evidenced by prescribed environmental monitoring. A negative result based on accumulation of organic carbon, anoxic sediments, significant reduction in macrofauna, etc. can result in a decrease in stocking level permitted.

It has been suggested that a site-specific biomass “ceiling” be imposed in B.C. instead of a feed usage limit. Any requested increases in production would then be subject to a thorough environmental assessment on site.

It appears that in other jurisdictions (Europe, U.S.) salmonid farms have been preferentially located in fairly shallow water (20m or less). This is due to the perception that if the discharge effluent goes below the thermocline it will accumulate on bottom and use up oxygen near the cage operation (c.f. report Swedish Steering Committee for Aquaculture 1983). In addition, the cage structures tend to be less deep (c.f. Hargrave 1994) on the east coast of Canada, in the U.S. and elsewhere. Obviously the experience in B.C. has resulted in different conclusions and practices (see siting, below).

Recent technological advances in marine and freshwater cage culture methods are described in Boghen (1995). For example, global cages (or modified version of Kiel cage) can be rotated and submerged to a greater or lesser extent. The rotation reduces fouling, predation from above is not an issue, and during storms it can be submerged. It allows use of more exposed (less controversial) sites. The benefits exploited by this approach in eastern Canada have been impressive. Off-shore salmon farming in partially submersible net-cages has also been described by Ackefors and Enell (1990). In addition, closed containment systems are being developed in Nanaimo, B.C. and may provide the potential for higher stocking density with much greater control of stocks and waste discharge.

One area of concern particularly for the First Nations people, which is difficult to quantify and for which there has been no research, is the smothering or fouling of nearshore clam beds and other resources from various practices of net-cleaning and settlement of solid wastes on nearby beaches. The use of copper-based antifoulants (three products used currently in B.C.) consisting of 26% cuprous oxide to dip nets to reduce fouling is becoming a common practice in B.C. and will greatly reduce the risk of organic impacts from fouling organisms. However, there is insufficient information about the dissolution rate and effects of the copper from the nets on other marine organisms. Currently application of antifoulant paints to nets requires a Pest Control Service Licence from the Pesticide Management Program of the provincial Pesticide Control Act, and must be supervised by a certified applicator. Comments received back from the Broughton Archipelago subcommittee question whether this supervision or safe practices are always followed. A report on Norwegian goals towards a sustainable salmon industry in ICES (1996) indicate that one of the goals is to reduce the use of copper in antifoulants by 80-100%.

The use of disinfectants and anaesthetics and their disposal is an issue which needs clarification.

The use of antimicrobials and pesticides is also actively being reduced as much as possible in various salmon-farming countries (ICES 1996) in favour of advanced husbandry techniques, particularly the use of vaccines. There are real and preconceived concerns related to residues in food species vital to the subsistence economy of First Nations people in B.C.

One of the greatest problems in Europe is sea-lice. Currently, dichlorvos and hydrogen peroxide are available for use in baths to treat sea-lice in Europe. These are apparently soluble in water and do not end up in sediments, but may be taken up by biota in the water column. More research into pesticide effectiveness and environmental effects, and alternative uses of pesticides (such as Ivermectin in feeds) are being pursued (ICES 1996). The obvious mitigation to the use of antibiotics and pesticides is the development and application of suitable vaccines for diseases.

J. TRAINING

Training required for farm personnel is discussed in the submission for the review by the B.C. Salmon Farmers Association (1996). There is no standardization required in training and education for farm technicians, and the requirements for farm managers are not described in detail. There are college and university programs on aquaculture technology, which have been partially supported by the industry. Specific companies also provide training on and off-site. The consistency of this training, and turnover of personnel is not clear. Support staff includes specialists with training and education suited to their function (veterinarians, managers and other consultants).

K. SITING

The discussion paper on siting of salmon farms for this review by Catherine Berris includes details on current siting criteria for B.C. Initial siting evaluations must not be bypassed and should be thorough. Several documents have been published to aid in siting fish farms in B.C. The first is the biophysical suitability survey for most of the B.C. coast (Ricker et al. 1989; Ricker and Truscott 1989; Ricker and MacDonald 1992, 1995) and the second is the more comprehensive coastal resource use atlas (CRIS 1989). The Ricker volumes are based on bio-physical criteria and do not take other siting issues into account. They require updating in some regions based on advances in technology and mitigation practices, which will change the biophysical suitability criteria. Environmental criteria for these atlases were developed by Caine et al. (1987). The siting criteria were originally developed for chinook, and so need updating and modification for Atlantic salmon.

MAFF, MELP and DFO agreed on some basic guidelines as standard for siting of fish farms, but these have not always been followed. These include spacing of farms 3 km apart, siting a minimum of 1 km from gazetted rivers (salmonid), 1 km from native reserves, 1 km from parks or ecological reserves, 1 km from boat anchorage and 125 m from shellfish beds. The last is a DFO request which may be appropriate for protecting wild resource stocks, but precludes the combined culture of finfish and shellfish. In Scotland, the requirement for spacing of farms is 8 km, unless farms are very small.

Siting factors which seem optimum with respect to waste discharges and environmental quality based on studies in B.C. include depths greater than 30-45 m with a sloping topography (Cross 1993, Anderson 1992, 1996); topographic shape to avoid back-eddies and depositional holes (Gormican 1989); clearance of 15 m between the bottom of the cage structures and the seafloor (Weston 1986); background levels of oxygen greater than 6.5 mg/L (Weston 1986) well below the depth of the net-cages; temperatures of 5-16 C (Weston 1986); subtidal currents of 3-5 cm/s over most of the lunar tidal cycle in a non-depositional area (i.e., coarse sediments); and current direction perpendicular to nets to reduce flow restriction (Gormican 1989). Finally, siting in brackish or estuarine areas is avoided because of the fluctuations in physical conditions (which is hard on the fish), and because these are areas known to promote toxic algal blooms and concentrations of sea-lice.

The consensus seems to be that efficient siting combined with appropriate production limits and stocking density for the assimilation capacity of the site are the key to avoiding progressive degradation leading to anoxia in sediments.

Land-based culture of salmonids (for grow-out) has been practised in some areas, but the consensus at present seems to be that this is less cost-effective than marine cage culture. The growing use of land-based culture for some finfish species, to avoid environmental impacts and fish health impacts, and as competition for coastal resources increases, is discussed in ICES (1996), as is the advent of enclosed sea-bags for culture. The example is given in B.C. of the purchase of the land-based Domsea Farms and reopening of the land-based marine aquaculture operation there. Unfortunately, recirculation technology and biofiltration to remove ammonia from seawater is far from being successfully developed for commercial scale finfish culture. Such seawater recirculation technology has been developed for research purposes at a number of universities (such as U. of Victoria), but they are technically cumbersome and complex, and are expected to handle much smaller discharge loads than would be required in a commercial operation. Flow-through sea-water systems will still have to discharge nutrient-laden effluent to the ocean, but in a point-source rather than diffuse pattern. The use of deep discharge outlets for this purpose will create dispersion patterns similar to those experienced at a sewage outfall. Problems involved with land-based culture are different but would require an entirely new review. They are similar to those involved in a hatchery but would be on a much larger scale.

Caution should be used in comparing siting criteria with other countries, since hydrographic and weather conditions are different from B.C., and husbandry practices may be different, as is evident with site depths and net-cage depths. In Norway, the LENKA process for aquaculture siting followed by the more updated MOM program is used to develop and modify siting criteria. In terms of waste discharge control, Norway's Pollution Control Act sets out specific husbandry and remediation processes, including limits on feed conversion ratios and stocking density. More details on siting are given in the paper on Siting by Catherine Berris for this review.

L. FALLOWING

Larger licence areas have more versatility to move operations to avoid excessive sediment nutrient buildup or to avoid blooms, etc. and are therefore more practical from a husbandry point of view. However, such fallowing practices also serve to spread sediment loading over a greater area, thus potentially increasing the risk of adversely affecting a sensitive or important bioresource. Fallowing per se is not currently practised with any regularity by salmon farmers in B.C. Some sites are left fallow for a year or more if a problem is identified (algal blooms, disease outbreaks, sediment outgassing), however, most operations are only fallow for a few months between grow-out cycles. Salmon farmers have found (discussions with L. Erickson, MELP) that a 2-3 month fallowing period between cycles reduces mortality in smolts. In addition a relationship has been found between concentration of sulphides in the sediments and incidence of disease in cultured yellowtail (Arizono 1979). Mark Sheppard, SARC, Assoc. Aquaculture Vets of B.C., indicates that fallowing allows separation of year classes, improves hygiene, interrupts the life cycles of most infectious agents, and alleviates organic buildup beneath cages. He indicates that the current situation in B.C. has created farming production plans based on a 'maximum site usage-no fallowing' approach, and suggests that an obligatory fallowing/increased site approval approach may be the optimal solution without necessarily translating to an expansion of the aquaculture industry.

Sediment recovery rates after fallowing are discussed in more detail in the section on "Sediment Impacts" in this paper. Weston (1986) and ESSA (1993) state that B.C. salmon farmers report sediment deposits reappear underneath salmon farms within 4-6 mo (no published source of information). Anderson (1992, 1996) states that there is no evidence of irreversible damage to benthic habitats from the organic enrichment due to food and fecal waste from salmon farms. A consensus of information suggests that recovery of invertebrate abundance, species richness and biomass in sediments to values close to those at reference sites is probably an adequate indicator of recovery. MAFF video surveys illustrate recovery of large dominants and visual sediment characters between 6-12 months in most cases (Figure 12).

We do not have any clear answers about how long it takes a farmed site to recover under specific historical and production conditions. Unfortunately, we're not likely to understand recovery patterns until fallowing is practised more widely in B.C. What is of more concern is the persistence and effects of foreign elements in the sediments (antimicrobials and metals). There are no clear answers about the fate of these elements in B.C. salmon farming operations.

M. HARROWING OR OTHER DISPERSAL METHODS

The practice of harrowing (turning over the sediments under cage operations) disperses the organic waste which has built up beneath cages. A submersible mixer is used to artificially add current (see Gowen et al. 1991). A submersible pump has also been tried but doesn't prevent initial impact and further disturbs benthic biota.

An example of the practice of harrowing was given by O'Connor et al. (1993) and ICES (1996) in Ireland. Harrowing under a net-cage operation for four days showed marked spreading and dilution of the local benthic accumulation and therefore more rapid improvement on site in moderate current areas. They caution that on the wrong tide the practice could simply contaminate near-shore or sensitive areas normally outside the influence of impact from net-cages, or may resuspend nutrients and stimulate algal blooms. Hatfield and EVS (1996) suggest that harrowing should only be done in winter months when the temperature is low and light conditions are unsuitable for algal growth, and on a strong ebb (off-shore) tide. This is also good advice for the application of net-cleaning operations.

Kerry et al. (1996) discuss the effects of harrowing on oxytetracycline resistance in marine sediment microorganisms beneath a salmon farm. The question has also arisen as to the effects of harrowing on other pathogens and parasites such as sea-lice (see ICES Oct. 96 proc. and comments by I. Fleming, EAO Public Registry).

N. FEED AND FEEDING

Since feed is the most expensive single component of a farming operation (about 60%), and is directly related to waste discharge, it is in the best interest of the salmon farmer to a) minimize waste feed by monitoring waste and biomass in cages, and b) maximize feed assimilation or growth potential using optimum feed formulations. The use of high-energy feeds is reducing the food conversion ratios for salmonids, and therefore the waste discharges measured (see section on solid and dissolved discharges in this paper). Folsom and Sanborn (1993) indicate that the quantity of feed required per salmon has been substantially reduced over the last decade from feed conversion ratios of 2 to about 1.2 not including waste feed (see also Einen et al. 1995). This is true for ideal laboratory conditions and varies in the field.

Records kept at the average farm include tonnes of feed used in each cage, number of morts and harvest number. Records at company offices also include biomass of smolts delivered, total feed sent to site during the production cycle and total number and weight of fish delivered to the processor. These records are accessible to MAFF inspectors and are returned on the Annual Aquaculture Statistical Report and/or confirmed from Cultured Finfish Quarterly Report from processors for product received from farms. This information is confidential on a site by site basis, but needs to be summarized and analyzed to determine trends and problem areas. Based on information from the industry, a range of FCR's in B.C. has been measured from 1 (morts and waste feed taken out) to 1.65 (no adjustment for morts and waste). An average FCR of 1.5 is considered conservative for B.C. Atlantic salmon (C. Backman, MAFF). Chinook FCR's are higher, ranging from 1.7 to 2.0. The lower claims for FCR's for industry in other jurisdictions may be related to the method of calculation.

In contrast with the data received by MAFF, examination of compliance data for MELP on Form I reports for 1994 and 1995 using annual biomass versus total annual feed suggest FCR's for farms where data is available ranging from .07 to 7.55. This range reflects problems with reporting, or errors in calculations of feed usage by farms. For some of the farms, values reported show that the current optimal feed conversion ratio (about 1.2) is being met. The newer MELP form does not include production numbers, but does include feed usage. That different aspects of this information are collected by different ministries is redundant, inefficient and increases the reporting requirements for the farmers.

One area in which there has been less improvement than in feed formulations is the reduction of waste feed. With estimates ranging from 3-20% for the industry, and because waste feed may account for 70% of organic carbon input to sediment directly below cages (Gowen and Bradbury 1987) this factor is very important.

Using their dynamic model for Atlantic salmon nutrition and discharges, Einen et al (1995)'s simulations suggest that reducing the ration from the estimated maximum daily amount by 50 and 75% would not be effective in minimizing nutrient discharges from fish farms and would result in reduced production. They conclude that fish should be fed to appetite at which point growth rate is maximum and FCR is minimum. Results of their equations indicate that the best way to minimize FCR is to employ diets formulated to contain the minimum nutrient concentration to meet the nutrient requirements of the fish. In particular, the reduction of phosphorus in feeds has been a focus to reduce risks of eutrophication, especially in freshwater (Gowen et al. 1991).

Rosenthal et al. (1995) point out that the use of computerized automatic feeding regimes does not allow for day to day variations in fish appetites. Cross (1988) examined automatic versus manual feeders (study of one farm near Sooke, B.C.) and found that deposition rate of feed pellets and feces was much higher using automatic feeders, with sediment distribution unchanged. Consensus seems to be that a mixture of hand/automatic feeders is the most efficient. Automatic feeders are used for a base amount, with the rest fed by hand based on day-to-day fish condition and appetite. Feeding frequency and timing (i.e., when the fish are hungry but not burning weight) is important, as is paying attention to the natural cycles of the fish related to season and temperature (see Thorpe and Cho 1995). In addition, there is a small but noticeable dependence of appetite on weather (H. Rosenthal, pers. comm.). Thus efficient feeding requires experienced technicians. To avoid shoreline effects from water column turbidity and waste discharges, it may also be useful to do major feedings on ebb tides.

There are currently methodologies available to monitor the amount of waste feed under net-cages. These include video and acoustic techniques (Mayer and McLean 1995). They are used at some farms in B.C., particularly in relation to reducing feed wastage during the application of medicated feeds (Mark Sheppard, SARC).

O. FRESHWATER MONITORING AND MITIGATION

Temperature and other conditions can change so dramatically seasonally in lakes that sampling needs to be done monthly. Clearly increased production and nutrient levels are evident in Georgie Lake, B.C. and MacIsaac and Stockner (1996) conclude that measurements of periphyton are useful for freshwater salmonid culture impacts. No post-operation recovery work has been done. More work is needed on the estimation of long-term impacts of waste discharges on lake processes and productivity, using nutrient loading models for coastal B.C. lakes. Taylor and Perrin (1989) also emphasize the complexity of interactions and the need to understand the dynamics of a lake system thoroughly before its use for aquaculture.

Phillips (1987) suggested that land-based systems (although costly) and fallowing are useful mitigation measures for controlling excessive impact in lakes and rivers from intensive aquaculture in Scottish lochs. Fallowing allows phosphorus in water to dissipate over time with flushing.

In contrast with marine systems, results from existing studies on lake cage culture suggest that benthic organic enrichment is less likely to significantly change the sediments in Georgie and O'Connor lakes due to the extremely high existing total organic carbon levels and very thick layer of light, flocculent organic ooze already present from natural sources. In addition, there are fewer concerns in freshwater than in marine systems about commercial or food species in the deep benthos (30 m or more) or unique habitat resources below the penetration of light or the thermocline such as lake-weed beds. The real concern in freshwater systems is the potential for water column eutrophication.

X. RISK ASSESSMENT

Freshwater and Marine Ecosystems overview—philosophical issues

Assessing the magnitude of impact of intensive aquaculture effluent on receiving waters is clearly a complex effort. However, compared to other issues being examined in this review (fish and human health, escapees) assessing the risks of waste discharges from an intensive aquaculture operation would seem to be relatively straightforward. Quantitative risk assessment is almost impossible to do on ecosystems. Much of the data is open to conflicting interpretation (unless arbitrary criteria are set) or can be ambiguous at best. For example, increased productivity from nutrient input can be viewed as positive from a commercial point of view, or as negative artificial "tampering" with natural conditions. Because ecosystems are multidimensional with a vast quantity of possible factors to be examined, data is almost never complete. Many types of ecological data are also qualitative in nature.

In addition, the possible interactions among effluent components can be the most difficult to assess. Based on the application of the Precautionary Principle for reducing the risks of environmental and health impacts from an industry, this argues for the philosophy that the fewer additives or foreign substances discharged to the environment, the better we will be able to predict impact.

It is furthermore critical that the best models be put to use with the most reliable data to assess or quantify risks from salmon farming. Furthermore, it is vital that such modeling exercises be compared to actual farm data. Several examples of the complications which arise in trying to model impacts and risks of discharges to the environment and/or recovery after removal of the source of the impact include the following:

- the potential effects that the increased biota (water column and benthos) around farms have on the fate of the discharge. If deleterious effects occur directly beneath the net-cages, but enrichment occurs outside the perimeter of the cages, the increased turnover of organic material by the enriched communities may "nibble" away at the organic material around the edges, thus helping to keep the impacted area reduced in size and maybe even speed up assimilation of organic material during recovery.
- patchy destruction of benthos by natural means (for example, the hoovering action of grey whales feeding on bottom patches) is actually considered the driving mechanism for maintaining high species richness in a region because it opens up patches for colonization by the opportunists which would normally be out-competed in stable habitats by the more "mature" biota (see Temporal Mosaic Theory described in review by Burd et al. 1990). However, it is the SIZE and DURATION of these patches which is critical to either increase or reduce biodiversity in an area. Too large or long a "hole" in the bottom, or the destruction of limited patches of isolated stocks of important species will reduce biodiversity and change the natural balance of the ecosystem. For example, the destruction of an isolated rocky outcrop of dense numbers of sea urchins may allow the development of a kelp bed in its place.
- the effects of age and historical discharge patterns of an operation on the rate of recovery after removal of the source of impact.

In recent years, a method of ecological impact classification using Fuzzy Logic (which accurately describes much ecological data) has been used (for most recent review for aquaculture see Silvert 1995) to provide a formalism for incorporating semi-quantitative and qualitative data into risk assessment. Instead of setting inflexible criteria, it allows for a classification of effects based on degree of acceptability between 0 and 100%. The principle uses a classic mathematical combination method with weighted ratings for a whole series of impacts (weighted according to estimated potential risk or importance). In other words, for the aquaculture industry, the weighting for a factor of excessive waste buildup in sediments might be heavier than the weighting for aesthetic objections to net-cage structures or the use of lights at night. Fuzzy logic therefore uses a subjective weighting of importance for types of effect. In the end, you come up with a single number which gives an "impact" score from totally unacceptable (0) to beneficial (1). In this type of analysis, it is mainly the consistent application of the criteria scale for each factor which is vital. An example of the application of this type of method to mariculture is given by Roth and Kristensen in ICES (1996).

A. IDENTIFYING RISKS

A complete list of identified risks from waste discharges from salmon farms needs to be compiled. Each category would then have to be broken down into component effects or site-specific sub-effects. Following is a Summation of risk factors, past, present and future.

Salmonid aquaculture methods have changed so dramatically since the mid-1980s that much of the older literature on waste discharges is only partially useful. In the past, with feed conversion ratios of 2 or greater, waste sedimentation rates were higher, although production levels were lower in B.C. (see Table 2, this report). Also, less was known about siting so that many farms were set up in areas with natural low oxygen basins due to limited flushing and bottom currents. This meant that optimum oxygen in the water column could not always be maintained and anoxia was almost inevitable in sediments. Practices of morts disposal were quite varied, and algal bloom damage to stocks was higher because of less knowledge. Risks in those days were sediment and lower water column anoxia and subsequent effects on benthic infauna, epifauna and nekton. In the 1980s Norway also considered "regional" risks to be oxygen depletion in isolated basins (see Aure and stigebrandt 1990).

Most studies now suggest water quality is not an issue in well-flushed coastal marine waters of B.C. salmon tend to be one of the most sensitive indicators of water enrichment. At present, it is possible to make conservative calculations of carrying and holding capacity of regions based on oceanographic data and information on other nutrient input sources (see Current Approaches section of this discussion paper). Ireland did have rigid marine water quality sampling but is relaxing this due to lack of necessity.

If aquaculture in B.C. expands considerably in more isolated basins with the advent of better technology to avoid damage from toxic algal blooms there is a possibility that a critical mass may be reached which will exceed the carrying capacity for nutrients or biological oxygen demand of isolated bodies of water. This is why it is important that efforts be made to model carrying capacity of the more vulnerable or isolated bodies of water such as Clayoquot Sound.

In addition, Hansen and Blackburn (1992) noted increases in general algal growth in response to anthropomorphic input of nutrients. They examined lab changes in sediment COD and BOD due to excessive algal sedimentation and found a temporary stimulation of anaerobic respiration processes and increased ammonia release from sediments. Modelling exercises (Ross et al. 1993) examined the combined effects of changes in light conditions, nutrient enrichment and zooplankton grazing on algal populations in fjords. The most dangerous scenario is a reduction in zooplankton grazing, which can result in high phyto biomass for a longer portion of the year. In systems in which phytoplankton production is nutrient limited (isolated from outside ocean and tidal exchange), the worst combination is reduction in grazing rate combined with an unusual increase in nutrient loading (Ross et al. 1993).

Water quality is definitely at risk from smolt grow-out culture and commercial hatcheries in freshwater (see section on Freshwater).

On a local basis, most countries now consider the greatest risk to be excessive benthic sedimentation, leading to anoxia and decimation of benthic fauna. Observations from B.C. monitoring programs also warn of the potential dangers of impacting the benthos regions of entire bays by farms which are sited in unsuitable locations and have to keep moving the cages around the bay in order to avoid out-gassing. Scotland also now emphasizes benthic rather than water column monitoring.

Less well-defined but locally very important risks from salmon farming include danger to local intertidal areas from smothering by suspended particulate material. Water column particulate levels seem to be high around salmon net-cages based on video footage examined to date and water column turbidity measurements around salmon cages (MAFF, KTFC, MELP 1996 monitoring data). In addition, any on-site net washing operations will release large loads of particulates into the water column. If levels of particulates in the water are high enough to significantly increase the shoreline loading during flood tides and carry antibiotics and other contaminants to intertidal and water column shellfish, sensitive species could be affected. The persistent concern among First Nations people about clam beaches near salmon farms would suggest that this is a risk which has been largely ignored and must be considered more closely.

Finally, the risk of medications in sediments and the water column is unknown and needs to be examined further in B.C. Most antibiotics degrade rapidly in marine water but accumulate in sediments. Some studies described in ICES (1996) indicate that there is evidence that antibiotics in sediments stimulate the release of phosphates from sediments into the water column, which is of great concern in freshwater. In addition, various studies warn or measure reduced bacterial assimilation of organic loads due to the presence of antibiotics in sediments (see Impacts on Sediments section of this report).

There are strict guidelines for the application of antibiotics, and the pesticide Ivermectin can be prescribed by veterinarians. No biocides or pesticides are currently officially approved for use in marine aquaculture, but there is some question as to whether some are used (Hatfield and EVS 1996) in B.C. farms. The only potential scenario visible at present which could affect zooplankton, especially crustacean larvae, is the use of highly toxic pesticides such as dichlorvos, which is presently not used in B.C.

The high concentration of zinc in feeds also poses a risk due to its toxicity to biota and long half-life in sediments. Levels in some locations are considerably greater than B.C. Water Quality Objectives (MELP). This problem has only been recently discovered by on-site monitoring by MELP. The few studies on copper concentrations from net antifoulants do not indicate an environmental threat from this metabolic metal, but there is little control on its use and safe handling in farm operations.

Folke et al. (1994) point out the larger scale global ecological concerns for this industry, which are similar to most industries in the western world, its reliance on and transplanting of existing resources (i.e., fisheries for feed), and reliance on fossil fuel economy. One issue that may seem rather distant to aquaculture in British Columbia, with only 4% of the world market, but that falls in this section is the effect that global salmonid aquaculture has on the populations of fish such as the pollock, menhaden and herring that are used as ingredients for the feed. The demand for the protein from these species by intensive salmonid culture is a factor that drives the commercial harvest of these species. This is a larger issue outside the scope of this review.

B. PRIORIZATION OF RISK FACTORS

Based on the results of this review and the summation above, the following general categories are ordered more or less from greatest to least risk overall, but could be rearranged on a site-specific basis or in the event of a significant change in the size or operation of the industry:

Negative

- organic overloading of sediments (intertidal and subtidal) beyond assimilation capacity leading to anoxia and killing of sensitive shellfish and other biotic resources
- smothering of important food or commercial species due to increased sedimentation rates (subtidal and intertidal)
- assimilation of foreign chemicals added to feed or used in operations (antibiotics, pesticides, metals) into other biota
- increased water column and shoreline turbidity due to net-cleaning and resuspension of solids from feed and fecal waste
- eutrophication of freshwater lakes and rivers from hatchery and smolt operations
- antibiotic resistance in sediment bacteria reducing assimilation of organics or stimulating increased release of phosphorus in freshwater
- water column oxygen depletion of poorly flushed water bodies
- benthic and shoreline impacts from inadequate disposal of farm debris or sewage from workers

Positive (to be weighed against negative)

- increased productivity of benthic communities and kelp beds around salmon farms
- increased productivity of oligotrophic freshwater lakes
- potential for combining finfish aquaculture with shellfish longline culture to enhance feeding by shellfish on particulate feed particles in water column

If this type of risk analysis is to be done, decisions must be made about “weighing” various risk factors based on their relative importance. In order to do this, the industry “scenario” must be taken into account (present level of production, reduced production or increased production, locations of farm sites, husbandry practices, etc.). In effect, such a weighting and risk analysis must be done on a site-by-site basis for some risks, and on a regional or water-body basis for others.

THIS IMPLIES THAT A THOROUGH SITE BY SITE ENVIRONMENTAL ASSESSMENT NEEDS TO BE COMPLETED BEFORE decisions about site-specific risks can be completed. The environmental program for MELP and video documentation from MAFF, MELP and KTFC need to be completely analysed and missing sites and data gaps identified. Each site must then be reexamined in the context of established biophysical siting criteria and in consultation with local residents to determine any important biotic resources which may be at risk from existing farms.

NOTE THAT THE WEIGHTING OR IMPORTANCE OF EACH RISK FACTOR IS OF SPECIAL CONSEQUENCE FOR FIRST NATIONS PEOPLE. There must be a careful distinction made between what constitutes a risk to the population of B.C. at large, versus a risk to local communities only, versus a risk to First Nations within their hereditary territory and food gathering regions. First priority with respect to risk weighting must be given to those people most affected.

In order to help weight risks on a site-specific or regional basis, it is important to utilize discharge and distribution models for fish farm effluents, such as the one in development by MAFF (Chandler and Carswell 1995) or others discussed in this review. Such models require baseline data in detail from all sites in B.C. in order to fine-tune it and ground-truth the outputs from the model. Further development of this model is also required to improve accuracy of predictions. For example, assumptions need to be examined about percent waste feed, currents throughout the water column and bottom topography, orientation of net-cages, etc.

Determinations must be made regarding the scale of acceptability for each risk factor from 0 to 1. This is not a trivial task, and should be done for all risks in consultation with affected people.

Based on the above requirements, a combinatory matrix of algorithms (fuzzy logic) can be constructed to assess the degree of acceptable effects from a given production level and a given aquaculture site.

C. COMPARISON WITH OTHER INDUSTRIAL WASTE DISCHARGES

Salmon farming effluents are different from point source discharges because the effects are diffused over the entire operation area, move in three dimensions and are therefore more difficult to monitor æ there is no simple gradient. Folke et al. (1994) argue on the other hand that farms are point sources unlike atmospheric or riverine input.

ESSA (1993) compares the actual depositional areas of salmon farming with other industrial wastes such as pulp mills, log handling areas and sewage disposals. They note that the actual area impacted tends to be much less than for other organic discharge industries, but no scale or concentration of nutrient outputs are given. On the other hand, Folke et al. (1994) compare nutrient outputs from salmon farming in Sweden with comparable sewage output from a large city (Stockholm). They point out that the dynamics of intensive salmon farming are similar to those of a stressed ecosystem (i.e., benthic impacts). Their assumptions that salmon farming has resulted in coastal eutrophication and stimulation of algal blooms are not supported, however, and the lack of evidence of either assertion are argued in a response to the paper (Black et al. 1996, in press). Brooks (BCSFA 1997) also points out that the C/N/P ratios are different in salmon farm discharges than from sewage outfalls, and that there are no organic toxicants or heavy metals contamination (with the possible exception of zinc and therapeutants).

Weston (1986) compared the output from net-cages with other discharges (natural from rivers, and from wastewater treatment plants and industries in Puget Sound). Based on a farm with 250,000 kg salmon and surface currents of 8-16 cm/s at peak, he found a much higher water flow through net-cages than other discharges. Only a major river has comparable flow rates. Therefore concentrations of discharge and BOD are much more diluted in salmonid aquaculture compared with point source discharges from sewage. The nutrient loading from such a facility can be compared with a small river or small dairy. In terms of "population equivalents" he compares a 250,000 kg fish farm BOD amd nutrients to the untreated sewage from 10,000 persons. Weston (1986) states that this comparison may be misleading and unwarranted because the sewage discharge issue is one of "local" impacts and, more importantly in well-flushed areas, contaminants. In addition, disinfection of sewage results in additional toxicants. Pathogens (bacterial and viral) related to sewage are not a factor in aquaculture. Finally, Weston (1986) points out that a sewage discharge is freshwater, which produces pH and stratification effects not evident from mariculture.

The sediment redox depression is considered much lower in extent and influence from salmon farms than from sewage dumping grounds or pulp mills in Scotland (Gowen et al. 1988; Brown et al. 1987).

Gormican (1989) states that total ammonia values at a station over the Iona Island sewage outfall resulted in levels of 9.42 um/L whereas he and Weston (1986) predicted a rise in ammonia levels of about 1.4 umol/L in waters passing through farms of about 250,000 kg, with local containment due to dilution from tidal mixing and rapid uptake by phytoplankton (Glibert and Goldman 1981). At some production levels in B.C. farms, this ammonia output could be increased by a factor of 5.

These arguments point out three things: 1) it is impossible to simplistically compare salmon farming outputs with those of other industries, 2) it is necessary to understand the impacts of all such anthropogenic sources to make sensible decisions about coastal zone management and ecosytem protection, and 3) nutrient input is hardly an evil in itself, it is the sensitivity of the location and ultimate fate of the nutrients that is of concern.

XI. DEVELOPMENT OF CRITERIA

The development of acceptable environmental criteria for any industry requires an understanding of the risks. Following the application of appropriate risk assessment, the selection of criteria is much easier.

Currently, there are B.C. Water and Sediment Quality Objectives developed for freshwater and marine systems by the B.C. Ministry of Environment, Lands and Parks which can be applied to specific contaminants such as organics and metals. This will provide useful guidance in determining acceptable limits for zinc, copper and potentially some chemicals in salmon farm effluents. However, there are no guidelines for antibiotics, anaesthetics, etc. In addition, there are no criteria for sediment organic accumulation rates, TOC, redox, sediment sulphides, etc, as these vary naturally. Therefore, we have no criteria on which to base regulations for marine aquaculture operations.

Results of this review do suggest some possible guidelines which can be set up to regulate the industry. Potentially, such guidelines could include settlement rates to sediments of <4 g C/m2 per day to prevent organic buildup. Washington state has developed TOC guidelines relative to sediment particle size (see Current Approaches section). However, TOC levels in B.C. seem to be higher naturally than these guidelines would permit. This suggests that more comprehensive guidelines are required, which may include redox levels and sulphides relative to particle size. Hargrave et al. (1997) have suggested levels which show specific impacts under fish farms on the east coast of Canada.

Microbial	**Macrofauna**	**redox (mV)**	**S= (uM)**
normal	normal	>+200	<50
Oxic	normal, enhance density, biomass	+200-+100	50-200
hypoxic	reduced, pollution tolerant taxa	+100-0	200-2000
anoxic	none	0-<-200	>2000

Sowles et al. (1994) suggest guidelines for “unacceptable” benthic impact conditions for Puget Sound, including: azoic conditions or outgassing adjacent to or directly beneath cages, the presence of white bacterial mats in marine sediments, and feed and feces buildup extending more than 5 m away from the footprint of the cages. This requires the use of visual survey techniques. Other factors which would seem to be useful include ratios of Capitella capitata complex to total abundance of macrofauna.

The Waste Management Permits for freshwater hatcheries do state discharge guidelines for phosphorus and total suspended solids, but there are no guidelines for cage culture either in freshwater or marine systems.

Based on the current regulatory structure, it is evident that the responsibility for waste management lies with MELP. However, since the majority of reporting from the industry to government is to MAFF, there is an immediate inefficiency in the system. In addition, dwindling government resources will make it progressively harder to regulate and monitor the aquaculture industry. Recommendations for regulations, monitoring, etc., will be done jointly by the TAT team.

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APPENDIX A. LIST OF CONTACTS

This list is not exhaustive. It does not include members of the Technical Advisory Team and associated consultants (Ann Hillyer and Marvin Shaffer), EAO office and Review Committee for the Salmon Aquaculture Review. It also does not include the names of numerous members of the public and other organizations which submitted written comments and questions. These are all compiled on the project registry with the EAO office in Victoria.

MAFF
Clare Backman
Baron Carswell
Ed Black
Joe Truscott
Mike Coon

MELP
Lloyd Erickson
John Deniseger
Bill Cox
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Various members of associated First Nations groups

NTFC
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Dorothy Kieser
Ed Donaldson
Robie MacDonald
Peter Olesiak

DFO Atlantic region

Bill Silvert
Barry Hargrave

Universities

Lou Hobson, Biology, U. Victoria
Max Taylor, Oceanography, UBC
Harold Rosenthal, U. Kiel, Germany

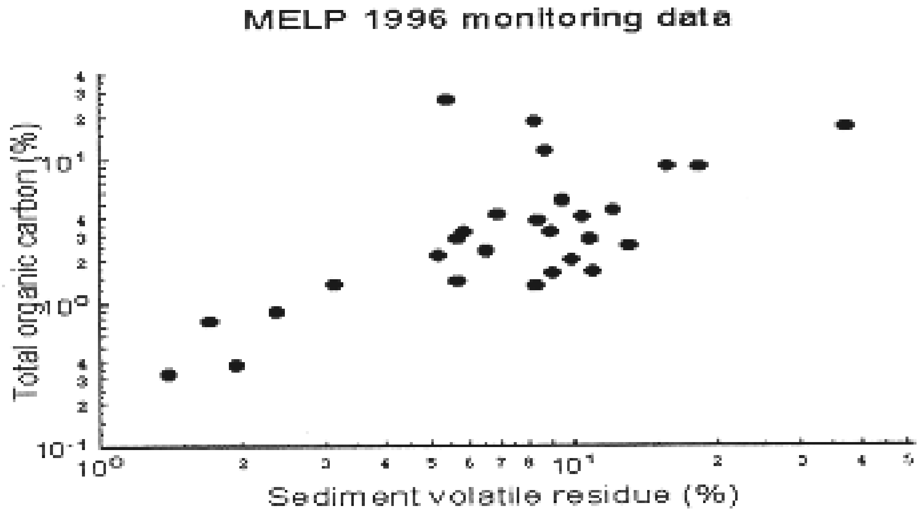
B.C. Salmon Farmers and consultants

Dale Blackburn (no response)
Ken Brooks, consultant BCSFA
Bill Vernon
Bob Everitt

Other public and consultants

Peter Chandler
Jacqueline Booth
Alexandra Morton

Figure 1. Relationship (log/log) Between SVR and TOC for MELP Field Monitoring Data.



MELP 1996 monitoring data

Note: SVR is approximately twice TOC.

Figure 2. Relationship (log/log) Between SVR and Total N for MELP Field Monitoring Data, 1996.

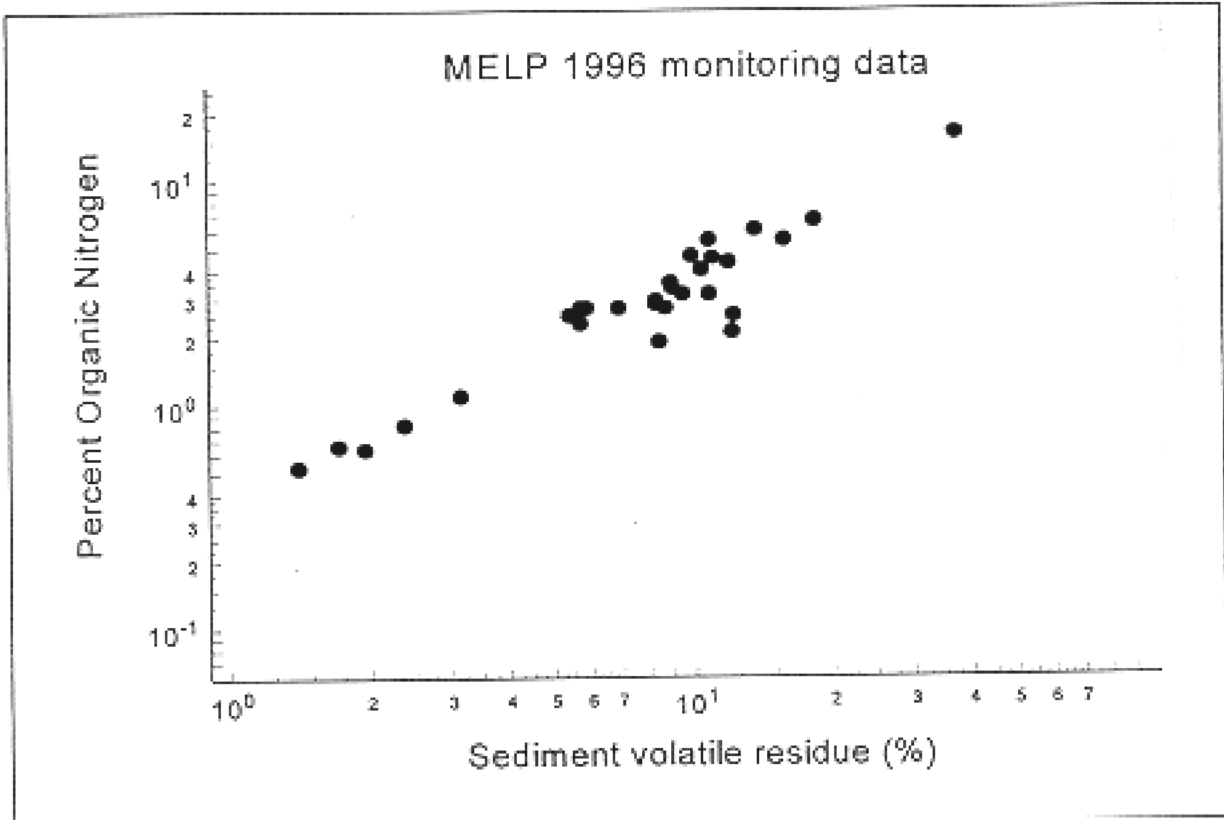


Figure 3. Total Organic Matter (% dry wt.) Versus Percent Silt/Clay for Data from the East Coast.

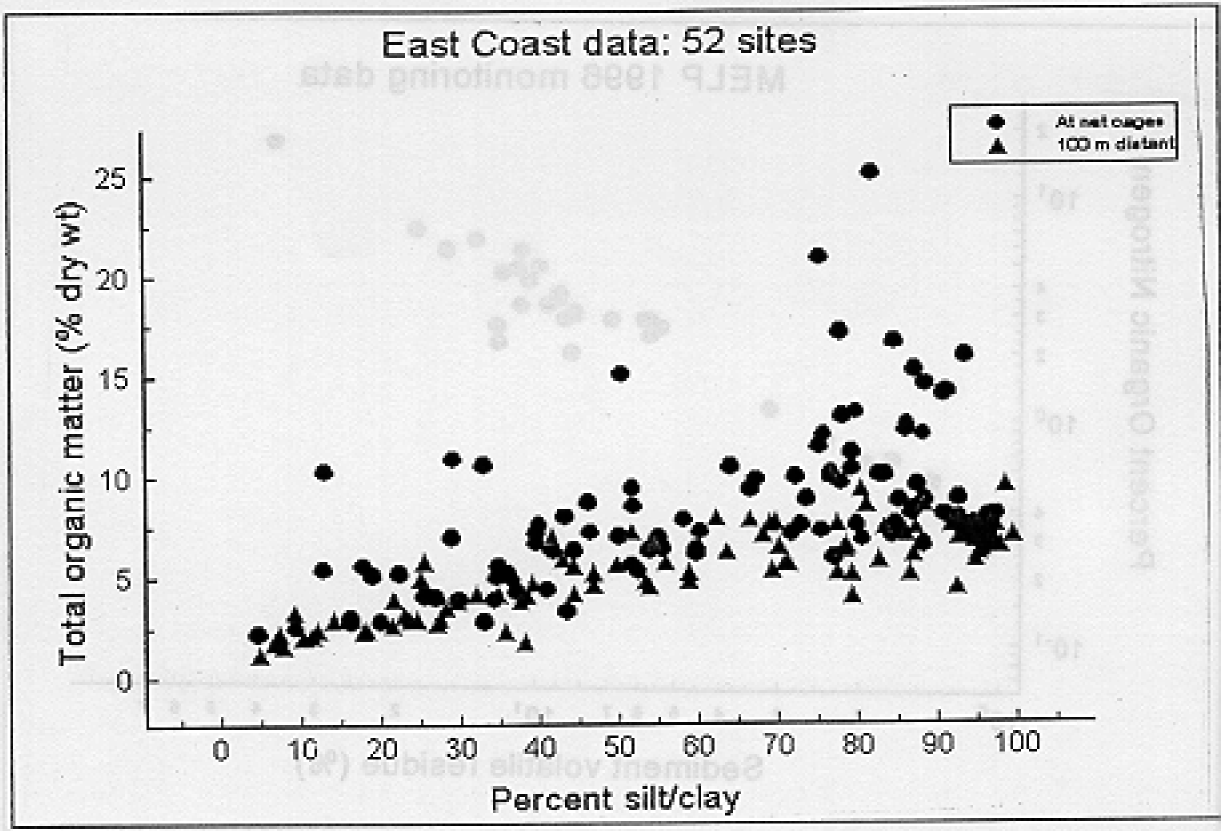
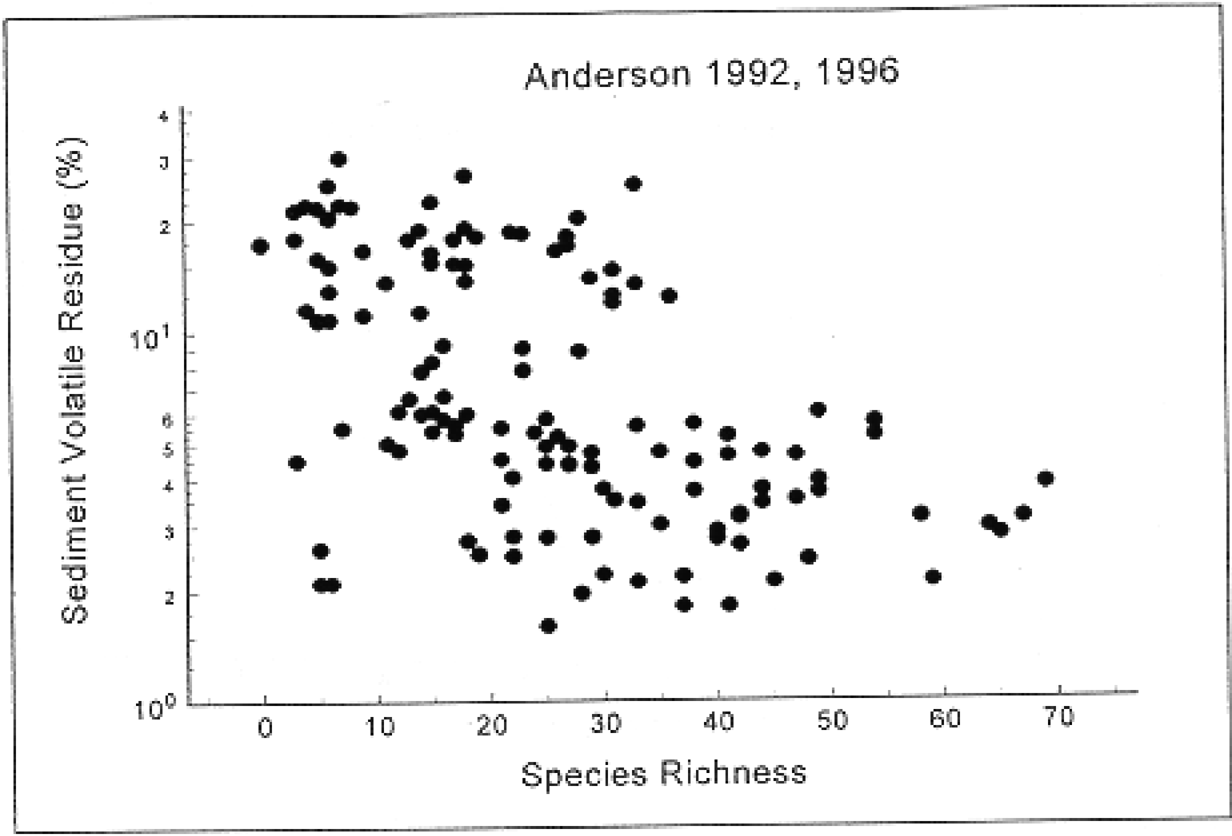


Figure 4. Relationship Between Species Richness (number of taxa) and Total Volatile Residue .



Note: From samples taken under fallowed sites by Anderson (1992).

Figure 5. Relationship of TOC (%) Under Net-Cages to TOC at Reference Stations

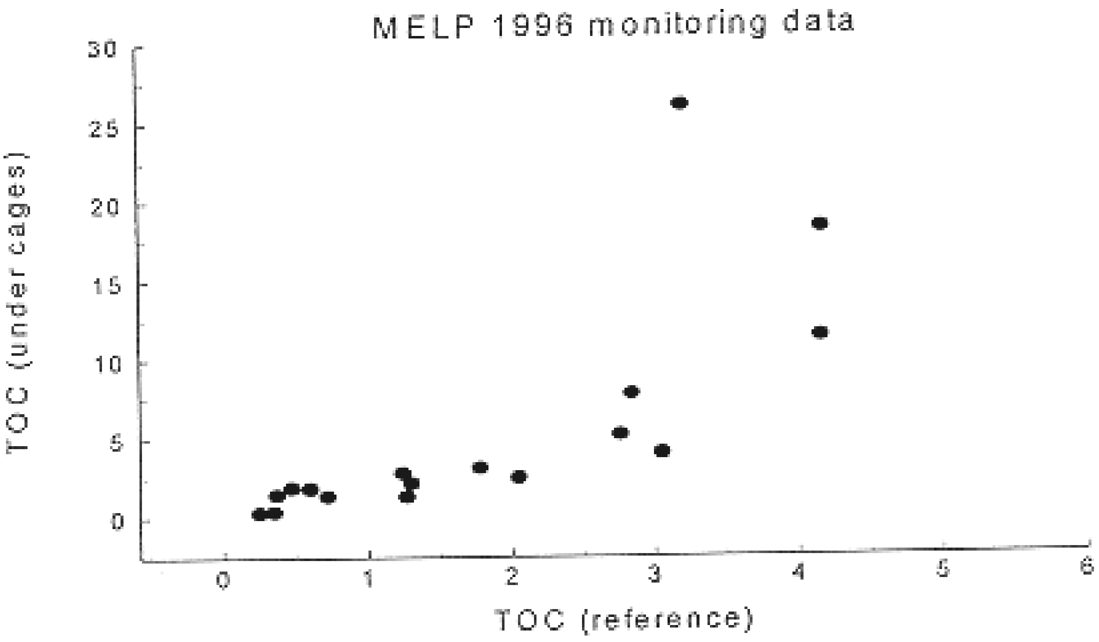
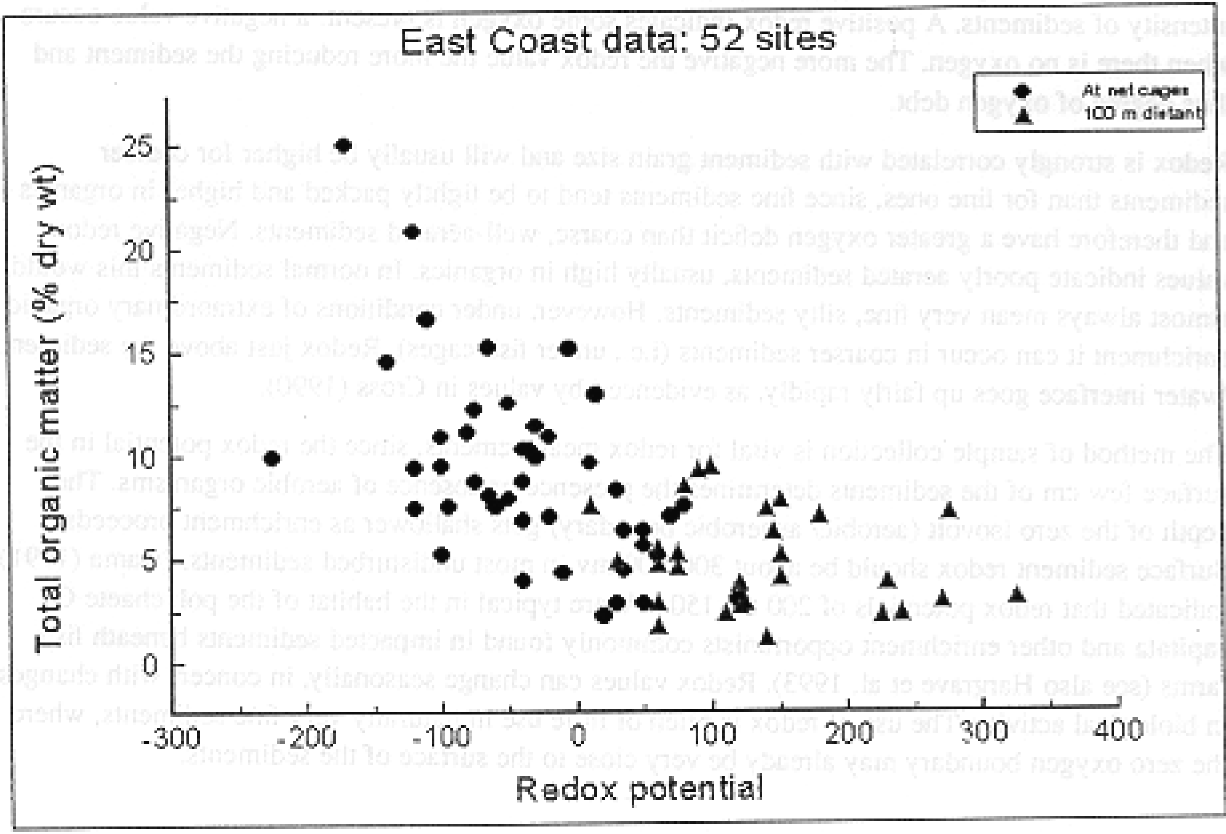


Figure 6. Redox Potentials (millivolts) for Sediments at the Perimeter of Net-Cages (circles) Versus Sediments 100 m Distant (triangles).



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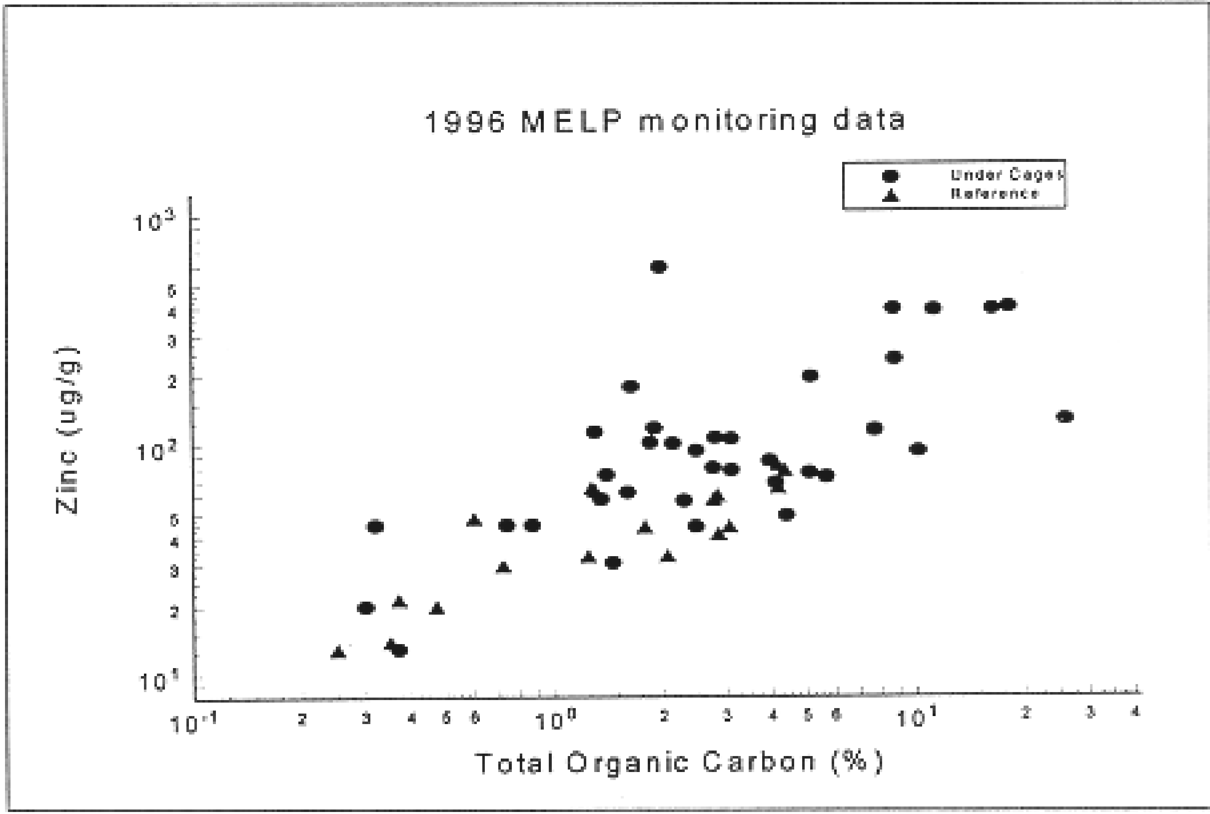
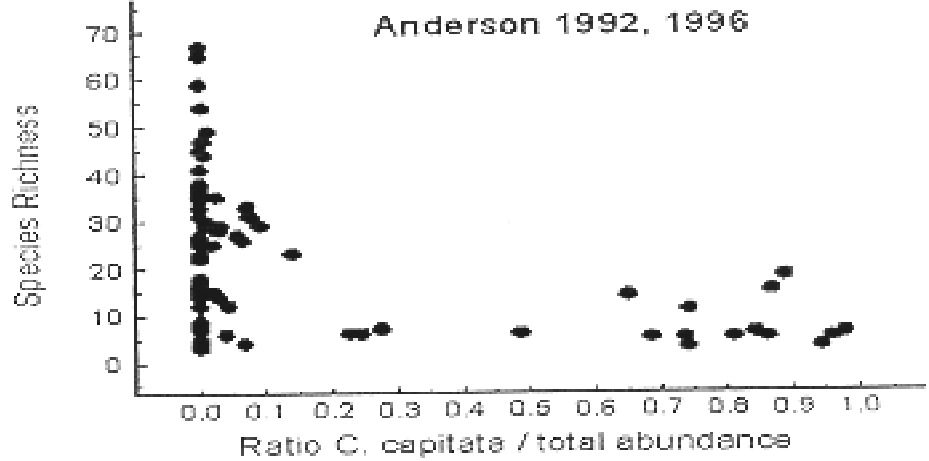
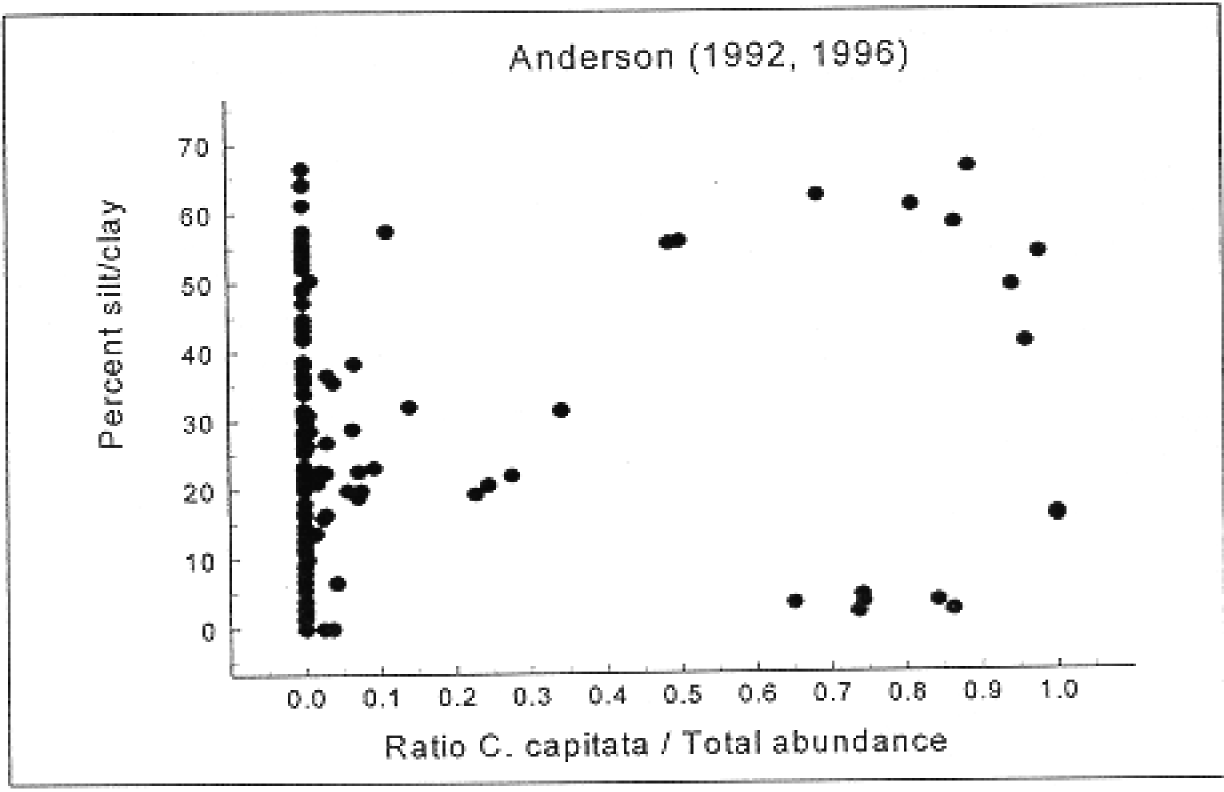


Figure 8. Ratio of Abundance of C. capitata to Total Faunal Abundance, Versus Species Richness for 1991.



Source: Anderson, 1992

Figures 9,10. Ratio of C. Capitata/Total Abundance Versus Sediment Characters.



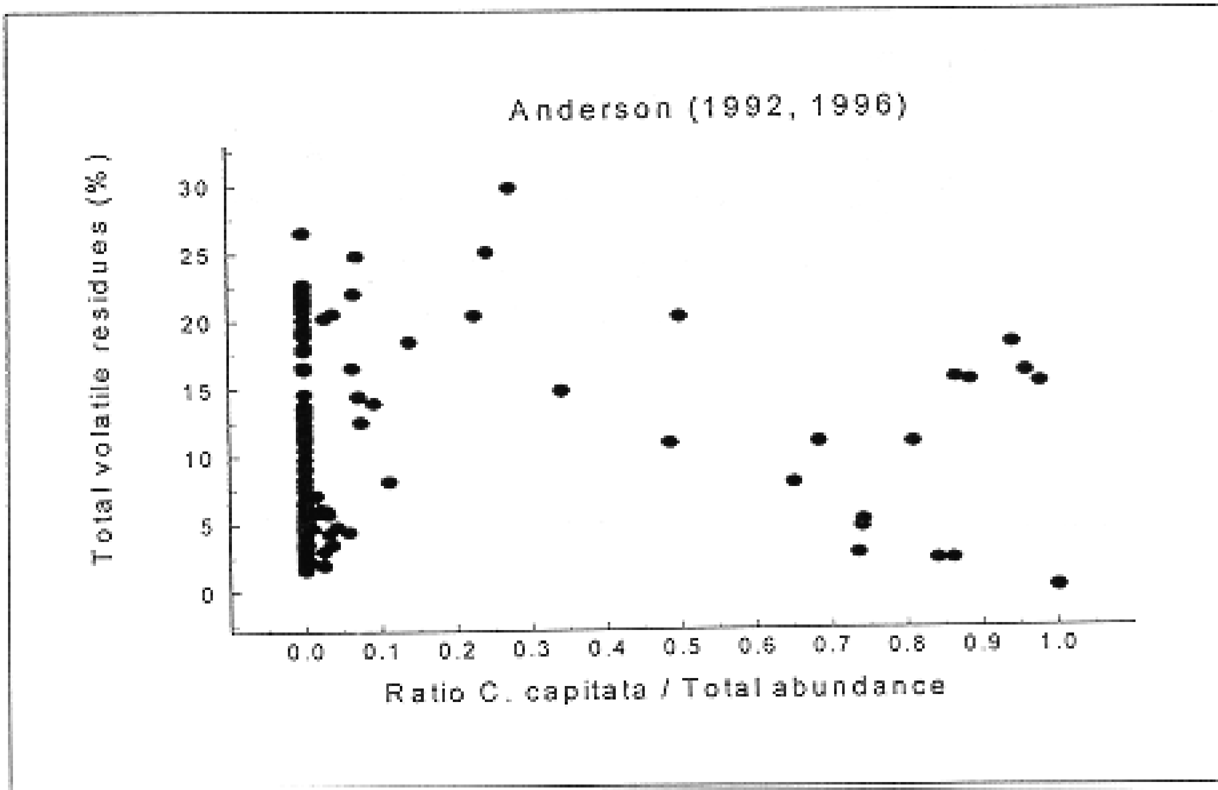
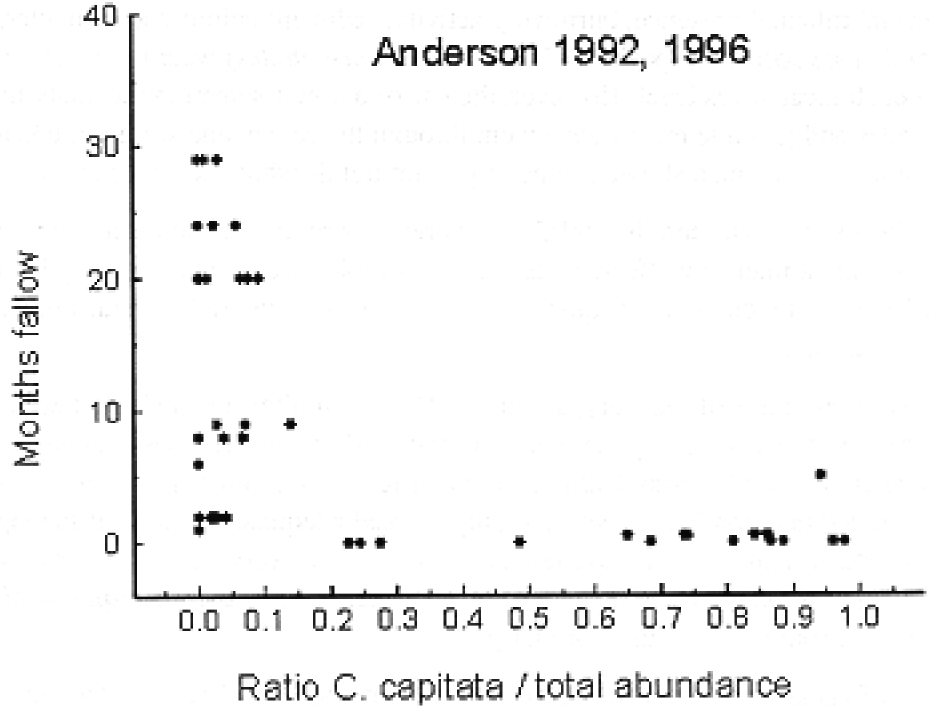


Figure 11. Ratio of C. capitata to Total Abundance Related to Fallowed Time from Previous Salmon Farms in B.C.



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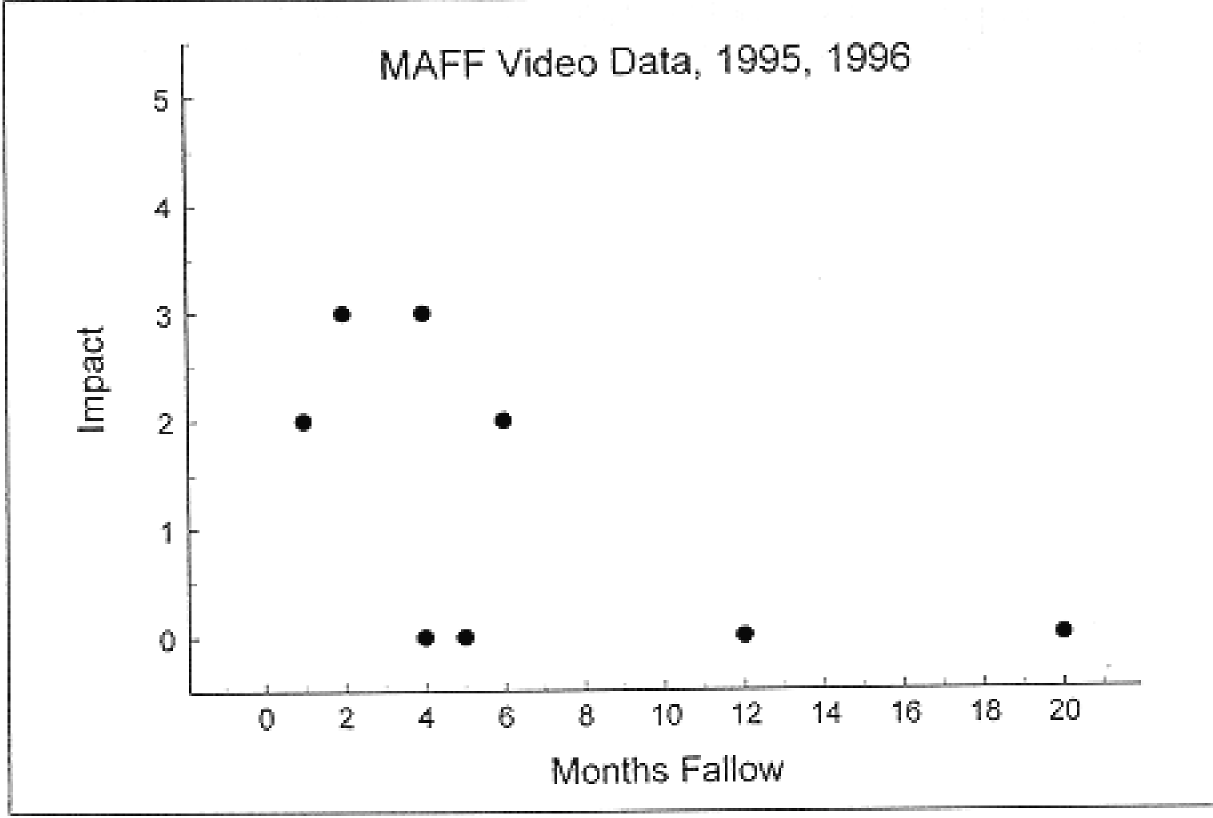

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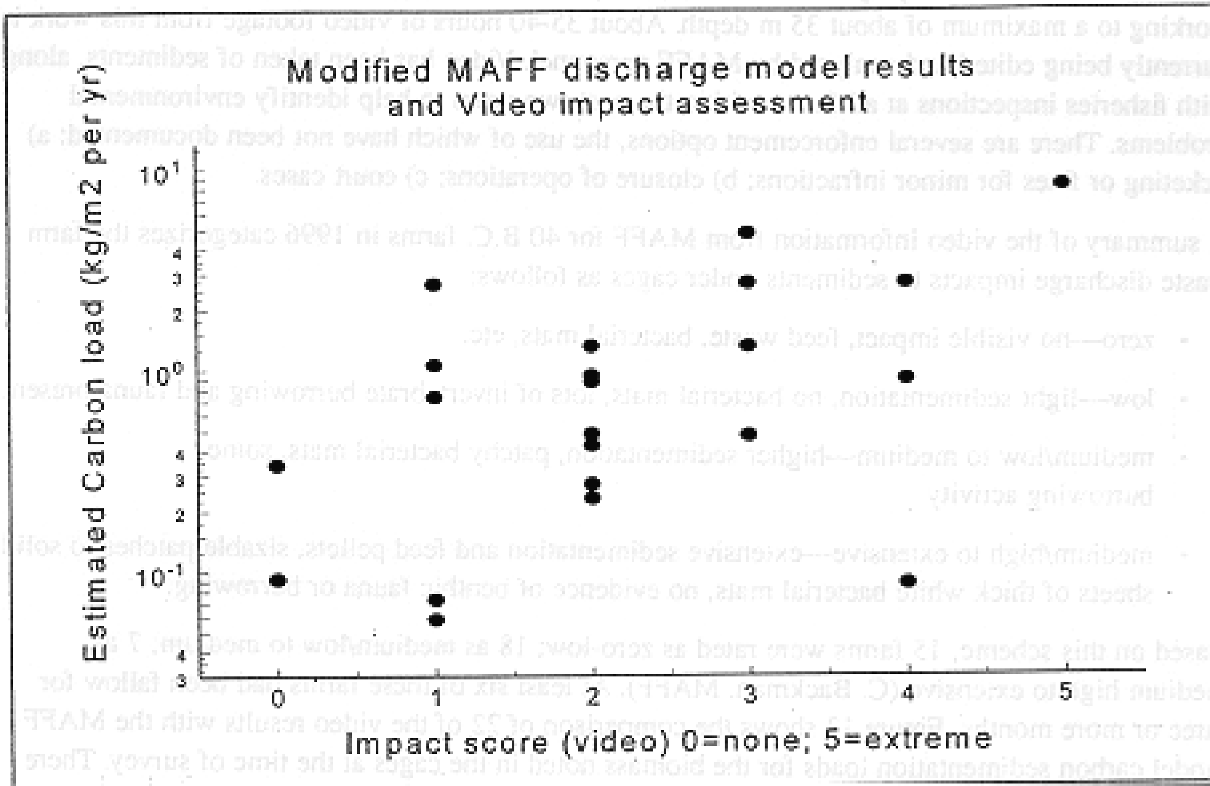

SALMON AQUACULTURE REVIEW

AQUATIC MAMMALS AND OTHER SPECIES

DISCUSSION PAPER

PART E

This paper was prepared on behalf of the Environmental Assessment Office by:
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EXECUTIVE SUMMARY

This is one of five discussion papers on various aspects of the commercial net-cage salmon farming industry in British Columbia. The major portion of this discussion paper describes the interaction between that industry and aquatic animals in B.C. and other areas of the world, with particular emphasis on the Broughton Archipelago. The paper also discusses the interaction between the salmon farming and commercial prawn fishing industries, as well as the potential impact on local biota of the use of night lighting on commercial salmon farms. With regards to the interaction between salmon farming and aquatic mammals, the paper emphasizes seals, river otters, sea lions and whales, and also discusses sharks, other fishes, birds and invertebrates. Animals such as seals, sea lions, river otters and sharks prey on salmon in net-cages, and salmon farmers practise a wide range of control measures in an attempt to reduce or eliminate such predation. There is evidence that some control measures, such as Acoustic Deterrent Devices (ADDs) have an effect on whales and porpoises that do not prey ("non-target") on the farmed salmon. Further, there is some evidence and personal opinion that the locations of certain farms significantly alter the normal migration pathways of both fish and marine mammals.

Our major findings and recommendations are summarized as follows:

Major Findings

1. Effectiveness of Acoustic Deterrent Devices (ADDs): Effectiveness is variable among farm sites in B.C. and appears to diminish with time. Pinniped attacks still occur even with the use of ADDs.
2. Impacts of ADDs: The long-term impacts of high intensity signals from ADDs on marine mammals are not known; however, pinnipeds that are not deterred by ADDs may experience hearing damage at close range. Harbour porpoise avoid exposure to the ADD signal by altering their normal movement patterns.
3. Killing of Aquatic Mammals around Farm Sites: The population effect of the practice of killing mammal predators around salmon farms is not known, given current information limitations. The Department of Fisheries and Oceans (DFO) records show large numbers of individuals killed over short time intervals.
4. Other Predator Control Technologies: Improvements to and the maintenance of physical barriers between farm fish and predators should provide long-term effective means of predation control. It is important to install such systems from the beginning of farm operations, before aquatic mammals establish predatory behaviour
5. Interaction between Birds and Fish Farms: Birds prey on smaller juvenile fish, causing mortalities and potentially inducing stressed states in fish. There is little knowledge about the effects of deterrent practices at salmon net cage operations on bird populations.
6. Prawn Fishery Interactions: The interactions between commercial prawn fishing and commercial salmon net cage operations comprise specific physical conflicts (e.g., tangling of fishing lines with anchoring structures) as well as the reduction of prawn fishing areas due to the areas

occupied by salmon farms. There is no information concerning the biological interaction between salmon aquaculture and prawns.

7. Night Lights: The data from organized studies on this topic in B.C. show that fish in the net cages do not consume significant amounts of wild fish that may be attracted to the net cages by the lights at night. Further scientific study of this issue is needed.

Recommendations

1. All existing salmon farms should be required to develop and implement a "predation control plan" within two years, and incorporate approved predation control plans into the aquaculture operating licence.
2. The use of Acoustic Deterrent Devices should be phased out at all intensive fish culture operations over two years.
3. The killing of predators at farm sites should be strictly controlled.
4. Fish farms should be located at an appropriate distance from seal and sea lion haul-out sites.
5. The practice of "night lighting", should be restricted, pending the results of further research.

I. INTRODUCTION

This discussion paper presents an overview of the interactions between intensive salmon aquaculture and other animals, with an emphasis on the interaction with marine and coastal mammals. Interactions between commercial net-cage culture of salmon and other species include birds, wild fish and invertebrates. The word interaction is used to reflect the bi-directional nature of this issue. The presence and activity of intensive aquaculture can and does affect many aspects of the biological and physical environment. Conversely, many physical and biological components of the environment affect various aspects of fish production. The status of such interactions in other areas of the world is also described. One of the main causes of production losses in the B.C. salmon farming industry is predation-related losses of fish (Tillapaugh et al. 1994). Some of the measures taken by fish farmers to control predation may affect the health and normal migration patterns of aquatic mammals and possibly other species. Intensive salmon aquaculture is one of the main justifications for developing and using Acoustic Deterrent Devices (ADD), also known as Acoustic Harassment Devices (AHD), which are used to deter seals and sea lions from the vicinity of farms.

This paper describes the above interactions in as much quantifiable detail as possible, drawing first on published knowledge in the scientific literature, and then on unpublished data from public and private sources. The information used for this paper was gathered from several sources. Electronic databases (eg., BIOSIS, WAVES, ASFA) were searched with several search strategies from 1980 to the present. Internet web sites were scanned for relevant information. The bibliography on the interactions between aquaculture and the environment, commissioned by the Environmental Assessment Office (EAO), was an important source of literature leads. Within the published data, material in the peer-reviewed international journals was considered first. Review chapters and papers, as well as published proceedings of workshops and conferences, were useful in ensuring that our coverage of the knowledge base was sufficiently comprehensive, and that those sources were used as a resource for relevant literature.

Anecdotal evidence from meetings and interviews with individuals is included in the text or presented verbatim as an Appendix. Anecdotal evidence included first-hand information transmitted verbally or submitted in paper form, such as in letters, reports, and photographs. We contacted marine mammal experts in several other areas (U.S., Tasmania, U.K.) and requested information and sources of information on marine mammals and the effects of acoustic deterrents on marine mammal physiology and behaviour. We also conducted interviews with representatives of the salmon farming industry, government groups involved in the regulation of the industry, and special-interest groups. Personal meetings to hear the experiences of individuals and groups, at venues such as the Review Committee meetings, as well as the subsequent correspondence have been very valuable for this process.

This version of the discussion paper represents the development of previous drafts based on: comments received at the various meetings with First Nations Groups, Review Committee, and the public; written comments received on previous drafts from several groups and individuals (listed at the end of this paper); and personal communications with various individuals (listed at the end of this paper). Comments from other members of the Technical Advisory Team were also very valuable in the writing of this paper. The text on interactions with birds and invertebrates contains contributions by Dr. Brenda Burd.

This discussion paper first describes the animals involved in the interactions with commercial salmon net-cage culture in B.C. and the nature of those interactions. The control measures currently practised by salmon farmers are reviewed. An overview of the status of these interactions in other countries around the world is discussed to give a broader perspective on the interactions in B.C. There is a discussion of the conditions in the Broughton Archipelago, the study area designated for this review. The following issues are discussed as separate topics: a) the nature and use of Acoustic Deterrent Devices; b) interactions between commercial prawn fishing and commercial salmon farming; and c) the potential impact on local biota of using lights at night on salmon farms. Finally, our assessment of the risks of these various factors for potential impact on the environment are presented, followed by our major findings and recommendations.

II. ISSUES

Aquaculture operations generally attract both pelagic and benthic organisms. This is true for net-cages in the ocean as well as discharge points around hatcheries and pond culture systems. The nature and magnitude of the effect is very much dependent on the site characteristics. The interaction between intensive salmon aquaculture and aquatic mammals, birds, and fish is based primarily on the presence of a concentrated amount of fish, which represents food for such animals. In a 1987 survey of the salmon farming industry in B.C., Rueggeberg and Booth (1989) studied the interaction between intensive salmon aquaculture and wildlife. Over 50 % of the respondents (73 farm sites: 60% of the salmon farms and 62% of the companies in B.C.) reported interactions with river otters, seals, mink, sea lions, and great blue herons (see Table 1). In addition to this, the growth and fallout of the epifauna (fouling plants and animals that grow on the structures) also attract such animals. The excess, or uncaptured, feed also attracts the animals. The physical structures of salmon net-cages may provide shelter for some benthic animals.

Table 1. Wildlife reported interacting with salmon farms in B.C. in 1987.

Animals	Number of Net Cage Sites Affected
River Otters	**22**
Seals	19
Herons	15
Kingfishers	11
Sea Lions	6
Mink	4
Gulls	3
Diving Ducks	2
Eagles	1
Cormorants	1
Alcids	1
Unspecified	4

Source: Rueggeberg and Booth (1989).

This discussion paper addresses several issues in addition to the interaction between intensive aquaculture and aquatic mammals. There is concern in government and the public about the impact aquaculture may have on wild populations of invertebrate and finfish species, as well as about topics such as the potential interaction between commercial prawn fishing and the physical structures (e.g., anchor structures) associated with the aquaculture cages. This discussion paper also addresses the concern that the use of lights over the net cages at night to increase the feeding hours attracts invertebrates and wild fish into the cages, and that those species are being eaten by the cultured fish. Other related topics such as the potential changes in the invertebrate populations below net cages due to the fallout of excess feed and feces is covered in the discussion paper on waste discharges by Brenda Burd.

Thus, the main issues addressed in this discussion paper are:

- The interaction between commercial salmon cage culture and aquatic mammals;
- The interaction between commercial salmon cage culture and birds that prey on the cultured fish;
- Effect of commercial salmon aquaculture on commercial prawn fishing;
- Effect of commercial salmon aquaculture on wild fish populations; and
- Effect of night lighting at commercial salmon farms on wild fish populations.

III. INFORMATION REVIEW

A. AQUATIC AND COASTAL LAND MAMMALS AND BIRDS

Aquatic and Coastal Land Mammals

Harbour Seals

Harbour seals (*Phoca vitulina*) are consistently cited as being the species most frequently involved with salmon farms in B.C. In a survey conducted by van de Wetering (1989), which included responses from 61 salmon farms, 30 farms reported losses due to predation by aquatic mammals. Of these losses, seals accounted for about 43%, river otters about 41%, and sea lions and mink about 13% and 2.5% respectively. In the same survey, about 73% of the respondents experienced losses they believed were due to one individual seal, whereas those which reported losses due to two and three individuals comprised about 13% each of the respondents. Other unpublished data from the B.C. Ministry of Agriculture Fisheries and Food (BCMAFF) indicate the same trend where seals account for the majority of the interactions. In one of their surveys, 33 of the 45 salmon farms surveyed reported seal attacks (Bill Harrower, BCMAFF, 1996). Two farms reported interactions with only sea lions.

The mature harbour seal is between 1 and 1.7 m in length and weighs about 70 kg. Its diet is composed mainly of small fish in shallow waters, but as opportunity arises hake, herring, and salmon are also eaten. An adult harbour seal consumes about 1.8 to 3.2 kg of fish per day (Olesiuk and Bigg 1988). Harbour seals are non-migratory and use specific 'haul-out' sites (Tillapaugh et al. 1994). Haul-out sites can shift according to need or opportunity. The main breeding season for the harbour seal is the late summer (July and August) for the south coast and earlier (May and June) for the northern coast (Olesiuk and Bigg 1988). The harbour seal population in B.C. is estimated at over 100,000 animals (Tillapaugh et al. 1994).

River Otters

River otters (*Lutra canadensis*) are commonly sighted on salmon farms (van de Wetering 1989). The results of the survey by Tillapaugh et al. (1994) corroborate that finding. Surveys have documented the losses of farmed fish due to river otter predation (Aylard 1986; Howard 1977; Rueggeberg and Booth 1989). Rueggeberg and Booth (1989) reported that in all areas investigated except Clayoquot Sound, the loss of farmed fish due to harbour seals was greater than that due to river otters.

River otters range in size from 0.9 to 1.3 m in length and 5.0 to 13.6 kg in weight, with the males being larger than females. The diet consists mainly of fish in intertidal and subtidal regions. Like the harbour seal, they are opportunistic feeders; they will consume almost any fish species that is abundant and easily caught. Harbour seals consume a variety of small fishes in shallow water. River otters can consume any one of 18 species of marine fish (Balke 1993), as well as a variety of invertebrates, birds, salamanders, etc. The female and her offspring are the basic social unit, although they may at times congregate into multiple family units. Adult males tend to be solitary but large groups of "bachelor" males are often seen (Larsen 1983; Woolington 1984). Such congregation seems to depend on season and the availability of prey. River otters appear to have territories that can be quite large and may overlap with territories of other individuals under some circumstances. They will move within those territories according to food abundance and availability (J. Balke, pers. comm.). River otters reproduce in the spring. There have been no inventories to determine the size or distribution of river otter populations in coastal B.C.

Sea Lions

Although sea lions do not pose a major problem to most salmon farms in B.C., there are some reports of significant interactions. The two species of sea lions in B.C. both interact with salmon farms. The Northern or Steller sea lion (*Eumetopias jubatus*) are large tan-coloured animals. The males are about 3 m in length and between 500 and 1000 kg in weight. The females are about 2.4 m and between 180 and 230 kg in weight (Olesiuk and Bigg 1988). The prey consists mainly of fish such as hake, herring, pollock, dogfish, and salmon, but during the breeding season in June and July the diet consists mainly of octopus and rockfish (Olesiuk and Bigg 1988). The daily food consumption can range from about 5 to 20 kg per day per individual. The population in B.C. has been estimated at approximately 7,000 animals (Olesiuk and Bigg 1988). Steller sea lions are non-migratory but move between winter haul-out sites and summer breeding rookery sites.

The California sea lion (*Zalophus californianus*) can range from about 1.4—1.7 m (females) to 2.0—2.5 m (males) in length, and from about 70—110 kg to 20- 400 kg in weight (Olesiuk and Bigg 1988). Both sexes are dark brown in colour, but adult males have a light crest on their foreheads (Olesiuk and Bigg 1988). Their diet is similar to that of the Steller sea lion, described above. Unlike the Steller sea lion, California sea lions are migratory. Breeding occurs at rookery sites between central California and Baja California and into the Sea of Cortez (Osborne et al. 1988). Only the male adults and subadults migrate to B.C. waters to winter. They arrive in September and leave in May (Olesiuk and Bigg 1988), and are often seen in association with Steller sea lion groups. Their haul-outs and rafting areas are concentrated in the waters around the southern half of Vancouver Island. The wintering population in B.C. has been estimated to be about 3,000 (Olesiuk and Bigg 1988).

Mink

Reports of mink (*Mustela vison*) interacting with salmon farms in B.C. are minor but consistent. Adult males are about 0.5—0.7 m in length and from about 0.7 to 1.5 kg in weight, with females being slightly smaller. The dorsal surface is dark brown to black and the ventral side is lighter in colour (Cowan and Guiget 1978). Mink can prey on a wide range of animals that live in or around the water including fish, amphibians, reptiles, crustaceans, and others.

Shark

Dogfish (*Squalus acanthias*) is a shark commonly found in B.C. waters. While there have been a number of anecdotal reports of dogfish attacks on net-cages, the magnitude of this interaction is not known at this time. The fish are first attracted to mortalities in the cages, which drive them to gnaw at the bottom of the primary nets. Once the net is torn, the dogfish can then enter and feed on mortalities and attack live fish. These holes have been the cause of escape fish and provide entry points for other predators such as seals and river otters. Sharks are not listed in the surveys of Rueggeberg and Booth (1989) and van de Wetering (1989), which concentrate on mammal and bird wildlife.

There is concern that the basking shark (*Cetorhnus maximus*) population in B.C. may be negatively affected by commercial salmon net cage operations in the Clayoquot Sound area in B.C. There is one observation of a dead basking shark being taken out of a salmon net cage in Dixon Bay (Rod Sam, pers. comm.). Darling and Keogh (1994) report that the small population in that area may be the only one remaining on Vancouver Island, and possibly in B.C., and therefore warrants conservation measures.

Nature of the Interactions

Predatory aquatic mammals feed on the captive salmon being reared in the net-cages, and the salmon farmers attempt to deter the animals by a variety of ways. The losses to the salmon farm are direct mortalities that result from feeding activities by the wildlife, as well as mortalities that result from wounds experienced during such attacks. Maximum damage due to predators can mean the loss of nearly all of the fish in a net-cages. Damaged fish have reduced market value. Injury and stress make fish more susceptible to infection and disease. These are easier to document than the possible stress caused by the presence and attacks by the predators, and the effects of such stress on production and health. Two respondents in a survey of aquaculture-pinniped interactions in the northeastern U.S., reported that the outbreak of Hitra disease was observed first, and to the largest degree in pens where seal attacks occurred (Anon. 1996). Another respondent reported a 4-5% increase in disease-related mortalities in pens that experienced seal attacks. Respondents in the survey conducted in B.C. reported health problems such as myxobacterial infections from scale loss due to fish trying to escape predators, as well as vibrio and bacterial kidney disease outbreaks related to stress from seal attacks (Tillapaugh 1994). Fish health and disease issues are discussed in detail in the discussion paper on fish health.

Of the 61 B.C. farms in the 1987 survey by van de Wetering (1989), about 50% reported losses due to predation by wildlife (see Table 1). This consisted of losses of 79,180 fish from 29 farms, and the escape of 49,000 fish from three farms due to net damage. As a cost to farms, net damage is second to the lost fish. In the same survey, net damage due to seals was reported by about 20% of the respondents, whereas net damage due to river otters was reported by about 18% of the respondents. The Rueggeberg and Booth (1989) survey reported that losses to salmon farms due to predation by all wildlife in 1987 was about 105,000 fish (58,000 lost to seals; 30,600 lost to river otters). An additional 44,000 fish were reported lost due to holes made in the nets (see discussion paper on fish escapes). These data came from 73 farm sites. Extrapolating these results to the total industry, it was estimated that the total industry losses due to predation and escapes due to net damage was 147,000 and 61,600 fish, respectively. In total, this represented 1.5% of the total industry production in that year. Eight farms in the Rueggeberg and Booth (1989) survey reported equipment damage due to river otters and mink, totalling approximately $22,000.

There is evidence documenting harm to the wildlife entering farm enclosures. There are reports of both seals and river otters getting tangled in the nets (van de Wetering 1989), although this is an infrequent problem (2% of the farms surveyed by Rueggeberg and Booth 1989). The relatively small percentage of problems in B.C., compared to other areas such as Scotland (Ross 1988) seems to be due to the use of smaller mesh sizes (2-5 " compared to 6-11" in Scotland; Winsby et al. 1996).

Rueggeberg and Booth (1989) stated that the following factors affected the interaction between intensive net-cage aquaculture and wildlife:

- farm size, age, and net-cage structure;
- size and species of salmon raised;
- proximity to colonies or concentrations of wildlife;
- site management practices; and
- the size and colour of mesh used in predator nets.

One factor that can affect the frequency of interactions between commercial salmon net-cage culture and harbour seals is the changing numbers of both farms and aquatic mammals. The harbour seal population has been increasing since the mid 1960's when the population was at an all-time low of 15,000 animals as a result of bounty and commercial hunting. The population has since been recovering at a rate of 12% a year (Olesiuk and Bigg 1988). Since 1990, that rate of population increase has slowed (P. Olesiuk pers. comm.). The results of a new population census in 1996 will soon help determine whether the population is beginning to stabilize (P. Olesuik pers. comm.). However, there is little or no data available on the population changes for other aquatic mammals. The incidence of aquaculture-aquatic mammal interactions could increase with any increase in fish farm numbers. Even if the numbers of salmon farms do not increase, the population of harbour seals is increasing in B.C. Individuals have also commented to the author that there have been more seals in various areas than ever before (e.g., R. Best, 1996). Most marine mammals are reported seen in the spring (March to June, van de Wetering 1989). Other unpublished studies show that most marine mammal interactions with salmon farms occur in the fall through the early spring, with the majority of interactions occurring in the late fall and winter (Bill Harrower, BCMAFF, 1996). The summer seems to be the only season when the interactions are minimal.

Methods of Predation Control

Based on the data from the surveys of Rueggeberg and Booth (1989) and van de Wetering (1989), the methods for controlling predation on B.C. salmon net-cage aquaculture are summarized in Table 2. The wide range of control methods depends on the unique combination of the characteristics of the farm site and the nature of the problem. Again, data for dogfish are lacking because most of the major surveys omitted fish groups. Van de Wetering (1989) reported that the use of physical net barriers was the most effective control device. Tillapaugh et al. (1994) reported that most of the respondents of their survey (85%) stopped using seal bombs because they were not effective in deterrence.

Table 2. Control methods used with animals attracted to salmon farms.

Method	Seals	River Otters	Sea Lions	Mink	Aerial Birds	Diving Birds
Dog	0 | 0	0 | *	0	(*)	*	*
Noisemaker	0 | **	0	0	-	0	-
Underwater ADD▲	(*)	-	(*)	-	-	-
Seal Bomb	(*) | *	-	(*)	-	-	-
Night Watchman	0	*	0	-	0	-
Gun/scare	0 | *	0 | *	*	(*)	*	(*)
Gun/kill	*	(*)	(*)	-	0	0
Trapping	-	*	-	(*)	-	-
Electric Fence	-	* | *	-	(*)	-	-
Double Bottom Net	** | **	-	**	-	-	-
Bag Net	** | **	** | *	**	(*)	-	-
Curtain Net	(*)	(*)	(*)	-	-	(*)
Top Net Only	-	* | **	-	(*)	**	*
Top and Jump Net	-	*	-	(*)	**	-
Top Net Sewn	-	(**)	-	(**)	(**)	-
Jump Net Only	-	(*)	-	-	-	-
Strings/Wires	-	-	-	-	(*)	-

Symbols after | signify data from van de Wetering (1989) ** = highly effective; * = moderate-highly effective (>50% of the respondents); 0 = low-no effect; - not applicable; () Sample size less than 10; s "first generation" ADDs.
Source: Rueggeberg and Booth (1989) and van de Wetering (1989)

This section presents a discussion of various control measures for aquatic mammals. Physical barrier and scaring techniques are discussed first, followed by the use of lethal methods. The survey by van de Wetering (1989) showed that only a small percentage (about 10% or less of the 61 respondents) of farms in 1987 used underwater acoustic devices, seal bombs or noise makers. There is a significant local as well as global concern about the use of current models of ADDs to scare aquatic mammals away from natural concentrations of salmon, salmon enhancement facilities and salmon net-cage operations. Because of this concern, this subject is discussed under a separate section below. The following glossary, adapted from Tillapaugh et al. (1994) clarifies the terminology used in the following text.

Glossary (from Tillapaugh et al. 1994)

Mesh size	Maximum distance between two opposite corners of mesh when stretched.
Primary net	Net used primarily to hold or enclose fish. Smolt nets (eg. 3/4" mesh size) are for smaller fish, while growout nets (eg. 1.5" mesh size) are for larger fish. See Figure 1.
Double bottom	A second bottom fastened to a primary net, usually used to mitigate the effect of dogfish. These are often made from salmon seine body web. See Figure 1.
Skirt	A panel of mesh sewn below a primary net, to separate the net cage bottom from a double bottom. See Figure 1.
Buffer zone	Distance separating the primary net from the predator net or two bottoms of double bottomed net.
Double bagging	The process of enveloping one primary net with another surplus or primary net of the same dimensions (mesh sizes may differ). There is no buffer between the sides of the double bagged nets.
Predator net	Any net designed specifically to exclude predators. Mesh size and strength are usually greater than those of the primary nets.
Predator curtain net	A panel of predator net which usually surrounds more than one primary net, but which lacks a bottom panel.
Individual predator net	A predator net, complete with bottom, which encompasses a single primary net, with a buffer space between the predator and primary net, and usually equal to the width of the cage walkway.
Modular predator net	A predator net, with a bottom panel, which surrounds a portion of the net-cages (usually 4) in a larger cage system.
Full system predator net	A predator net, with a bottom panel, which surrounds a large group of nets, and usually an entire cage system. These are often constructed in sections which are sewn together in the water (in situ).
Internal weight	A weight (usually light) which holds back either a primary or predator net from within the net cage. It is generally not secured to the net it is weighting. Internal weights for primary nets are often suspended from cage railings. See Figure 2.
External weight	A weight (usually heavier than the internal weight) which holds back either a primary or predator net from outside of the net cage. It is either directly fastened to the net or connected to it by pulleys and lines. External weights are usually secured to the cage decks. See Figure 2.
Downhaul weight	A type of external weight. A heavy weight suspended from the cage system to which a net is secured by a rope, which runs from the net, through a pulley at the weight and which is secured either to the deck or rail of the cage system.

Physical Barriers and Scaring Techniques

Most salmon farms surveyed in 1988 used double-bottom nets, dogs and guns. There are, however, wide variations in the reported effectiveness of particular control methods or devices among farms. For example, in the survey by van de Wetering (1989), the frequent use of dogs and gun shots to scare predators was effective in scaring away river otters but did little to scare away seals. Almost all respondents reported that dogs and gun shots did not eliminate predator problems. There was general agreement that bag nets were effective at controlling predation by seals and river otters, but that seal bombs and electric fencing were particularly effective in controlling seals and river otters, respectively (van de Wetering 1989). However, as the data in Table 2 and that of Tillapaugh et al. (1994) show, seal bombs are not always effective in deterring seals. Unpublished information from BCMAFF states that electric fences are effective on wooden cage systems, but were difficult or impossible to maintain on metal structures or the newer plastic circular cages (Bill Harrower, BCMAFF, 1996).

Figure 1—Typical salmon net-cage

Figure 2—Primary net weighting Systems

Characteristics of Predator Net Systems that Reduce Seal Predation

Tillapaugh et al. (1994) conducted an extensive survey of the salmon farm industry and reviewed in great detail many of the technical aspects of salmon net pens to determine which factors were most effective at reducing predation by harbour seals. The results of that survey are still current and relevant (B. Harrower pers. comm.). Improving physical barriers to harbour seals seems to be the most promising means of dealing with this chronic problem (see Tillapaugh et al. 1994; Reeves et al. 1996).

Common Method of Seal Attack

Seals prey on caged salmon by either biting them through the net and consuming the viscera, or by gaining access to the net pen through holes torn in the net. Such holes may be made by seals tearing the net, or by dogfish ripping the nets to feed on dead fish. One of the most common ways in which harbour seals attack fish is to manipulate the nets. The seal pushes the net downwards, creating a pocket and thus trapping a fish. It is easier to create such folds with a more flexible net. Corners in rectangular net pens can be collapsed easily around a fish. Depending on the nature of the net material, harbour seals can manipulate both the predator net and the primary or grower net simultaneously in this way in areas where the buffer zone between the predator and the primary net is insufficient. Harbour seals will also look for small openings in the predator net system, typically where the nets are attached, through which they can pass into the buffer zone itself and thereby have only one net (the primary net) to manipulate (B. Harrower pers. comm.). Reducing the flexibility of the net and increasing the angles at “corners” using octagonal pens or eliminating corners altogether by using circular pens are two factors that can greatly reduce predation (see Figure 3). The following are characteristics of predator net systems which influence the degree of success in reducing seal predation (Tillapaugh et al. 1994).

Reducing Primary and Predator Net Flexibility

The ability of harbour seals to manipulate the nets is related to net flexibility. In general, larger fish cages (30m x 30m) appear to experience less predation than smaller (12m x 12m or 15m x 15m) pens. This is simply due to the fact that the fish can stay away from the sides of the net cage where the attacks take place, and it is thought that seals cannot easily manipulate the nets into folds in large net-cages because of their size and weight. This is also true for circular pens (B. Harrower pers. comm). The type of material from which a net is made also determines flexibility. Many farms are now applying antifoulants to the nets which also reduce flexibility.

Reducing Mesh Size

Mesh size is also a significant factor in reducing predation. Smaller mesh sizes reduce the visibility of fish to a seal and make the nets more rigid. The most common mesh size of predator nets is currently a 5” mesh, which is small enough to also exclude dogfish. The rigidity and bright orange colour also help prevent entanglement of diving ducks (Tillapaugh et al. 1994). The mesh size of the primary nets can also affect predation levels. Tillapaugh et al. (1994) observed that mesh size and the incidence of predator attacks seemed to be positively related. Tillapaugh et al. (1994) note that 1.5” mesh is standard for growout but that from a predation standpoint 1.0” is preferable.

Figure 3—Three net-cage shapes showing differences in corner angles

Note: Smaller angles make it easier to trap fish in folds of the net.

Buffer Zone

The width of the buffer zone is very important to the level of predation. The objective is to create a buffer sufficiently wide so that a seal cannot push the net in against the primary net. On rectangular pen systems, buffer zones are typically the width of the walkways (three or more feet wide; B. Harrower pers. comm.) The width presumably varies somewhat with tidal flow, which would create some shifting or billowing of the nets. A new external downhaul weighting system suggested by Tillapaugh et al. (1994) helps pull the predator net away from the primary net and maintain tautness. Such new technology has additional advantages: 1) much heavier weights can be used without compromising the need to pull net pens out of the water for maintenance and repair; and 2) there would be less stress on the cage system (Tillapaugh et al. 1994; B. Harrower pers. comm.)

Pen Shape

Corners seem to be key locations of harbour seal attacks (Figure 3). Predation from the sides and bottoms of nets seems to be a more common and frequent problem in the industry and circular pens seem to be less susceptible to this type of attack. Circular pens are becoming increasingly popular (B. Harrower) because they are less expensive than the rectangular pens and a more efficient use of rearing space. They have also turned out to be effective at reducing seal predation from the sides and bottom, because their relatively large size makes them heavy and difficult for a seal to manipulate. Of course, there are no corners. However, it is more difficult to surround them with a predator net with an adequate buffer between the primary and the predator net (B. Harrower pers. comm.).

As mentioned above, there is general agreement among surveys that protective nets limit predation on net-caged salmon (Rueggeberg and Booth 1989; van de Wetering 1989; Tillapaugh et al. 1994). Rueggeberg and Booth (1989) concluded that bag nets or curtain nets, combined with double-bottomed nets, were the most effective methods for seals and sea lions as well as for diving birds, whereas surface nets such as top nets, jump nets and electric fences are most effective for river otters and mink. BCMAFF current recommendations (Bill Harrower, BCMAFF, 1996) are as follows: Full system predator nets are more effective than bag nets where systems consist of adjoining cages. Such full system predator nets should be installed at start-up. They should be externally weighted and tied back to anchor can-buoys to maintain adequate buffer space. They must be lashed to the walkways in such a manner that there are no gaps between the upper edges of the net and the walkways. Net strips should also be hung from hand rails to walkways to prevent access to the walkways. Individual bag nets are useful where cages are separated (e.g., circular cages). Larger net-cages are less likely to be successfully attacked than smaller ones. Primary nets should not be changed to larger sizes until herring appear in the vicinity, because as an alternative food source, their presence may reduce seal attacks on the farmed fish. As fouling on nets makes it more difficult for seals to manipulate the nets, it may be useful to allow some fouling in the winter. All primary nets should be externally weighted with large weights suspended by downhauls from the walkways. Double bottoms should be separated from the bottoms of primary nets by skirts and weights.

Killing of Predators

DFO records document the numbers of marine mammals killed each year (Table 3). DFO records for reported kills under the authority of the issued permits, by quarter, show that about 100-200 animals were killed each quarter in recent years, and that the killings are highest in the October-December quarter. It is clear from those records that some sites have particularly high killing rates. Eliminating persistent predators by killing them is a last resort in almost all cases. Killing or trapping animals and relocating them generally are not effective deterrent measures in most cases since those animals are often replaced by others of the same species. There are always exceptions, and some farms find trapping and relocating mink particularly an effective control measure (Rueggeberg and Booth 1989).

Table 3. Pinniped kills by species, 1989—96

Year	# of Active		PREDATOR KILLS	Licences
	Harbour Seals	California Sea Lions	Stellar Sea Lions	
1989	**2**	**3**	**0**	**0**
1990	60	790	6	5
1991	66	502	7	5
1992	65	431	7	9
1993	64	380	13	7
1994	71	528	4	8
1995	79	589	25	14
1996*	82	475	36	10

**preliminary estimate only—1996 data collection and analysis is incomplete.*

Source: Department of Fisheries and Oceans (DFO). Attachment to letter from R.M.J. Ginetz, Regional Aquaculture Coordinator, DFO to Daphne Stancil, Project Director, Salmon Aquaculture Review dated February 14, 1997.

Table 4 summarizes results from the survey of Rueggeberg and Booth (1989) concerning the use of guns for controlling predation on farms. Tillapaugh et al. (1994) found that at a majority (79%) of the farms, persistent seals had to be killed at some time. Certain animals are protected by provincial and federal laws. Seals and sea lions are protected under the federal Fisheries Act and can be killed legally only under licence under that Act; all B.C. salmon farms possess such valid licences (Winsby et al. 1996). Fish farmers also must have a licence from DFO to kill seals. In 1994, 80 such licences were issued. More than 450 animals were killed that year (P. Olesiuk; pers. comm.). Farmers who are issued such licences must have valid firearms licences, demonstrate that non-lethal methods were ineffective, submit reports of the kills, and at least try to recover the animal for research. Mink and river otter are protected by the British Columbia Wildlife Act and most birds are protected under the federal Migratory Bird Convention Act. All birds are protected under the B.C. Wildlife Act (1982).

Appropriate licences for each species are required to kill particular animals. As stated above, this method of control is at the extreme end of the spectrum and is used as a last resort. Aside from the loss of life, the farmers are fully aware of the public sensitivity to taking such drastic measures. Another practical problem associated with the shooting of predators is that since most predators are nocturnal, keeping watch throughout the night represents an expensive cost to the operation.

Table 4. The use of guns to control animals attracted to salmon farms

% of Respondents that:	Seals	Sea Lions	River Otters	Mink	Birds
used guns to scare	> 50 %	20 %	35 %	5 %	10-20 %
used guns to kill	~ 25 %	10 %	15 %		5 %
found the use of guns to scare an effective control measure	45 %	65 %	45 %		
found the use of guns to kill to be an effective control measure	50 %	80 %	45%		25 %

Source: Rueggeberg and Booth (1989).

Birds

The most direct effect of birds on salmon aquaculture is through predation, mainly of smolts and smaller fish. This loss can be direct, through taking fish, or indirect, through stress related to injury or presence of predators. Stressed fish tend to be more susceptible to pathogens and injured fish may be less marketable. Birds may also cause damage to nets through tearing, etc., or be a nuisance by getting into feed bags, defecating on farm structures, or becoming tangled in nets. Mortalities from such entanglements were low, although precise numbers are not available. A project aimed at assessing the effects of B.C. aquaculture industry on its marine bird populations was undertaken in three phases by Harriet Rueggeberg and Jacqueline Booth for the Canadian Wildlife Service. They published a series of four technical reports in 1988 and 1989, including phase I (literature survey), phase II (assessment of geographic overlap) and phase III (two reports—one case study on a mussel farm, one case study on a salmon farm). The phase II report includes a model of potential importance of an area to a particular bird species. Great blue herons, belted kingfishers and diving ducks were the most frequently reported species found tangled in various covering nets on salmon farms.

Price and Nickum (1995) reviewed the interaction between birds and various aquaculture sectors in Canada. In the survey by Rueggeberg and Booth (1989), the existing overlap between bird use and aquaculture was ranked as being high for goldeneye, and medium for bufflehead, scoters, cormorants, grebes, gulls, loons, mallards, mergansers and raptors. At the time of writing of the above four reports, the overlap between aquaculture and bird colonies and moulting concentrations was relatively low.

The above surveys indicate that the most common birds around salmon cage culture were the great blue heron (*Ardea herodias*), mostly found in the southern Vancouver Island area, and the belted kingfisher, especially common around fresh water (Booth and Rueggeberg 1988, 1989). The kingfishers were not considered to be a great problem around most farms surveyed, in terms of losses, and they fed mostly on the pile perch and shiners attracted to the net-cages by excess food and fouling organisms. Herons can be a problem when fish in net-cages are small. Gulls and crows are most often noted as a nuisance with respect to raiding feed bags or defecation. Similar problems occur with a variety of species at hatcheries. The direct impacts of mariculture on marine birds are the accidental drowning by fouling in net-cages and the shooting of birds by farm operators. In general, predation by birds is only a problem for smolt operations. Cormorants have also been found to be a problem at a few B.C. salmon farms (Booth and Rueggeberg 1989) and are an even bigger problem in Scotland. Cormorants and mergansers are reported as a problem to aquaculture in eastern Canada (Anderson 1986), but the control of smolt release time can mitigate the problem (Krohn et al. 1995).

Indirect effects of farm operations include the alteration of habitat and food, and the contamination of food (Vermeer and Morgan 1989). While there is some concern that contaminants in sediments and altered benthic communities could indirectly affect marine birds dependent on these resources, no chemical contamination of sediments has been shown to occur outside the near vicinity of the net-cages (see discussion paper on waste discharges). However, the presence of enriched benthic biota and fouling shellfish can attract certain birds to salmonid aquaculture operations. For example, scoters may eat the mussels attached to net-cages and oyster trays (Rueggeberg and Booth 1989). Since Jones and Iwama (1991) have shown that shellfish in close proximity to salmon net cage operations can contain antibiotics, it is possible that birds feeding on the shellfish on the nets can ingest any contaminants in such feed. Rueggeberg and Booth (1989) note that areas classed as medium to good for salmon farming (as of January 1989) were located predominantly in the Kyuquot-Nootka Sound and Queen Charlotte Strait regions (criteria used for chinook salmon, Oncorhynchus tshawtscha). Since the optimum depth for most bottom-feeding diving bird species is 10 m or less (Booth and Rueggeberg 1989), there should be little overlap with salmon farming operations. Surf and white-winged scoters dive to greater depths, but 20 m probably encompasses all possibilities.

There is some question as to whether diseases can be transferred from farmed fish to birds and vice versa. An example in Willumsen (1989) suggests a link between gulls and the spread of the causative agent of enteric redmouth disease (ERM), Yersinia ruckeri, in salmonid operations in freshwater. The bacterium was found in the intestines of gulls frequenting fish cage and hatchery operations. Pathogens can therefore be transmitted to fish via the feces of birds. The study also suggests that it is unwise to dump dead fish and leave them unburied in open landfill sites where they are accessible to gulls. At the time of the review by Booth and Rueggeberg (1989) there were no known cases of bird-related parasite or disease transfer in temperate marine fish culture. In Europe, birds have been implicated in the transmission of three fish viruses (SVC, VHS, IPN) via feces and regurgitation of fish. Birds can also be intermediate hosts to parasites which may infect fish or humans (Price and Nickum 1995). Further discussion of disease issues are found in the discussion paper on fish health.

Methods of Control

Curtis et al. (1996) present a comprehensive review of common techniques for controlling bird-related predation around aquaculture facilities. They report that total exclusion is the only assurance of complete control over potential bird predation problems. Furthermore, they report that the use of a single technique is rarely effective and that the combination of two or more techniques in controlling bird-related predation is usually required. As in other forms of predation, proper siting and management procedures can minimize the need for costly predation control. It is least costly to design and include predation control devices or structures at the time of building rather than adding or modifying structures after a predation problem has started (see the discussion paper on siting, written by Catherine Berris). Migratory routes and areas where fish-eating birds are known to congregate should be avoided. However, it is possible that such routes or gathering areas may change depending on food availability. Increasing water depth in hatchery ponds may discourage feeding by birds. Removing or altering possible perches (e.g., fences, posts, telephone and light poles, wires, feeders, handrails, vegetation, etc.) around ponds, net-cages or other rearing structures may also reduce the potential for predation. It may help to have particularly vulnerable stocks such as small fingerlings or smolts near human activity or presence. Feeding near the surface, as opposed to feeding underwater, will encourage predation by birds; thus floating pellets may be worse than sinking pellets in this regard. Proper feed storage will help keep to a minimum the attraction of birds and other animals to the site. Examples of physical barriers for partial exclusion of birds include the use of overhead lines and wires, or perimeter fencing and wires, all of which can be electrical. Birds can be frightened away from a site by a number of techniques. Various noises such as species-specific distress calls, pyrotechnic devices (e.g., screamers, bombs, rockets, gas explosive cannons) and electronic noisemakers (intense high-pitched noise) have shown some effectiveness. However, such frightening techniques may be limited in usefulness because birds can quickly lose their fear for such techniques. Visual scare devices such as lights (e.g., flashers, revolving beacons, strobe lights), scarecrows, predator models, mirrors, streamers, presence of a vehicle, and radio-controlled planes and boats have also been used with varying degrees of success. Other scaring devices include water sprays over the rearing units and human and dog patrols. As a last resort, lethal techniques are commonly used.

For the situation in B.C., Booth and Rueggeberg (1988) report that predator nets or curtains have been most effective in discouraging bird predation. Draped nets or bags cover sides or enclose entire net-cages. A mesh size of 4-6” has been found adequate to protect stock, but may be sufficiently large to entangle and drown some diving birds particularly when they are not kept taut by weights or anchors (Booth and Rueggeberg 1989) . In the Booth and Rueggeberg (1988) survey, four or five salmon farms reported instances of herons or kingfishers trapped or tangled in top nets. Two farms reported diving birds caught in predator nets surrounding cages. Double-bottomed net-cages are also used when other predators, such as seal or dogfish, are a problem. Top nets of 4-6” mesh are also used (or wire, tape, etc.).

The survey by Booth and Rueggeberg (1988) showed that the scaring devices used in B.C. included noise makers, water sprays, scarecrows, dogs, lights and firearms. The latter requires a permit from conservation officers (separate for scaring or killing). Siting guidelines for salmon farms in B.C. include avoiding known or suspected concentrations of predator species (Caine et al. 1987). Scaring devices do not work very well, as birds become accustomed to noise and adjust their feeding times to avoid people or dogs. However, Booth and Rueggeberg (1989) indicate that dogs were quite effective in keeping birds away. The incidence of net entanglements at salmon farms at the time of the survey was much lower than that reported for the gill-net fishery in B.C. (Booth and Rueggeberg 1989).

Summary Findings of Previous Surveys

The survey of Rueggeberg and Booth (1989) made the recommendations below to minimize harmful interaction between salmon farming and wildlife. While these data are nearly 10 years old, and from a time when the distribution of farms was different than it is today (e.g., most of the respondents came from the Sechelt/Sunshine Coast area), it is our opinion that the essence of these recommendations are still relevant and important to the salmon aquaculture—wildlife interactions today.

- The location of seal and sea lion rookeries, haul-outs and wintering sites, as well as marine bird colonies or concentrations, should be considered when siting salmon farms.
- Anti-predation measures should be implemented first to prevent problems, rather than trying to correct problems that develop.
- Time and funds should be committed to monitoring and maintenance of control measures and devices in good working order.
- Good fish husbandry is complementary to good predator control (e.g., storing feed securely and regularly removing mortalities).
- Bag nets and double-bottomed nets are the most effective controls for seals and sea lions. Seal bombs and shooting are effective only if used before animals have established permanent interest in a site. Underwater acoustics may be effective, but there is a problem with habituation after two to three years (see discussion above on ADDs).
- Top nets and a combination of top and jump nets are the best controls for river otters and mink. Electric fences are also effective for these animals if properly installed and maintained.

- Top nets (maximum mesh size 3” and brightly coloured) or other similar overhead barriers such as wires (0.5—1m spacing), if kept taut and at least 1m above the surface of the water, are effective in controlling aerial bird predation.
- Underwater predator nets (mesh size smaller than 4” to prevent entanglement) are most effective in controlling slashing or predation by diving birds.

There is general agreement among surveys that protective nets limit predation on net-caged salmon. Full system predator nets are the most effective methods for seals and sea lions as well as for diving birds, whereas surface nets such as top nets, jump nets and electric fences are most effective for river otters and mink. BCMAFF recommendations (Bill Harrower, BCMAFF, 1996) are as follows:

- Full system predator nets are more effective than bag nets where systems consist of adjoining cages. Such full system predator nets should be installed at start-up. They should be externally weighted and tied back to anchor can-buoys to maintain adequate buffer space. They must be lashed to the walkways in such a manner that there are no gaps between the upper edges of the net and the walkways. Net strips should also be hung from hand rails to walkways to prevent access to the walkways.
- Individual bag nets are useful where cages are separated (e.g., circular cages).
- Larger net-cages are less likely to be successfully attacked than smaller ones.
- Primary nets should not be changed to larger sizes until herring appear in the vicinity, because as an alternative food source, their presence may reduce seal attacks on the farmed fish.
- As fouling of nets makes it more difficult for seals to manipulate the nets, it may be useful to allow some fouling in the winter.
- All primary nets should be externally weighted with large weights suspended by downhauls from the walkways.
- Double bottoms should be separated from the bottoms of primary nets by skirts and weights.

B. WILD FISH

The discussion below addresses the issue of effects on other finfish. Effects on benthos are covered in another section of this discussion paper. Furthermore, possible heath effects are discussed in the discussion paper on fish health. Finally, the impact of escaped fish on the biological community is addressed in a separate discussion paper.

There are several reports of significant interactions between wild fish populations and aquaculture in fresh water. Kilambi et al. (1978) observed an increase in the abundance and survival of largemouth bass, Micropterus salmoides, during and after the cage culture of rainbow trout, Oncorhynchus mykiss, and catfish, Ictalurus punctatus. They also noted an increase in primary production, as well as an increase in the population of the bluegill, Lepomis macrochirus, a food species for the largemouth bass. Therefore, the increase in the bass population probably had at least direct and indirect causes. Bluegill and redear sunfish, L. microloplus, have been found near catfish cage culture in a freshwater reservoir (Collins 1971). Loyacano and Smith (1975) have also found significantly more native species around the area of catfish cage-culture sites.

There are several observations of wild fish populations interactions with aquaculture in sea water. Rosenberg and Loo (1983) reported abundant cod, eel, and flatfish around mussel culture sites feeding on the cultured animals falling from the farm. Carss (1990) found that the biomass of fish around rainbow trout and Atlantic salmon cages was significantly higher than in control areas removed from aquaculture sites. Most of this increased biomass was thought to be escaped rainbow trout that stayed in the area and continued to feed on pellets. Carss (1990) also found the saithe (*Pollachius virens*) population to be up to 12 times higher around culture sites than in control sites. Unpublished data from BCMAFF observations near and under salmon net-cages in B.C. indicate an increase in populations of flatfish (*Pleuronectiformes*), perch (*Embiotocidae*) and rockfish (*Scorpaeniformes*) (Bill Harrower, BCMAFF, 1996).

C. INVERTEBRATES

Crabs and groundfish tend to be attracted to the perimeter of net-cages in low-to-moderate impact zones (no azoic sediments) by the extra feed pellets falling through the net-cages (Cross 1988, Carss 1990). It is obvious that fouling organisms such as shellfish can benefit from the extra particulate output from salmon aquaculture operations. There is a potential for the complementary use of intensive (nutrient-producing, e.g., salmon) and extensive (nutrient-requiring, e.g., shellfish) aquaculture operations (Rosenthal et al. 1988). There is evidence that shellfish growth is enhanced around salmon farms, possibly due to the increase in primary productivity (Jones and Iwama 1991; Stirling and Okumus 1995). The study by Jones and Iwama (1991) showed that antibiotics are taken up by such oysters near salmon net-cages. Maximum uptake of several antibiotics and clearance times for oysters were much faster than for salmon (30 days to undetectable versus 69-73 days for salmon). Please refer also to the discussion paper on health.

Echinoderms (e.g., sea cucumbers) as a group generally show the greatest decrease in abundance and are the first species to disappear with increasing organic enrichment of sediments under salmon net-cage operations (Mattson and Linden 1983—in Gowen et al. 1988 and see other references therein). This subject is treated in more detail in the discussion paper on waste discharges. A staff member of BCMAFF has observed geoduck (which appeared to be stressed based on responses to tactile stimuli) living in concert with white bacterial mats in Sechelt, particularly when a fairly thin flocculent anoxic layer was found overlying pre-existing sandy sediments (Baron Carswell, unpublished data).

A survey by MacLeod (1990) investigated the interactions between the salmon farming industry and the commercial shrimp and prawn fishery. The main conclusion of that study was that there was no significant interaction between these two activities. The trawling commercial fishery reported no physical interaction with salmon farms. The trap commercial fishery of prawns involves the setting of traps on long-lines at specific depths in rocky, steep and deep areas. The only concern that prawn fishermen had was current and abandoned anchoring sites used by salmon farms to anchor net-cage systems. These anchoring systems can be a long distance from the net-cage. There is the remote potential for the tangling of the long-lines with these anchoring systems. Salmon farmers felt that there was little potential for interacting with prawn fishing activities. Using one sample site as an example, it was estimated that salmon farms occupied 0.6% of the areas which were important to commercial prawn fishing (MacLeod 1990). A simple model predicted that if salmon farming activities expanded maximally to occupy all possible areas within the limits of this sample site, salmon farms would occupy 5% of the total prawn fishing area. Northern Vancouver Island areas have the highest potential for interactions between salmon farming and prawn fishing activities. In contrast to these reports of little to no interaction between the commercial prawn fisheries and aquaculture, the author (GKI) has spoken with a commercial prawn fisherman in the Broughton Archipelago who has had to cut his long lines free due to entanglement with aquaculture anchoring systems. That fisherman also has had prime prawn fishing grounds taken over by salmon net-cage sites. He also pointed out, however, that he had moved on to other prime fishing grounds, and that the net effect on his take over time was not that significant at the present time.

For a more detailed discussion of the effects that salmon farms may have on benthic communities and on water column productivity, please see the discussion paper on waste discharges by Brenda Burd.

D. OTHER ANIMALS

There are various reports of other animals being affected by salmon farming activity. For example, R. Best (1996) indicates a significant increase in the bear population around salmon farms in the Clayoquot Sound area. The authors were informed of other individual instances of bears eating unstored fish feed. In contrast, we have received anecdotal information reporting very few sightings of bears around salmon farms in the Powell River area (M. Fraker 1996). Historically, bear-related issues were more common earlier in the development of the industry when practices of feed storage may not have been as controlled as they are today. The authors could find no published reports or documentation of these interactions.

E. STATUS IN OTHER AREAS

This section deals mainly with marine mammal and aquaculture interactions.

United States

Aquaculture-pinniped interactions in the northeastern U.S. were summarized recently in a report to the U.S. National Marine Fisheries Service (Anon 1996). A seven-member task force studied various aspects of this issue, although they concentrated on the interactions with the harbour seal and the grey seal (*Halichoerus grypus*). The nature of the interaction of these species and salmon farms is basically the same as described above for B.C. After March 1995, fish farmers could no longer kill marine mammal predators to control losses. Predator problems in Washington state are similar to those in B.C. (Tillapaugh et al. 1994). Predation by sea lions are the main problem in Puget Sound. River otters are reported from salmon farms from all regions in Washington.

Scotland and Ireland

Significant interactions between seals and net-cage salmon farms do occur in the U.K. In Scotland, where salmon aquaculture-pinniped interactions are common, there has been much discussion about this topic. In 1991, there were an estimated 100,000 and 20,000 grey and harbour seals respectively; seal populations were doubling about every eight years (Tillapaugh et al. 1994). The nature of the interactions were, and may still be, very similar to those reported in Canada. Atlantic salmon have been farmed since the 1970's. In 1994 there were 119 salmon-producing companies with 262 sites (V. Taylor pers. comm.). The estimated predation losses were approximately $ 2.0 million in 1990. Predator nets with extensive use of heavy weights to maximize tautness on all nets were the most effective method of reducing seal damage. These are in common usage in Scotland. ADDs have had little to no success in controlling predation there (Tillapaugh et al. 1994). However, they appear to be used extensively as over 100 Ferranti-Thompson acoustic deterrents have been sold (V. Taylor pers. comm.). The control measures are determined by a professional code of practice (The Scottish Salmon Growers' Association Code of Practice 1990; cited by Anon. 1996). Concerning the issue of controlling predators, the Code of Practice encourages good fish husbandry (proper disposal of mortalities, proper feed storage, etc.). Although it states that new sites will not be located near seal colonies, it does not specify minimum siting distances. The Code of Practice also encourages the use of non-lethal control measures. Other than during certain closed periods, fish farmers are allowed to kill marine mammals to control predation. Permits to use lethal force during the closed seasons can also be obtained to control persistent problems.

The nature of the predator-salmon aquaculture interaction in Ireland is very similar to that in Scotland. Although interactions between aquaculture and seals were increasing in 1991, due to increasing populations of seals, this was not perceived as a large problem (Tillapaugh et al. 1994). Predator nets and tensioning, as mentioned above were the most effective methods of control, as was the use of ADDs in Ireland. Explosives such as seal bombs are not allowed in Ireland, nor are they condoned by the Irish Salmon Growers Association. As in all other cases, elimination of the predator was stated as the last resort.

Chile

In a response to a questionnaire by Anon. (1996), the National Director of Fisheries of Chile reports that pinniped attacks on aquaculture facilities are not frequent, yet describes the issue as a serious problem for the industry. The proximity to sea lion haul-outs is one of the many siting criteria considered. The southern sea lion (*Otaria flavescens*) is the main animal of concern. The attacks usually occur in groups, where one or more animals push the net up from the bottom to crowd the fish and others attack from the sides. All marine mammals are protected under the Chilean Environmental Protection Law and the General Fishery Law and Aquaculture of 1991 (Anon. 1996). However, Tillapaugh et al. (1994) report that killing sea lions was permitted and that since high-powered rifles were not allowed, shotguns were used to control predators. A combination of non-lethal control measures (predator nets, acoustic devices, boat patrols) is considered successful; predator nets are most effective. There is an extensive study underway of non-lethal deterrence/mitigation measure for Chilean salmon growers (Anon. 1996).

Eastern Canada

The aquaculture-seal interaction in eastern Canada is similar to that for the eastern U.S. described above. The salmon farming industries are geographically and to some extent commercially tied. Growers are not allowed to kill marine mammal predators. The super chill conditions (< 0 Celsius) that occur in Atlantic waters can put the fish in a stressed state during such periods in the winter. If predatory attacks occur during those periods, high mortalities can result (Tillapaugh et al. 1994). Tillapaugh et al. (1994) report that insurance companies paid out $1.4 million in claims in 1991, mostly due to seal attacks. They also cite the report of a 300mt farm losing fish valued at $300,000 due to seal attacks. In a survey of the Bay of Fundy, New Brunswick, Johnson and Woodley (1996) found 32 of 69 farm sites using ADDs.

Norway

Pinniped attacks on Norwegian fish farms are not significant. Although the shooting of seals is allowed, little is reported. Similarly, some growers use predator nets, but most consider the predation problem insignificant. Harbour seals, grey seals and harp seals are the main species that interact with Norwegian salmon farmers. There are exceptional reports, however. Tillapaugh et al. (1994) report one grower’s claim of a single attack by 40 to 50 Greenland seals. Losses due to seal predation are compensated to growers by a fund from the Ministry of Fisheries and the Norwegian Fish Farmers Association. In the middle and northern parts of Norway, significant numbers of otters (*Lutra lutra*) and American mink (*Mustela vison*) are known to prey on farmed fish.

Tasmania

The Australian fur seal (*Artocephalus pusilus doreferus*) has caused problems for Tasmanian trout and salmon farmers (Tillapaugh et al. 1994). Pemberton (1989) reports that every fish farm in southeast Tasmania has experienced a seal attack, and that “the threat is continuous on all farms”. The extent of fish loss ranges from a few fish being killed or damaged to 40% loss of the entire stock in one case (Pemberton 1989). Attacks are usually at night by single individuals that do not damage the net. Even when holes are made in the net, they are small (20 cm). There is evidence that large salmon are attacked most often, although fish of all sizes are taken. Most of the attacks occur in late winter and spring. As might be expected, farms near seal haul-outs and those close to active fishing wharves are most vulnerable to attacks. As in B.C., permits can be obtained to shoot persistent individuals, but it must be shown that non-lethal measures have been unsuccessful. Acoustic deterrent devices have not been successful. In 1989, the use of seal bombs and emetics were being tested for efficacy (Pemberton 1989). Predator nets were the most effective means of control. Bag nets that were hung three to five meters away from the primary net-cage were effective in reducing predation. Trapping and relocation were tried and found unsuccessful because persistent individuals always returned to the site. The best control measure was a perimeter net that rose high enough out of the water to prevent animals from sliding over the top. The cost of such nets was much lower than the cost of fish losses due to predation. On one farm, the net was 30m in depth and over 1km in length.

New Zealand

There is a small salmon farming industry in New Zealand. The single respondent to requests for information by Tillapaugh et al. (1994) reported minor problems with the New Zealand fur seal (*Artocephalus fosteri*). That respondent knew of other seal problems throughout New Zealand, but the problem was minor. The primary problem was the harassment of fish, which reduced feeding rates.

F. BROUGHTON ARCHIPELAGO

The Broughton Archipelago has been designated as the focus site for this environmental review. The boundaries used for this review are the same for the Coastal Resource Interests Study. Briefly, the area encompasses Aylmer Point, south along approximately 127o12' W longitude, until it intersects the 50o30' N latitude; eastward from that point until it intersects the Johnstone Strait mid-passage line; continuing along that line until south of Domville Point; and then north to the Domville Point. The area includes 31 salmon net-cage tenures, all growing Atlantic salmon. There are two commercial hatcheries producing Atlantic salmon, as well as coho (*Oncorhynchus kisutch*) and chinook salmon.

Any specific geographical location within the Broughton Archipelago has unique physical characteristics. However, no particular salmon farm is unique with regard to many aspects of net-cage salmon farming. The Archipelago has many of the properties important to the successful culture of salmonid species. Like many other locations well-suited for salmon culture, it has a rich diversity and abundance of both biological and physical natural resources. It is home to many human communities, including First Nations. As in other salmon farming areas of the world, there have been many positive, and unfortunately many negative, interactions between the activities of the salmon farming community and the environment. The development of salmon net-cage farming, and the interactions of these activities with the people that live in the Broughton Archipelago, have been documented by Morton (1996a). Specific details can be found in that report.

Interactions between salmon net-cage farming and marine mammals have been reported in Morton (1996b). That report specifically describes, the effects that the use of ADDs are believed to have had on cetaceans in the Broughton Archipelago. Over a 10-year period, Morton (1996b) used photographic and acoustic methods to monitor the cetacean populations that reside or move through this area. A permanent hydrophone installed near Echo Bay was used to monitor the presence and movements of killer whales and Pacific white-sided dolphins by detecting their vocalizations. The hydrophone was monitored approximately 330 days per year. Cetacean presence and movements were also tracked by photo-identification of individuals and groups and by systematic recording of sightings. Data from that ongoing study shows an apparent strong effect of ADDs on killer whales and baleen whales (humpback, minke and gray; see Figure 4). There appeared to be a significant reduction, to complete elimination, of sounds from resident killer whales when ADDs were turned on.

Morton (1996b) states that there has been a reduction in the occurrence of both the killer whale and baleen whale populations in the Broughton Archipelago since ADDs have been in use. Declines in numbers of sightings of baleen whales in the area coincided with the introduction of ADDs, and a brief increase in the number of sightings in 1993 coincided with a temporary deactivation of ADDs in the area. These anecdotal observations demonstrate a correlation between two events but not a cause and effect relationship, and there may be other factors associated with the occurrence of these cetaceans. Morton (1996b) has not detected any changes in Pacific white-sided dolphin behaviour or occurrence since in the introduction of ADDs. Pacific white-sided dolphins have become increasingly common in inshore waters in recent years. Morton (1996b) reports seven individuals sighted in 1984 and estimates the population to be over 1,000 now in winter months.

G. ACOUSTIC DETERRENTS ON AQUATIC MAMMALS

Sound in Water and Marine Mammals

Sound travels very efficiently over great distances in water. Consequently, hearing rather than vision is the primary sense used by marine mammals to communicate, navigate, detect prey and avoid predators. Marine mammals produce a variety of acoustic communication signals. In addition, toothed whales produce high frequency echolocation signals to locate and capture prey. All marine mammal species tested have been found to have well-developed hearing capabilities. Passive listening is also important and may be used in navigation, predator avoidance and prey detection, particularly among baleen whales which do not appear to have echolocation capabilities. Yet, even species that have highly developed echolocation capabilities seem to use passive listening to detect prey and navigate (Barrett-Lennard et al. 1996).

Acoustic Deterrent Devices

The idea of using acoustic signals to repel marine mammals was first developed in the 1970's. ADDs may be defined as : A sound-generating device which, because of some combination of intensity, frequency or other characteristic(s), is aversive to marine mammals and keeps or drives them away from an area or structure (Reeves et al. 1996). The concept takes advantage of the fact that marine mammals have well-developed and sensitive hearing and that water is an excellent medium for transmitting signals. The first generation of ADDs were developed to deter pinnipeds from fishery areas and hatcheries. The 12-17kHz signal, in the range of maximum hearing sensitivity of harbour seals and California sea lions, was intended to be unfamiliar and unpleasant to the animals. It was hoped that such an output would be enough to repel animals from key areas. However, the general success of these devices was short-lived and in most cases animals habituated and returned to feed in close proximity to the sound source within a few seasons (Mate et al. 1987; Rivinus 1987).

Harbour seals can detect sounds between 1 and 180kHz, although above 60kHZ sensitivity is poor and frequencies cannot be discriminated. Their range of maximum hearing sensitivity is between 1 and 30kHz. In this range they can detect signals between 60 and 85 dB re 1µPa (Mohl 1968). California sea lions can detect sounds between 1 and 40kHz, with maximum hearing sensitivity between 2 and 16kHz (Schusterman et al. 1972 cited in Richardson et al. 1991). Steller sea lions have not yet been tested.

ADDs were first used on fish farms in British Columbia in 1988. Fish farms require permits from the Department of Fisheries and Oceans to operate an ADD. The early units produced signals between 12 and 17kHz at an output of about 180dB re 1 µPa at 1m (Tillapaugh et al. 1994). Initial reports in 1989 suggested that farmers were finding these units to be quite effective. Five out of eight farmers surveyed reported success at deterring harbour seals. However, at the time of the survey, the ADDs had only been in use for two months (Rueggeberg and Booth 1989). A subsequent survey in 1991 found farmers reporting low success with these units. It seemed seals had habituated to the sound (Tillapaugh et al. 1994).

In the early 1990s, new, more powerful ADDs were developed. These produce signals in the range of maximum hearing sensitivity of seals and are of such power that animals do not easily habituate. At close range they potentially could cause pain or injury. Two models came into use on the B.C. coast, the Airmar dB Plus developed by Airmar Technology Corporation and other models by Ferranti-Thompson Sonar Systems. The Airmar ADD produces a signal with the energy narrowly concentrated at 10 kHz with a strong harmonic at 20kHz. The output averages 194dB re 1µPa at 1m. The Ferranti-Thompson 'seal scrammer' produces a signal at 38.4 kHz at a level of 205 dB re 1µPa at 1m (Haller and Lemon 1994). Ferranti-Thompson has developed a triggering system for their ADD so that the unit is activated by the motion created by a seal hitting the net (Ron Ginetz. 1997. DFO oral presentation at Salmon Aquaculture Review Committee Meeting in Campbell River). This triggering system has been reported to be unreliable in practice (M. Roth, pers. comm.).

About 20% of the farm sites in B.C. currently use the new ADDs. Since 1993, the Department of Fisheries and Oceans has issued permits for 17 ADDs: , 11 Airmar ADDs and 6 Ferranti-Thompson ADDs.

Effectiveness of the New Generation of ADDs

There seem to be varying degrees of effectiveness from site to site, and effectiveness appears to diminish with time. It is likely that effectiveness varies to some degree among individuals due to experience, age, sex, social status, location, weather conditions and time of year (Reeves et al. 1996). Reeves et al. (1996) report that the new ADDs are effective for up to two years. Fraker (1996) presented data on levels of fish mortalities associated with first-time ADD use at two farms in B.C. and showed short-term (eight weeks) effectiveness. At least one company has given up the use of the new ADDs, changed their pen systems to large plastic circles and found that seal predation problems have been eliminated (Fraker 1996).

Only about 20% of the farm sites on the coast currently use the new ADDs. This may in itself be an indication of the relative long-term effectiveness of these devices, although there may be other factors associated with this figure. Since 1993, the DFO has issued permits for 17 ADDs, of which 11 are for Airmar ADDs and 6 are for Ferranti-Thompson ADDs.

Prior success at attacking penned fish seems to be a factor associated with ADD effectiveness. Most studies conclude that ADDs are probably most effective if used before harbour seal attacks occur. Animals that have successfully attacked are much harder to deter than naïve animals (Mate et al. 1987; Reeves et al. 1996; Rueggeberg and Booth 1989; Tillapaugh et al. 1994). This seems to be true even for the new ADDs. Animals that have experienced success expose themselves to the intense sound and may suffer hearing damage if sufficiently motivated by previous success and hunger. The possibility of hearing loss has been noted by several authors (Mate et al. 1987) but as yet has not been tested. Of course, hearing loss in problem seals would be counterproductive since a deaf seal is even less likely to be deterred.

The likelihood that a seal will have been successful in the past depends to a large extent on the nature of the predator net system (net mesh size of both the grower and the predator net, the rigidity of the net, tautness of the nets and adequacy of the buffer zone). All these factors are discussed in detail by Tillapaugh et al. (1994).

The effectiveness of an ADD at a site might also be determined, in part, by the choices that are available to the seal. Seal attacks seem to occur primarily between October and March with December, January and February being the peak months (Tillapaugh et al. 1994). Natural prey sources are low during those months. Another factor may be the proximity of farm sites to each other. It may be an easier decision for a seal to avoid a farm site where an ADD is broadcasting if an alternative farm site is nearby. In general it is likely that seals will select prey sources where the successful capture of prey, or return, outweighs the hunting costs. Prior success by a seal, before an ADD is introduced, may also be related to those prey choice decisions.

Effects of ADD Signals on Non-target Marine Mammals

The potential harmful effects of the new high-power ADDs on non-target marine mammal species is of significant concern. Non-target marine mammals are those species that do not attack penned fish or in other ways interact negatively with fish farms. Because marine mammals, cetaceans in particular, rely extensively on sound to communicate, navigate, hunt and avoid predators, there is a very real concern that the sounds produced by ADDs and the proliferation of ADD use could interfere with these basic survival needs. The hearing of toothed whales is many times more sensitive to sounds at ADD frequencies than is that of harbour seals (approximately 20 dB more sensitive; Richardson et al. 1995). Figure 4 illustrates the movement of whales in the proximity of ADDs in the Broughton Archipelago.

Concern about the possible impact on non-target marine mammals resulting from ADD use led to a study in 1994 by the Department of Fisheries and Oceans in the Broughton Archipelago to document the response of harbour porpoise to the new, more powerful ADD (Olesiuk et al. 1995). This study is the only controlled experiment to date which documents the response of a non-target marine mammal species to an ADD. The experiment was conducted near a farm site in the Broughton Archipelago. The study was divided into three six-week sampling periods. For the first three weeks of each six-week block, the ADD was deactivated; this was followed by three weeks of ADD activation. Systematic surveys were conducted from an observation point 5m above the water. Porpoise sightings were recorded as to time and position in the study area (Figure 5). Harbour porpoise sightings declined precipitously when the ADD was activated and this effect was repeated consistently during all three sampling blocks when the ADD was activated (Figures 6 and 7). The response to the ADD by harbour porpoise extended over a distance of least 3.5km, the maximum visible range of the study area. These results were highly significant and could not be attributed to any other variables.

Figure 4—Broughton Archipelago: movement of killer whales, location of ADDs and humpback whale feeding grounds

Figure 5— Map showing a) general location of study area; b) location of the observation station and ADD installation in the Broughton Archipelago; and c) boundaries of the porpoise sighting area under normal sighting conditions (dark shaded) and ideal sighting conditions (light shaded).

Figure 6—General distribution of sightings and resightings during: a) control periods when the ADD was deactivated; and b) experimental periods when the ADD was activated.

Figure 7—Effect of the ADD on the number of harbour porpoise observed in broad scans (top) and sector scans (bottom) for each 6-week sampling period.

Richardson et al. (1991) describe four zones around an acoustic source in assessing the effects of man-made noise on marine mammals: the zone of audibility (the largest zone), where the animal might hear the noise; the zone of responsiveness, where the animal would react behaviourally or physiologically to the sound; the zone of masking, where the noise level is high enough to interfere with detection of other sounds, such as communication signals, echolocation signals, prey sounds or other natural marine sounds; and the zone of discomfort or hearing loss. Olesiuk et al. (1995) use the spherical spreading loss model to describe the attenuation of the ADD signal (Haller and Lemon 1994) and the hearing threshold of harbour porpoise of a 10kHz signal, which is about 50dB re 1µPa (Anderson 1986), to estimate that the signal would be audible but indiscernible from background noise at 50km and discernible from background noise at 20km. These give some idea of the zone of audibility. The zone of responsiveness is at least 3.5 km from the source. Using data from human studies on sound levels associated with discomfort, Olesiuk et al. (1995) estimate that the zone of discomfort would be about 475m, roughly corresponding to the 400m zone around the ADD installation in which harbour porpoise were never seen during ADD activation periods. It should be noted that the population status of the harbour porpoise in B.C. is unknown. However, based on limited information and their status in eastern Canada, Gaskin (1992) suggests the population is vulnerable.

Based on known or inferred auditory capabilities, 10kHz ADD signals would also be audible to other cetacean species found in British Columbia coastal waters (Richardson et al. 1995). Species occurring commonly in protected waters and potentially in the vicinity of fish farms with ADDs, in addition to harbour porpoise, include Pacific white-sided dolphins, Dall's porpoise, killer whales, humpback whales, minke whales and gray whales. Although the hearing of baleen whales (e.g., gray, minke and humpback whales) is likely most acute at frequencies below 5 kHz (Richardson et al. 1995), it is likely that higher frequencies at intense levels are perceived by these species as well. Observations by Lien et al. (1995) in Newfoundland indicate that humpback whales may vacate areas where ADDs are operating.

Morton (1996b) presents data from long-term acoustic and observational monitoring of cetaceans in the Broughton Archipelago which show a decline in numbers of sightings of baleen whales and killer whales in the area. These declines coincide with the introduction of ADDs in the same area. While these observations do not verify an unequivocal relationship between the two events (numbers of whale sightings and ADD use), they concur with observations by Lien et al. (1995) in Newfoundland which indicate that humpback whales may vacate areas where ADDs are operating. Pacific white-sided dolphins appear to be one species that does not display avoidance behaviour in the presence of active ADDs. This species has until recently been considered an open water species and an occasional visitor to coastal waters (Leatherwood and Reeves 1983; Osborne et al. 1988), however, sightings of Pacific white-sided dolphins are becoming increasingly common throughout coastal B.C. The reason for this shift in distribution is unclear. Morton (1996b) documented seven individuals in 1984 and estimates the population now to be over 1,000 in winter months in the Broughton Archipelago.

Fraker (1996) presented sightings by fish farm workers of harbour porpoise, Dall's porpoise, Pacific white-sided dolphins and killer whales near farm sites when ADDs were active. It is difficult to evaluate these sightings as methods of data collection and experience of the observers are not provided. Furthermore, Olesiuk et al. (1995) showed clearly that not only did significantly fewer harbour porpoise remain in the study area when the ADD was active but that those animals that did venture in stayed for significantly less time. Duration of visits during activation and deactivation periods needs to be documented, and distinguishing multiple sightings of single animals by multiple observers needs to be known before the significance of these sightings can be evaluated. Perhaps of note is the lack of observations by farm workers of baleen whales in the Broughton Archipelago near farm sites with ADDs, which agrees generally with the findings of Morton (1996b).

The extent of responses to ADD signals may vary among cetacean species as well as among age and sex classes. Some species appear more susceptible to disturbance from human industrial noise than others, either as a result of the different roles played by sound in different species, differences in hearing sensitivity, or variation in the behavioural adaptability among species (Richardson et al. 1995). Masking of acoustic communication signals may take place, and species that rely on subtle acoustic cues to navigate, detect prey and avoid predators may be most sensitive to masking. Among the odontocetes (toothed whales, dolphins and porpoises), harbour porpoises appear to be quite vulnerable to disturbance and have vacated highly industrialized waterways, such as Puget Sound, while killer whales seem to adapt to high levels of human activity and noise (Calambokidis and Baird, 1994; Ford et al. 1994). Morton (1996) observed minimal responses of Pacific white-sided dolphins to ADDs. Certain age or sex classes, such as females with calves, may be more easily disturbed than others. Disturbance responses may also vary seasonally, according to food availability or other ecological factors. Behavioural responses aside, an important aspect to consider is the long-term effect on cetaceans from chronic exposure to ADD signals (Reeves et al. 1996). Even those species that do not exhibit avoidance behaviour may experience an accelerated rate of hearing loss with age. This hypothesis should be tested through appropriate research.

Studies of pinniped response to ADDs suggest that they may eventually habituate to the sound or lose hearing sensitivity in the frequency range of the ADD signal. The harbour porpoise study was only 18 weeks long and of insufficient duration to document the long-term response or potential for habituation by harbour porpoise. However, the study was conducted between June and October of 1994 and Airmar ADDs had been in use in the Broughton Archipelago during the previous year.

Concern about the impact of ADDs on non-target marine mammals is not restricted to B.C. As a result of the Olesiuk et al. (1995) study, there is concern about the possible effects on non-target marine mammals in eastern Canada (D. Johnson pers. comm.). In the Bay of Fundy, in eastern Canada, 32 of 69 farm sites surveyed in 1996 used an ADD, and of these at least 23 were the Airmar ADD (Johnson and Woodley 1996). ADDs are also used in the eastern U.S. The Gulf of Maine Aquaculture-Pinniped Interaction Task Force (Anon. 1996) state in their report that although they have some reservations about the effects on non-target marine mammals, they believe the new ADDs are a valuable and effective tool and should be available for use by the aquaculture industry. Although ADD use is prolific in Scotland, concern about their effects is leading to recommendations for research and adequate regulations of their use (V. Taylor pers. comm.). In B.C. there is some acknowledgement that even these new ADDS are not a long-term solution for the industry (see above) and that improvements to and maintenance of physical barriers to predators (i.e., predator nets) represent long-term solutions (Tillapaugh et al. 1994).

In March 1996 a workshop was held in Seattle to consider problems and uncertainties related to the use of acoustic deterrents in the conservation and management of marine mammals (Reeves et al. 1996). Several important findings and conclusions were made:

- Because sound appears not to be particularly aversive to pinnipeds except at very high intensities, it should not be the measure of first resort, since high intensity signals impact a larger area and thus other marine mammal species.
- Possible effects of sound on non-target species should be the first concern when: a) using ADDs; b) siting farms; and c) escalating efforts to drive away recalcitrant animals.
- Research is needed on the effects of exposure to sound on the hearing abilities of marine mammals. It is also needed on the physiological and behavioural consequences of long-term, chronic exposure to sound.
- Introducing a high intensity sound into the marine environment is potentially harmful to marine mammals and other biota. The physical, psychological and ecological impacts will usually be less obvious and less easily measured than the economic benefits.

H. USE OF NIGHT LIGHTING

The photostimulation of juvenile salmonid growth has been used in intensive fish culture because it shows promise for production of higher proportions of 1+ yr smolts (Kristinsson et al. 1985, Saunders et al. 1985,1987,1994—all in Saunders 1995, Chapter 1 in Cold-water aquaculture in Atlantic Canada, ed. by Boghen, A.). Imposition of a summer photoperiod (16-20 h/d) between August and November of their first autumn results in faster growth and larger fish, thus eliminating the second year of smolt growth. This may result in earlier attainment of market size during marine grow-out.

There are some potential effects of night lighting on surrounding biota. There are reports of such lighting attracting other fish species into the nets and the attracted fish being eaten by the farm fish. Another possible effect is that the infective copepodid stages of salmon louse (*Lepedophtheirus salmonis*) are positively phototactic. Therefore, use of increased light duration at certain times could affect the infection of the salmon by sea-lice. In addition, resident zooplankton (larvae and adults) and many larval forms of benthic infauna are negatively phototactic, avoiding the surface waters during day to reduce predation pressure. If photoperiod enhancement is only used in late summer and fall, there will be fewer larval forms in the water column than in spring. The growth of certain algal forms is sensitive to photoperiod and may respond to changes in photoperiod coupled with nutrient enrichment from sea-cages. Considerations of the potential effects of such lighting on the plankton population must include the dynamics of water current and transit time of the plankton through the farm area, as well as the reproductive and population cycles of the species involved. These real and potential effects, however, would be localized in the area of the net-cages, and accurate descriptions of the magnitude and the significance of such effects on plankton populations remain to be conducted through further study.

IV. RISK ASSESSMENT

The following assessment of risk relates to the main issues addressed in this discussion paper:

Interaction between commercial salmon cage culture and aquatic mammals

Deterrents

The use of ADDs to deter marine mammals from preying on the cultured fish has a real potential to damage the hearing of the target and non-target animals. These devices are specifically designed to irritate marine mammals. While early ADDs were designed to harass or annoy, the new generation of ADDs are designed to cause physical discomfort at close range. For example, harbour porpoises, are a 'non-target' species, are acutely affected by the sound output of ADDs. Experts in the hearing of bony fishes report that species such as herring may be affected by such devices. Little is known about the nature of this impact, and further study is needed.

Killing of Predators

At the population level, one may only speculate on the potential impact of such killing. Assessment of the impact would require baseline knowledge of the population numbers by region for each species. This is not available for most of the predatory and non-predatory species discussed above. The complexity of arriving at a reasonable estimate of such potential impacts precludes their reasonable consideration in this review.

There is economic risk to the farmer in an inability to control mammalian predators. Mortalities, damage and stress result from such attacks. Animals that are stressed by attacks could have compromised growth and disease resistance.

Interaction between commercial salmon cage culture and birds that prey on the cultured fish.

There is little knowledge about the effects of deterrent practices at salmon net-cage operations on bird populations. However, as with aquatic mammals, the killing of birds as a control measure may have a significant impact on local colonies.

The risk to the salmon farming operation from this interaction is the loss of smaller-sized fish (e.g., smolts) to predation. The comments above about the potential impact of stress from birds around the net-cages also apply here.

Effect of commercial salmon aquaculture on commercial prawn fishing.

While there may be some risk of economic loss to prawn fishers, due to interference by anchoring structures of the farms with fishing lines, there is too little evidence or information to assess that risk. The little data available suggests a minor interaction and risk.

Effect of commercial salmon aquaculture on wild fish populations and of night lighting at commercial salmon farms on wild fish populations.

This discussion paper and the following comments do not address the issues of: 1) escaped farm salmon on wild fish populations; 2) fish health issues; or 3) the effect of solid and nutrient discharges from salmon farms on local fish populations; those discussions can be found in the appropriate discussion papers. There is a risk that the lighting above salmon farm net-cages attracts local invertebrate and fish populations to, as well as inside, the net-cages and that the farmed fish consume these attracted species. While the studies by BCMAFF report little ingestion of certain fish species by farmed fishes, more research is needed to clarify this risk.

V. ASSESSMENT OF CURRENT APPROACHES

The Department of Fisheries and Oceans is the regulatory agency with respect to the interactions between commercial salmon net-cage aquaculture and pinniped species addressed in this discussion paper. Permits for the use of ADDs as well as for the killing of marine mammals for the control of predation are issued by DFO. The primary enforcement agency for those permits is therefore DFO. Both DFO and BCMAFF have funded studies that have contributed to our understanding of the nature of these interactions and the effectiveness of some of the control measures.

The current practice of managing the interactions between intensive salmon aquaculture and marine mammals and other species seems inadequate in enforcing the conditions of permits and licences. There seems to be a lack of will and resources within DFO to regulate the use of ADDs. It is not clear why the number of units in use in B.C. was allowed to increase from 6 to 17. Although the Review Committee heard the testimony of DFO that these were experimental, the conditions, requirements and lack of clear consequences in violating those conditions are not clear. There seems to be a perception that DFO does not have the resources to enforce the conditions of the permits and licenses.

The Technical Advisory Team acknowledges the great demands placed on the limited and dwindling resources of DFO to carry out its mandates. It is our opinion that inadequacies in such resources, as they pertain to activities that affect the interactions of intensive salmon net-cage culture and marine mammals, should be made clear by DFO.

VI. RESEARCH RECOMMENDATIONS

All harbour seal and sea lion haulouts in at least the Broughton Archipelago and Clayoquot Sound should be surveyed and mapped to improve information for siting decisions. Surveys should be done throughout the year to document seasonal changes in the use of haulouts.

Population assessments of harbour porpoise and perhaps other cetaceans, aerial or vessel, in the Broughton and / or other areas should be conducted. Surveys should be done throughout the year to document seasonal changes in abundance.

A rigorous survey of the aquaculture industry with regard to interactions with aquatic mammals and the other species covered in this paper should be undertaken. An inventory of pen systems and predation control systems used at all sites should be conducted. There should be a quantification of the degree of predation problem at each site. From such an assessment should follow a description of any relationships between the degree of predation and the type of control measures practised.

Studies in captivity should be undertaken to better understand the dynamics of the interaction of harbour seals and salmon in net-cages. This should aid the development of possible deterrence methods and / or techniques.

VII. CONCLUSIONS

The issues addressed in this discussion paper are far-ranging and complex. First of all, this paper contains a varied range of topics. Across all of these topics, however, there is a lack of basic information concerning the most fundamental aspects of each issue. Whether it involves the physiological effects of ADDs on different marine mammal species or the effects of night lighting on the local biota, a significant amount of research is needed. Researchers, industry members and government agencies should acknowledge this and participate in a planning process that will see such research conducted and applied. We believe that in general there is a responsible concern on the part of fish farmers for all aspects of the environment. This is based not only on the principle that sustaining an optimum environment in and around the fish farm is ideal for growing conditions, but also on an understanding of the nature of persons who are typically attracted to work and live in the beautiful landscape in which the farms are located. It is difficult to point out and emphasize the negative aspects of an industry in which many strive hard to maintain high standards of practice.

The lack of published data on the topics covered by this discussion paper has made the writing of the paper difficult. A concerted effort has been made to consider unbiased and objective information first. We gave serious consideration to all of the anecdotal information, which included reports of interviews, personal interviews and discussions, and written submissions from individuals and groups. This report represents our interpretation of all of this information. We appreciate that individuals, families and communities that live around fish farms, as well as groups that are active in protecting our environment, have worked hard to bring all the present and potential environmental impacts of commercial salmon cage culture into sharp focus for the scrutiny of the Technical Advisory Team and the Review Committee. We also appreciate that the salmon farmers and members of the community that support this industry have worked equally hard to demonstrate that commercial net-cage farming of salmon is growing, and can continue to grow as an environmentally sustainable industry that contributes economically to the local, provincial and national economies. We are deeply grateful for the time and great effort that was spent by all who participated in this process. We apologize if we have misrepresented your information. We have attempted to minimize such mistakes by the process of presenting you with drafts of this paper and getting your comments and corrections prior to preparation of this final version.

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APPENDIX A

Subsection of the Local Area Information Subcommittee concerning marine mammals and other species.

BROUGHTON LOCAL INFORMATION REPORTSUBSET: FARM FISH AND OTHER SPECIES

This represents information regarding Marine Mammals and Other Species obtained through interviews by members of the Broughton Local Information Subcommittee Report.

Purpose

The purpose of this report is to provide a written record of local knowledge, observations and other unrecorded information in the Broughton study area, as a basis for supplementing the information base available to the Technical Advisory Team and Review Committee for the Salmon Aquaculture Review (SAR). This process was intended to incorporate the full scope of observations, positive and negative, regarding salmon aquaculture in the Broughton Archipelago.

Background

As part of the SAR, the Broughton Archipelago was established as a case study area for demonstrating and assessing the five key issues: potential impacts of escaped farm fish; farm and wild fish health; potential environmental impacts of fish farm waste discharges; potential interactions between fish farms and marine mammals and fish farms; and fish farm siting concerns. Moreover, the socioeconomic implications of salmon farming were to provide a context for a consideration of the key issues.

At the first Working Session, a number of Review Committee members expressed interest in ensuring that local observations and anecdotal information with regard to salmon aquaculture in the Broughton Archipelago be included in the SAR process. As the Review Committee Terms of Reference provide for the establishment of subcommittees to refine and discuss particular issues, the Environmental Assessment Office determined that such a subcommittee could be established to respond to this interest expressed by the Review Committee members. The information obtained by this subcommittee was to be compiled in a structured and systematic manner in order to ensure its usefulness to the Technical Advisory Team and Review Committee.

Methodology

The Broughton Local Information Subcommittee ("the subcommittee") was established in October, 1996. The membership was made up of members or alternates of the existing SAR Review Committee who were familiar with the study area and chaired by a representative of the Environmental Assessment Office. The subcommittee membership was:

Chris Barlow, EAOMike Berry, Village of Alert BayBruce Burrows, UFAWU

John Hajduk, Aquaculture IndustryTrevor Jones/Pat Alfred, KTFCAnne Marie Koch, Regional District of Mt. WaddingtonBill Proctor, Regional District of Mt. WaddingtonTeresa Ransome, Regional District of Mt. WaddingtonWilliam Soltau, Pacific Trollers' Association

The subcommittee developed terms of reference which outlined the specific tasks and procedures determined necessary to complete the gathering of local observational information. The methodology that was developed included: identifying local residents in the study area from whom to gather information; preparing an unbiased observational record that could be used to record the information; conducting open-houses in various local communities to provide residents with an opportunity to relate their personal observations and experiences; and consolidating this material gathered into a single document.

In order to complete these tasks, the subcommittee determined that a local coordinator was needed. This person needed to be familiar with the communities in the study area, experienced in gathering public information, and regarded as unbiased. With the help of the local coordinator, Mary Murphy, a series of four consecutive open-houses was set up in the Broughton study area:

November 17, 1996 at the Echo Bay Community HallNovember 18, 1996 at the Regional District Boardroom in Port McNeillNovember 19, 1996 at the Alert Bay Community HallNovember 20, 1996 at North Island College in Sointula

In order to ensure that members of the public were properly notified and given an opportunity to share their observations and experiences with the SAR, the open-houses were advertised in several ways, including: posters put up in local communities, a general mail-out notice in each of the four communities, messages sent to the community channels in Port McNeill and Alert Bay, verbal contact of study area residents by the local coordinator and subcommittee members.

The open-houses were kept relatively informal; people were invited to come in and ask questions about the SAR process and to relate their personal observations and experiences to the EAO representatives. Also, many people preferred to take observation records and complete them on their own, and later forwarded them to the EAO.

The EAO has been working with the KTFC to collect additional observational information from First Nations communities in the study area and will add that information to this report upon receipt.

The EAO then compiled the recorded information and categorized it into seven separate sections corresponding with the five key SAR issues, socioeconomic issues, and other issues, comments or concerns. Since many of the observation records included more than one observation, experience or concern, the individual observations were separated and categorized accordingly.

Results/Trends

There was a total of 84 original observation records. As discussed earlier, many of these had more than one observation and others indicated a concern or issue rather than a specific observation. After separating and categorizing the individual observations and removing concerns/comments, the final total was 138. Of these, 22% [31] related to escaped farm fish; 14% [19] related to fish health; 17% [23] related to fish farm waste; 23% [32] related to the relationship between farm fish and other species; 26% [36] related to fish farm siting; and, 25% [34] related to socioeconomic issues. Some of the observations related to more than one of the key issues and were categorized accordingly. As a result, the total number of records in the report [175] is somewhat higher than the total number of individual observations [138].

Individual Interviews:____

Record #006 (b)

*1. What did you observe/experience?*b. Shot seal in the water

*2. Where did you observe/experience it?*b. Dead seal—south of Viner Sound

*3. When did you observe/experience it?*b. Dead seal—September 1966

*4. If you have observed/experienced this more than once, how often and when?*b. Dead seal found just once

5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*none provided
6. *Other comments related to the observation/experience?*

Record #019 (b)

1. *What did you observe/experience?*b. dead seal in the mouth of Viner Sound
2. *Where did you observe/experience it?*b. dead Seal—Viner Sound
3. *When did you observe/experience it?*b. dead seal—September 1996
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*none provided
6. *Other comments related to the observation/experience?*

Record #021 (a & b)

1. *What did you observe/experience?*a. Saw lights on in the dark. "Pit lamping." b. Decline of prawn fishery in Burdwood

2. *Where did you observe/experience it?*a. Mainland—Fife Sound areab. Burdwood
3. *When did you observe/experience it?*a. May, 1993, one timeb. Decline since 1993. 1994—no prawns
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*a. yes (names provided)b. yes (name provided)
6. *Other comments related to the observation/experience?*Suggests a feed cost comparison between farms in this region and farther south. Believes this would indicate heavy consumption of young fry, etc. in this region.Having them anywhere near moving fry is crazy.

Record #022

1. *What did you observe/experience?*Increased biological activity around the farm (sea life). Far more sea life in and around pens than there was before them. Structures (docks, nets) supported huge amount of native sea life.
2. *Where did you observe/experience it?*Winter Harbour [Northwest Coast of Vancouver Island]—Chinook, 60 ton farm
3. *When did you observe/experience it?*1983-89
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*none provided
6. *Other comments related to the observation/experience?*

Record #023 (b)

1. *What did you observe/experience?*b. Marine mammals occasionally harassed fish but never a serious problem. Gray whales/orcas often swan by. Used predator nets.
2. *Where did you observe/experience it?*Quatsino Sea Farms—Winter Harbour [Northwest Coast of Vancouver Island]
3. *When did you observe/experience it?*1987

4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*none provided
6. *Other comments related to the observation/experience?*

Record #027

1. *What did you observe/experience?*
   have observed whales (finback and calf) feeding on herring within 100 feet of pens while seal scarers were on.
2. *Where did you observe/experience it?*

whales—Greenway Sound—north of Kingcome

3. *When did you observe/experience it?*
   whales—September 1996
4. *If you have observed/experienced this more than once, how often and when?*
   whales seen in past years as well.
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   yes (names provided)
6. *Other comments related to the observation/experience?*

Record #033 (b)

1. *What did you observe/experience?*
   b. while anchored in bay—observed that farm's lights stayed on all night—this would attract small salmonids coming from creek—concern with small fry.
2. *Where did you observe/experience it?*
   b. Meral Island (Campbell River area)
3. WHEN DID YOU OBSERVE/EXPERIENCE IT?
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   none provided
6. *Other comments related to the observation/experience?*

Record #034 (a)

1. *What did you observe/experience?*
   a. I have scuba-dived at a fish farm when cleaning fish farm pens with a pressure washer. As we washed the pens, smaller fish would be attracted to the broken mussels and algae sinking in the water. The smaller fish included small herring, salmon fry and small perch. The Atlantic salmon and Chinook salmon would have a feeding frenzy. The bottom of the pens would be littered with dead fish. Most of the fish were unattractive to the eye and some were blind and had large sores on their bodies. The camp attendants would shoot any predator: otters, mink, seals, sealions, etc. There were many holes in the nets and they were not maintained—fish could have easily escaped.
2. *Where did you observe/experience it?*
   a. I was diving for Nordly's Diving Co. and we were working for Paradise Bay Sea Farm at Conville Bay on Quadra Island and Sonora Point.
3. *When did you observe/experience it?*
   a. September 8—28, 1993
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*

a. yes (names provided)

6. *Other comments related to the observation/experience?*

   a. Before the farm would harvest the fish, they would stop feeding the fish for a period of a week. This would make the fish even more aggressive—they would eat any smaller fish that would enter the pens. The farm we worked on didn't keep very good care of the nets—they had large holes in them. The pens would be heavy with mussels and algae and almost ready to break. If pens broke the fish would escape. I saw a dead seal and a dead sea lion. The sea lion was caught in the net and drowned after feeding on the farm fish. The seal was shot.

Record #037 (a)

1. *What did you observe/experience?*

   a. Salmon farming has negatively impacted crab fishing areas—the areas around and in general vicinity of fish farms have had a steady decline in crabs

2. *Where did you observe/experience it?*

   a. Betty Cove, Retreat Pass, Sledgley Cove, Deep Cove, Carrie Bay

3. *When did you observe/experience it?*

   a. about 3 years after fish farms moved in—still bad

4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*

   a. yes (name provided)

6. *Other comments related to the observation/experience?*

when farms run generators and lights—farm fish seem to eat them—don't seem to be as many crabs

Record #040 (b)

1. *What did you observe/experience?*

   b. As a former cod fisher, I have seen the Herring Bait people shoot at predators such as seals, otter, minks, eagles, ducks, etc. that come around the herring pond. This area is on an owned trap line—the animals that are shot is the living to the trap-line person. The fish farmer people shoot all the Johnstone Strait predators too. Save these other wild animals.

2. *Where did you observe/experience it?*
3. *When did you observe/experience it?*

   b. 1992-1996

4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*

   none provided

6. *Other comments related to the observation/experience?*

Record #053 (b)

1. *What did you observe/experience?*

   b. seal scarers—were about 2 miles from farm and we put a hydrophone down to hear—surprised at how loud it was—there was no mammals around—must have an impact—what kind of destruction are they causing—horrified by this

2. **WHERE DID YOU OBSERVE/EXPERIENCE IT?**

   b. about 2 miles away from farm—one by Echo Bay

3. *When did you observe/experience it?*

   b. February of 1996

4. *If you have observed/experienced this more than once, how often and when?*

5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   none provided
6. *Other comments related to the observation/experience?*
   tourists don't want bright lights and noise—want to see marine mammals—conflict!

Record #059 (c)

1. *What did you observe/experience?*
   c. salmon grilse swim around beach right near farm—guarantee a percentage get eaten—see them around the beach near the farms all the time—I'm there before salmon fishermen are
2. *Where did you observe/experience it?*
   c. Watson Cove; Viner Sound, etc.—places having real trouble with fish farms
3. **WHEN DID YOU OBSERVE/EXPERIENCE IT?**
   c. 3 years (1993-1995)
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   none provided
6. *Other comments related to the observation/experience?*

Record #0362

1. *What did you observe/experience?*
   In 1991 and 1992—"normal" killer whale activities —no sightings of 200-300 white-sided dolphin pods for extended periods in summer and fall—normal water clarity and temperatures with typical algae blooms—unharmful to fish in 1993, 1994, 1995—unusual killer whale activities (fewer sightings)—repeated sightings of 200-300 white-sided dolphin pods for extended periods in summer and fall—unusually clear water (100 foot visibility) and colder water temperatures—extensive algae blooms—harmful to fish—disappearance of local "chum" runs not involved in fishery activities
2. *Where did you observe/experience it?*
   Broughton area—Blackney pass and Johnstone Strait
3. *When did you observe/experience it?*
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   yes (names provided)
6. *Other comments related to the observation/experience?*

It appears to me a major change in offshore currents for 3 years during the summer and fall has resulted in the introduction of unusual water conditions and marine life—possibly changing typical fish runs and whale behaviour.

Record #063 (a)

1. *What did you observe/experience?*
   a. I have observed fish farmers shooting marine mammals and birds with rifles that ricochet bullets—once near me as I was kayaking..
2. *Where did you observe/experience it?*
   a. shooting happens at virtually all fish farms sometimes killing and maiming 30 animals (or more) per day per farm. This is unacceptable, unnecessary and cruel.
3. *When did you observe/experience it?*
   a. shooting has been observed over the last four years
4. *If you have observed/experienced this more than once, how often and when?*
   a. I have observed the shootings dozens of times over the last 4 years
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   none provided
6. *Other comments related to the observation/experience?*

Record #065

1. *What did you observe/experience?*

   Wildlife sightings in the immediate area of a salmon farm:
   harbour porpoise—sightings common—often within 10 meters of system nets—usually small groups of one or two adults with one sub-adult—occasionally groups of 5-7 feeding alongside farm pens
   harbour seal—sightings common—first two years of active site use no predation on farm fish—during second two years of site seasonal predation becoming heavy at times
   river otter—sightings common—no predation problems on farm fish
   northern fur seal—rare—3 -4 sightings over a 4 years period
   steller sealion—occasional sightings of individual males or groups of 2-3
   elephant seal—1 sighting of a large male—20 m from farm sight
   orca—occasional sightings of A clan or R clan residents passing farm site—transient orcas also seen within 5 km radius of farm
   gray whale—1 in area for 3-4 days feeding on bottom of nearby bay
   northwestern crow—common on site—feed on mussels, etc. from ropes, buoys, nets...
   raven—common—usually in pairs
   gulls (various spp.)—common
   coast blacktail deer / black bear / wolf—seen occasionally on surrounding beach and upland areas
   belted kingfisher—common
   great blue heron—common
   bald eagle—common
   perch / needlefish / herring—common
   pacific loon / red-necked grebe / marbled murrelet / common murre / rhinoceros auklet—occasional—seasonally common
   dogfish—occasional
2. *Where did you observe/experience it?*

   Carrie Bay on Bonwick IslandMeade Bay on Gilford IslandWicklow Point on Broughton Island
3. *When did you observe/experience it?*

   May 1990 to June 1994—most sightings of marine mammals were written into site log for Carrie Bay salmon farm (Stolt Sea Farms); September 1996—present
4. *If you have observed/experienced this more than once, how often and when?*

   common—observed everyday or 2-3 times per weekoccasional—observed 1-2 times per month—maybe on a seasonal basis
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*

many sightings were written into farm log book—some photographic records of marine mammal sightings were taken

6. *Other comments related to the observation/experience?*

The salmon farm I had experience with showed signs of increasing species of fish and invertebrates found in an artificial reef environment. This led to the presence of those species preying on these organisms. The marine mammals were affected when an underwater acoustical device was tried to discourage seal predation. The harbour porpoise seemed more sensitive to the device than the targeted harbour seal.

Record #066 (a)

1. *What did you observe/experience?*

   a. in the past years I have observed many whales at all sites that I have worked at. Conville Point stands out in respect to it being the only site that I (and other personnel) have watched a Gray whale for about an hour and a half right by the pens.

2. *Where did you observe/experience it?*

   a. orcas have been seen at Orchard Bay in Kanish Bay and photos taken at Sondrea Point right beside the pen systems. Most of these sites have the acoustic devices operating on them daily.

3. *When did you observe/experience it?*

a. Seasonally every year except for the Gray whale which I have observed only once at Conville Point. I have experienced and observed fish life, shell fish and many herring around and in the cages that grow faster due to the feed supply.

4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*

   a. photos were taken at Sonora Point of orcas—Paradise Bay Sea Farms has these photos. I have also observed that Atlantic salmon do not eat herring as believed by people in general. I have gutted and starved fish with herring in the pens and still they don't eat them

6. *Other comments related to the observation/experience?*

Record #067

1. *What did you observe/experience?*

   a. no effects from the currently used seal scarers on killer whalesb. wild cod fishery

2. *Where did you observe/experience it?*

   a. test trial in front of site on passing killer whales—approximately 200-300 feet from system (seal scarer)b. on site and around lease sometimes so close to system the boats could have tied up and fished

3. *When did you observe/experience it?*

   a. during summer of 1994 (June—July)b. during summer/fall of 1996

4. *If you have observed/experienced this more than once, how often and when?*

   a. only tried it once for 20 minutes as pod was passingb. this fishing occurred almost daily for 3 months

5. **CAN THIS OBSERVATION/EXPERIENCE BE VERIFIED (I.E., IS THERE A PHOTOGRAPHIC OR VIDEOTAPE RECORD; NAMES AND PHONE NUMBERS OF OTHER OBSERVERS)?**

   a. none providedb. other people witnessed this: tech's, assistant manager; even GM

6. *Other comments related to the observation/experience?*

Record #070 (a)

1. *What did you observe/experience?*

   a. There is a big lease in Sargeaunt's Pass, a farm on the corner where all the fish travel by. Why, I don't know. All the fry going out of the inlet go through or by there. Its fairly narrow. When everything's underwater, you can't see it. I'm very concerned about the fry. I hear they are using lights at night (haven't seen it personally). That will attract the fry and other things that will feed on them.

We have noted a decline in Chinook—although they have come back a bit in the last couple of years. The spawners will go through no matter what, but we depend upon the feeders, those that stay in the area—those are the ones that I am concerned about.

2. *Where did you observe/experience it?*
   a. Broughton Archipelago—primary concern around Knight Inlet, Sargeaunt's Pass
3. *When did you observe/experience it?*
   a. ongoing since farms came to area. Farm in Sargeaunt's Pass (Sea Farms Canada) has been active for three years.
4. *If you have observed/experienced this more than once, how often and when?*
   ongoing
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*

have voiced concerns about location of that particular farm to Larry Johnson, Fish & Wildlife Branch, Campbell Riveryes (names provided)

6. *Other comments related to the observation/experience?*

Record #071

1. *What did you observe/experience?*
   observed lots of ducks, herons, kingfishers, bald eagles, gulls, crows, and ravensobserved all kinds of porpoises when the herring were hanging and feeding off the systemsee lots of seals all the time (every day)sea lions, pacific white-sided dolphinssaw a pair of humpback whales swim bysaw about 25-30 orcas at once all in a podsaw other orcas (5-10) while coming into camp on the Salmo 1

2. *Where did you observe/experience it?*
   while working for Paradise Bay and also now at Eden Island—working for Stoltsaw the pair of humpbacks about 200-300 yards off of the Eden Island Farmsaw a pod of orcas off of Sonora Island between Sonora and West Thurlow Islandsee seals and sea lions pretty much all around Eden and Broughton Islands
3. *When did you observe/experience it?*
   see the ducks and other birds almost every daysaw the humpbacks at the beginning of October 1996; the pod of orcas was spotted at the end of January 1996
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   yes (names provided)
6. *Other comments related to the observation/experience?*
   seeing the whales at the different times I think was one of the best wildlife experiences I have ever seen—I brag about it to my family and friends, I just wish that I would have had a camera

Record #072

1. *What did you observe/experience?*
   My experiences and observations have been a wonder to me. All forms of wildlife abound and flourish in our site areas and I love the porpoises, seals, sea lions—once a humpback whale was scratching his or her neck on an anchor chain—then quickly circled the farm and disappeared (early 1996 at Arrow Pass)—every day brings ducks, gulls, crows, ravens, herons, and eagles (in the distance)
   When we have time (which is rare) wild fish are very abundant in our immediate area (Glacier Falls, Sargeaunt's Pass, Arrow Pass)—crabs are close by and prawn in some areas—unfortunately our work schedule does not allow much free time for fishing
2. *Where did you observe/experience it?*
3. *When did you observe/experience it?*
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   I have taken many pictures (as many have) and a videotape of our site at Sargeaunt's Pass with feeding and a general overview look. People with no idea what fish farming is now have a better idea, also a very positive idea. I am very proud of what I do and where I am employed.
6. *Other comments related to the observation/experience?*
   My only fish farming experience has been with Atlantic salmon and my observation is that this species is very adaptable to being raised in a pen. Our world needs to look at new and better ways to raise food for the population and how better than to use a resource ready and available, such as fish farming offers

Record #073 (a & b)

1. *What did you observe/experience?*

   a. observed changes, particularly in Chinook runs, since fish farms were established—observed that the run of salmon in Kingcome is depleted, especially of springtime feeders, fry coming out of rivers and of wintertime feeders—net pens are in migration path—moved out of guiding in that area because the stocks are so depleted—fry must be getting eaten, thus fewer large fish years later—believe pen fish must eat them; otherwise what's happened? —no commercial fishing in that region in years—sports fishing can't take that many—run was on its way back, becoming strong—then decline occurred

   b. cetaceans (orcas) aren't going on inside of archipelago like they used to—noticed a change about 5 years ago—used to do whale watching close to Retreat—but tailed off to nothing—think that fish farms could have an effect
2. *Where did you observe/experience it?*

   a. particularly salmon coming out of Knight Inlet—there are pens on Broughton Island, Fife Sound, Retreat, Betty Soundb. Broughton Archipelago area
3. *When did you observe/experience it?*

   a. noticed change over last 10 years—stopped fishing there 3 years agob. change in whale pattern began about 5 years ago—1991
4. *If you have observed/experienced this more than once, how often and when?*

   a and b. ongoing
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*

   a. yes (names provided)b. yes (names provided)
6. *Other comments related to the observation/experience?*

Record #074 (d, e & f)

1. *What did you observe/experience?*

d. seal scarers—high decibel readings—I've done a decade of whale watching and I'm concerned—check study on harbour porpoises done by Peggy Sowden (General Delivery Port Neville)—when I was working on a fish farm, the workers went out and shot a lot of seals—one night I turned the dials on the rifle sights so they couldn't shoot straight—I felt good—for a few days, I saved some seals

   e. not just concerned with mammals—also birds—on Swanson Island toward Knight, they use a CO_2 shotgun to scare away crows—this was a winter foraging area for ducks and other birds—now they are gone—the area was wiped out

   f. possible effect on whales because of their observed feeding patterns—we started working in a new whale watching area this past year—near Port Hardy—Gray whales—there are fish farms smack on the edge of the open sea in that area—I'm very concerned about the Gray whales—haven't noticed anything yet, but they feed in very shallow water, kelp beds—I'm particularly worried about the fish farm in Shelter Bay
2. *Where did you observe/experience it?*

   d. Broughton Archipelago and coast in generale. Broughton Archipelagof. Shelter Bay area—off Port Hardy
3. *When did you observe/experience it?*

   d. throughout 1990's—rifle incident was sometime between 1989 and 1991e. observed 1990-95—didn't go there much this year f. noticed possible problem in summer of 1988
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*

   f. yes (names provided)
6. *Other comments related to the observation/experience?*

Record #076

1. *What did you observe/experience?*
   worked on fish farm and observed that the farm fish ate a lot of wild feed—like herring, shrimp, and prawns
2. **WHERE DID YOU OBSERVE/EXPERIENCE IT?**
   all over coast when working and training—including Broughton area
3. *When did you observe/experience it?*
   5-10 years ago
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   none provided
6. *Other comments related to the observation/experience?*

Record #078

1. *What did you observe/experience?*
   over the years I've observed a large variety of wildlife around the farms and think they are attracted to the reef effect—I've seen killer whales and harbour porpoise right in by the system—the harbour porpoise hang around a lot—shiner perch gather around the pens in huge schools and feed on small feed and feed dust—there are also hundreds of other forms of sea life abundant around the farms
   seals also are a problem with 50xs, but since we've started using 100xs and painted/dipped nets, they aren't as much of a problem

2. *Where did you observe/experience it?*
   I've observed this at every farm I've worked at in the 5 1/2 years I've been fish farming—I've worked at Midsummer Island, Carrie Bay, Cedar Cove, Blunden Pass, Eden Island, and Arrow Pass
3. **WHEN DID YOU OBSERVE/EXPERIENCE IT?**
   throughout my years of fish farming
4. *If you have observed/experienced this more than once, how often and when?*
   all the time
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   none provided
6. *Other comments related to the observation/experience?*

Record #079 (c)

1. *What did you observe/experience?*

c. big increase in seal population—this too could be a factor in salmon and herring declines—they may be eating them—but this population started to explode in the last 10 years—around the same time as increases in fish farms

2. *Where did you observe/experience it?*
   c. Broughton Archipelago
3. *When did you observe/experience it?*
   c. since 1986
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   c. locals can confirm it
6. *Other comments related to the observation/experience?*

Record #080

1. *What did you observe/experience?*
   a. did an autopsy on a steller sea lion female killed by fish farmers at Carrie Bay because it was "attacking" their Atlantic salmon—stomach contents contained only herring (fresh)—there was not a piece of salmon flesh—photos available—steller sea lions are a protected species and fish farmers are not allowed to kill them if they are not attacking their fish—the bay was full of herring and that was what the sea lion was eating
2. *Where did you observe/experience it?*
   a. on the beach at Carrie Bay
3. **WHEN DID YOU OBSERVE/EXPERIENCE IT?**
   a. April 1993
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   a. yes (name provided)
6. *Other comments related to the observation/experience?*

Record #081

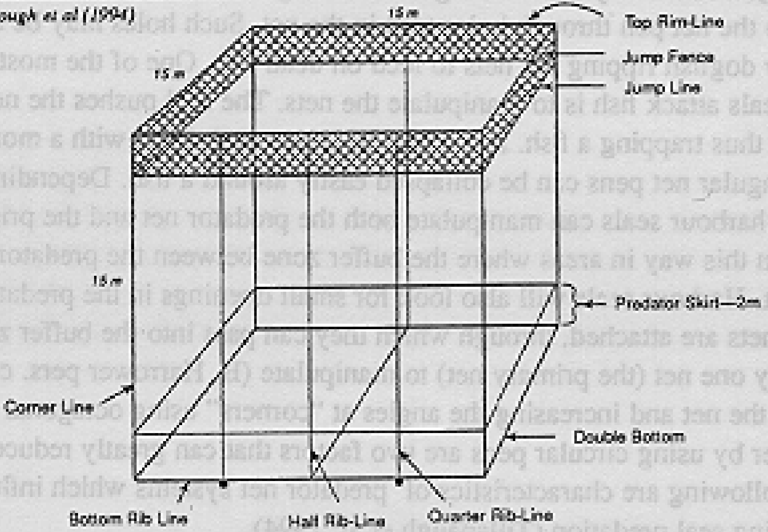
1. *What did you observe/experience?*
   harassment of whales by fish farmers in boats (presumably to take photos)watched farmers from BC Packers Greenway Sound site charge up to A30 pod of killer whales repeatedly causing whales to dive and change course
   received video taken by people from that farm severely harassing resting humpback whaleit is a violation of the federal fisheries act to harass whales

2. *Where did you observe/experience it?*
   Greenway Sound
3. *When did you observe/experience it?*
   July 1993
4. **IF YOU HAVE OBSERVED/EXPERIENCED THIS MORE THAN ONCE, HOW OFTEN AND WHEN?**
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   yes, videotape available (not provided)
6. *Other comments related to the observation/experience?*

Record #084

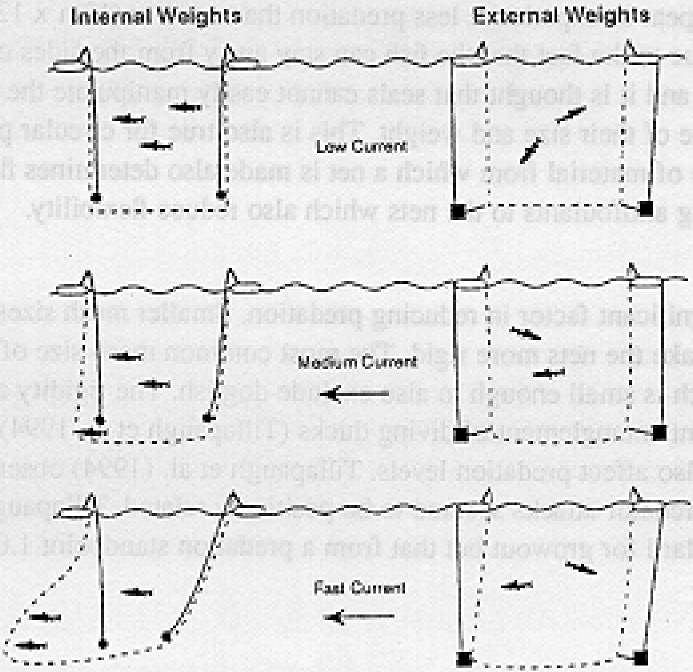
1. *What did you observe/experience?*
   dead and wounded gulls floating around fish farm in Simoom Sound—picked up one that was struggling and kept it alive for several days before it died on Christmas—birds were all wounded with shot
2. *Where did you observe/experience it?*
   Simoom Sound
3. *When did you observe/experience it?*
   Christmas time 1993
4. *If you have observed/experienced this more than once, how often and when?*
5. *Can this observation/experience be verified (i.e., is there a photographic or videotape record; names and phone numbers of other observers)?*
   yes, photos are available (not provided)
6. **OTHER COMMENTS RELATED TO THE OBSERVATION/EXPERIENCE?**

Figure 1—Typical salmon net-cage



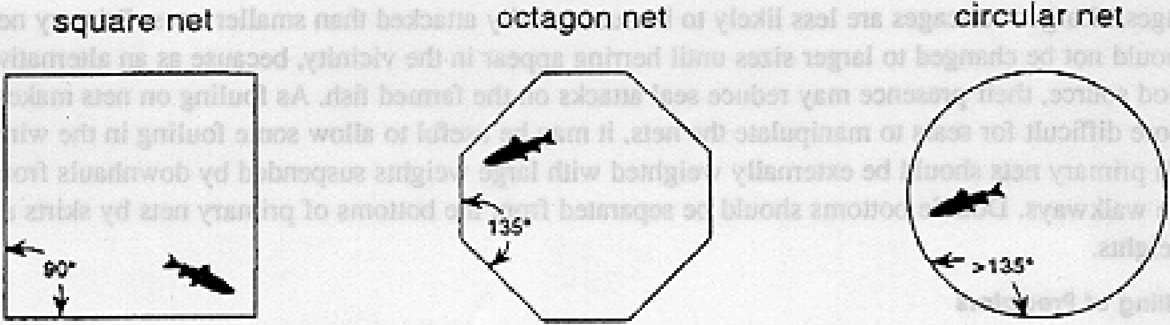
Source: Redrawn from Tillapough et al (1994)

Figure 2—Primary net weighting systems

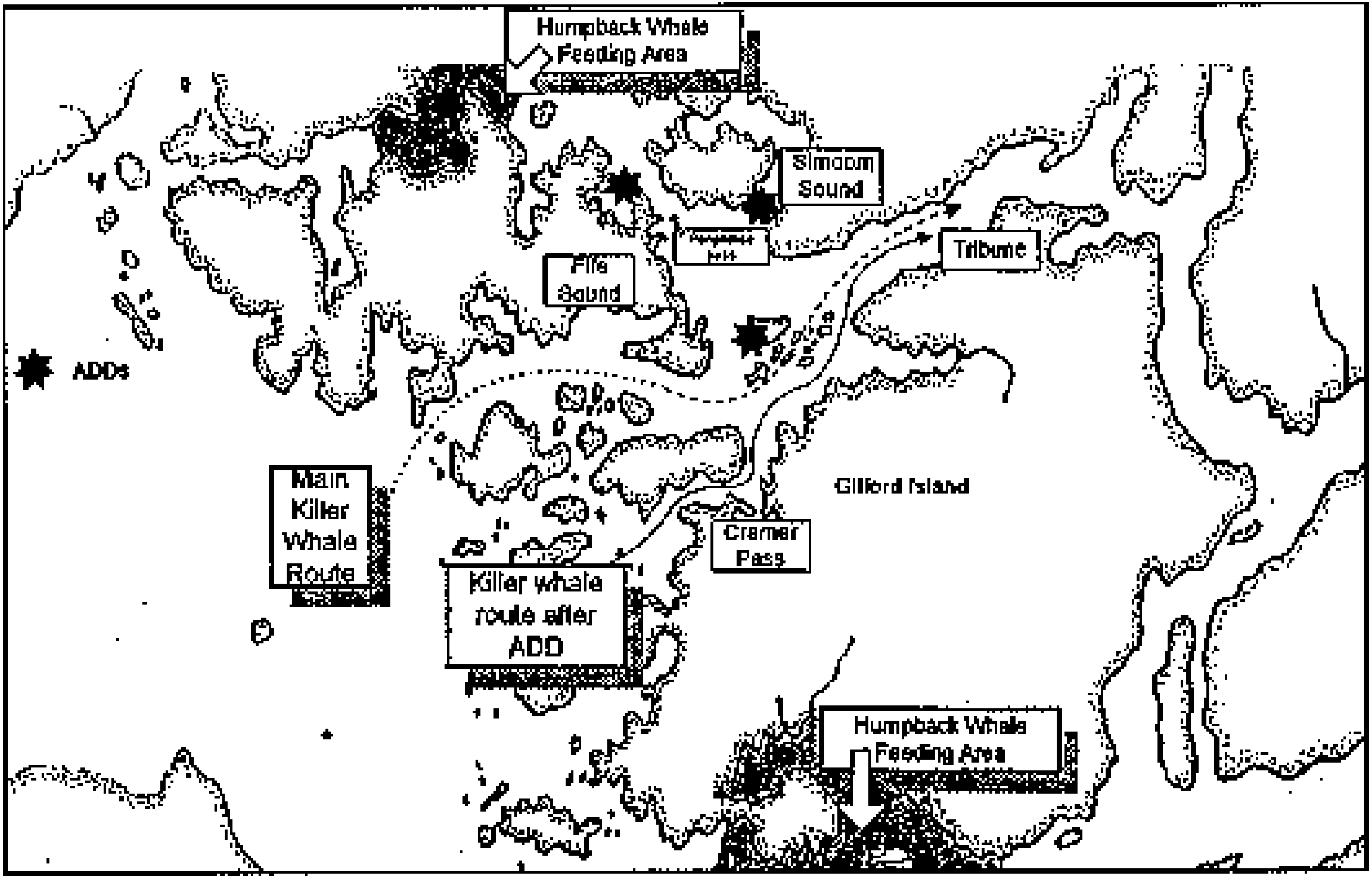


Source: Redrawn from Tillapough et al (1994)

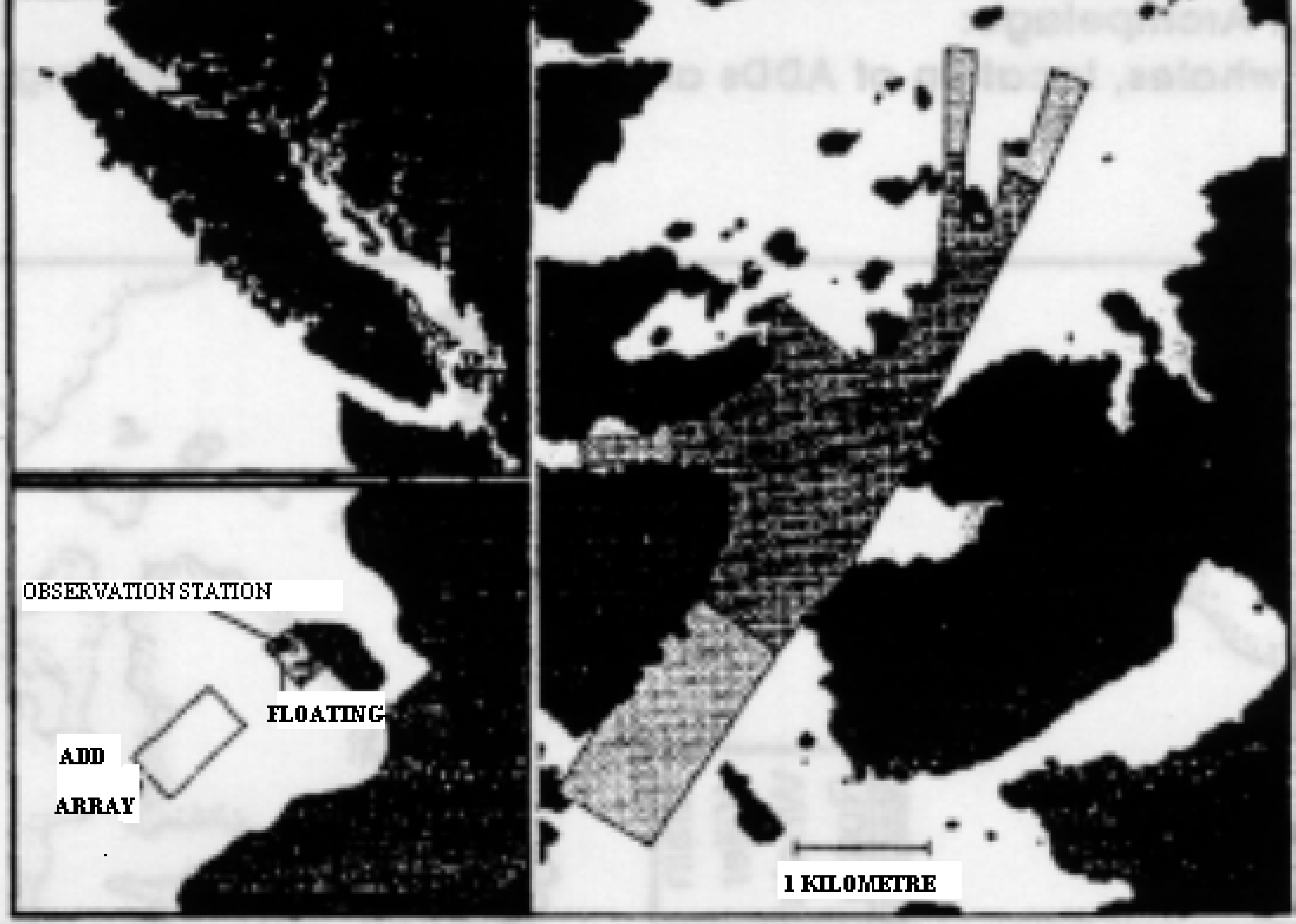
Figure 3—Three net-cage shapes showing differences in corner angles

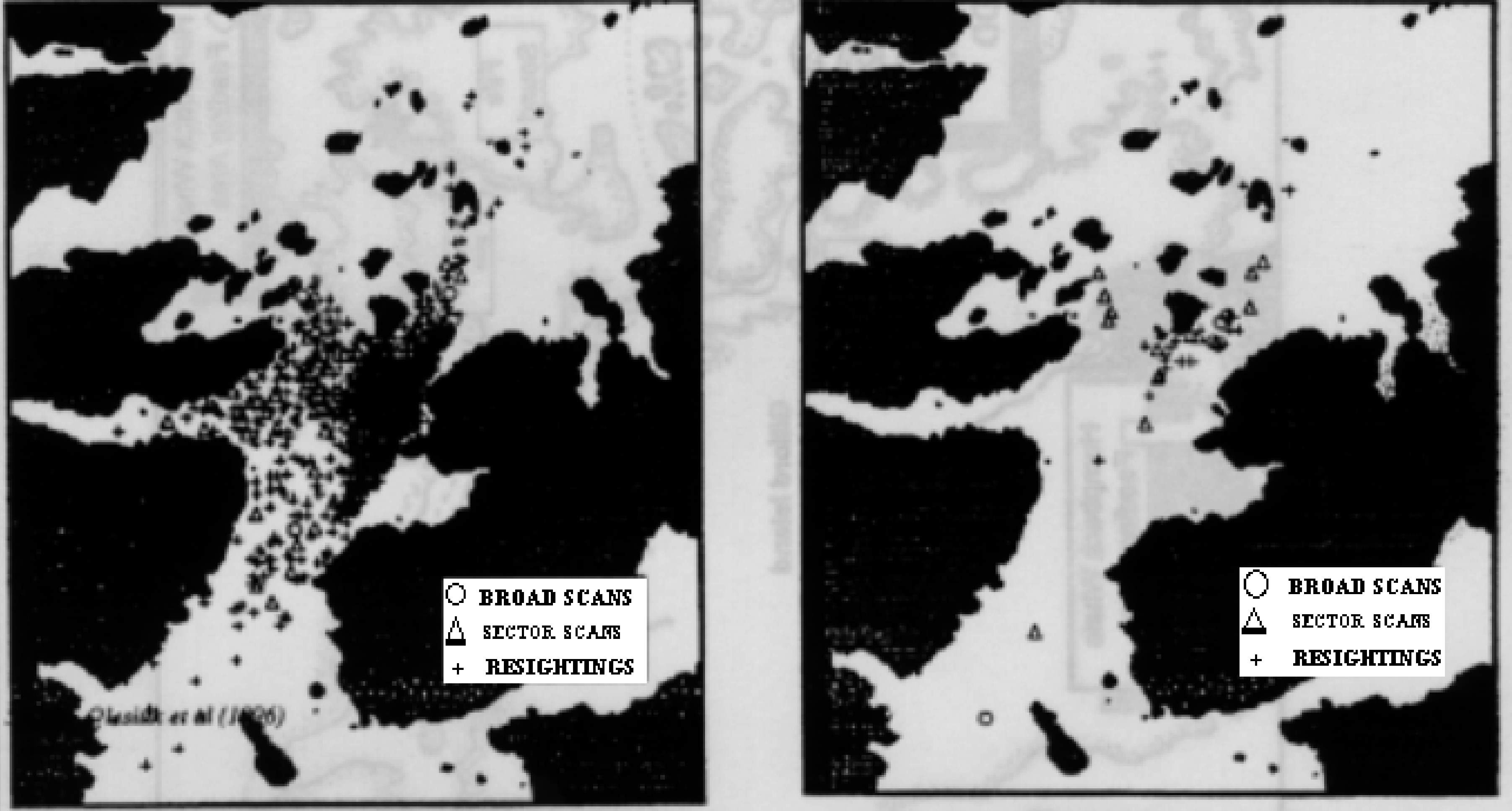


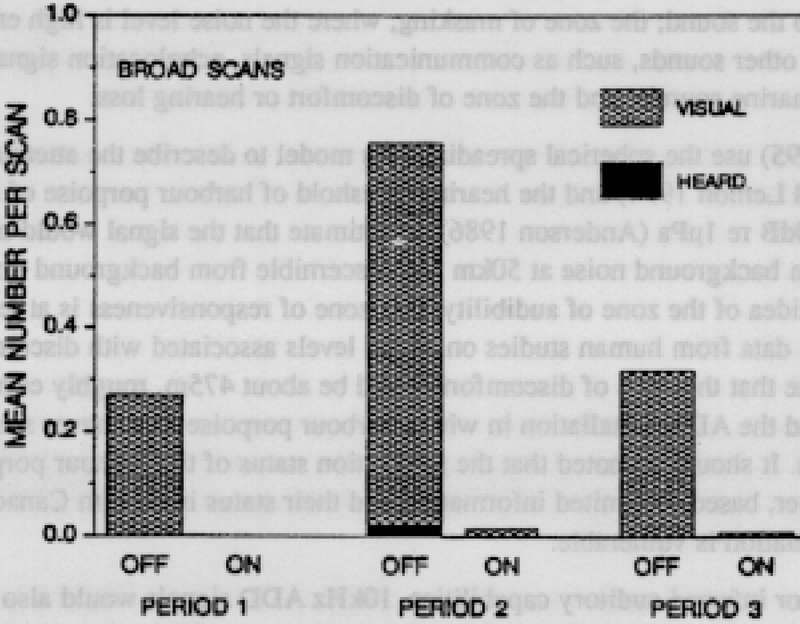
Source: Redrawn from Tillapough et al (1994)

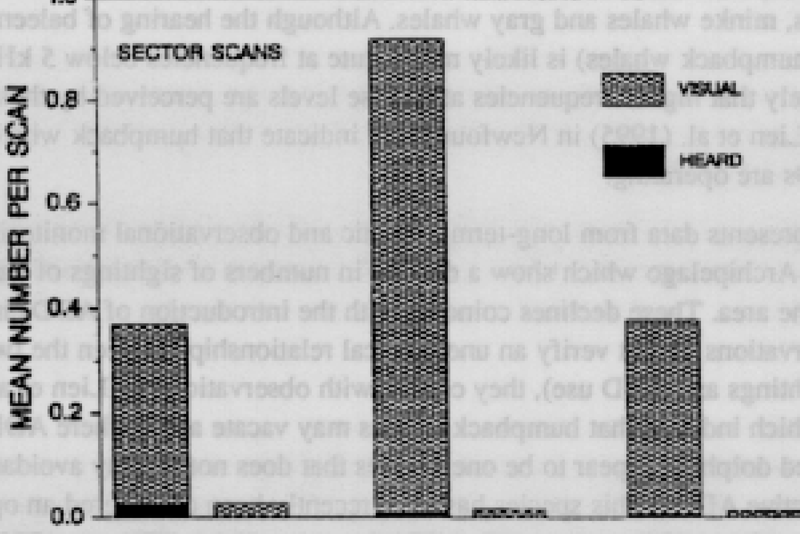


Source: Redrawn from Alexandra Morton


OBSERVATION STATION
FLOATING
ADD
ARRAY
1 KILOMETRE


○ BROAD SCANS
△ SECTOR SCANS
+ RESIGHTINGS
Olesiuk et al (1996)
○ BROAD SCANS
△ SECTOR SCANS
+ RESIGHTINGS


BROAD SCANS
VISUAL
HEARD
MEAN NUMBER PER SCAN
1.0
0.8
0.6
0.4
0.2
0.0
OFF
ON
OFF
ON
OFF
ON
PERIOD 1
PERIOD 2
PERIOD 3


SECTOR SCANS
VISUAL
HEARD
MEAN NUMBER PER SCAN
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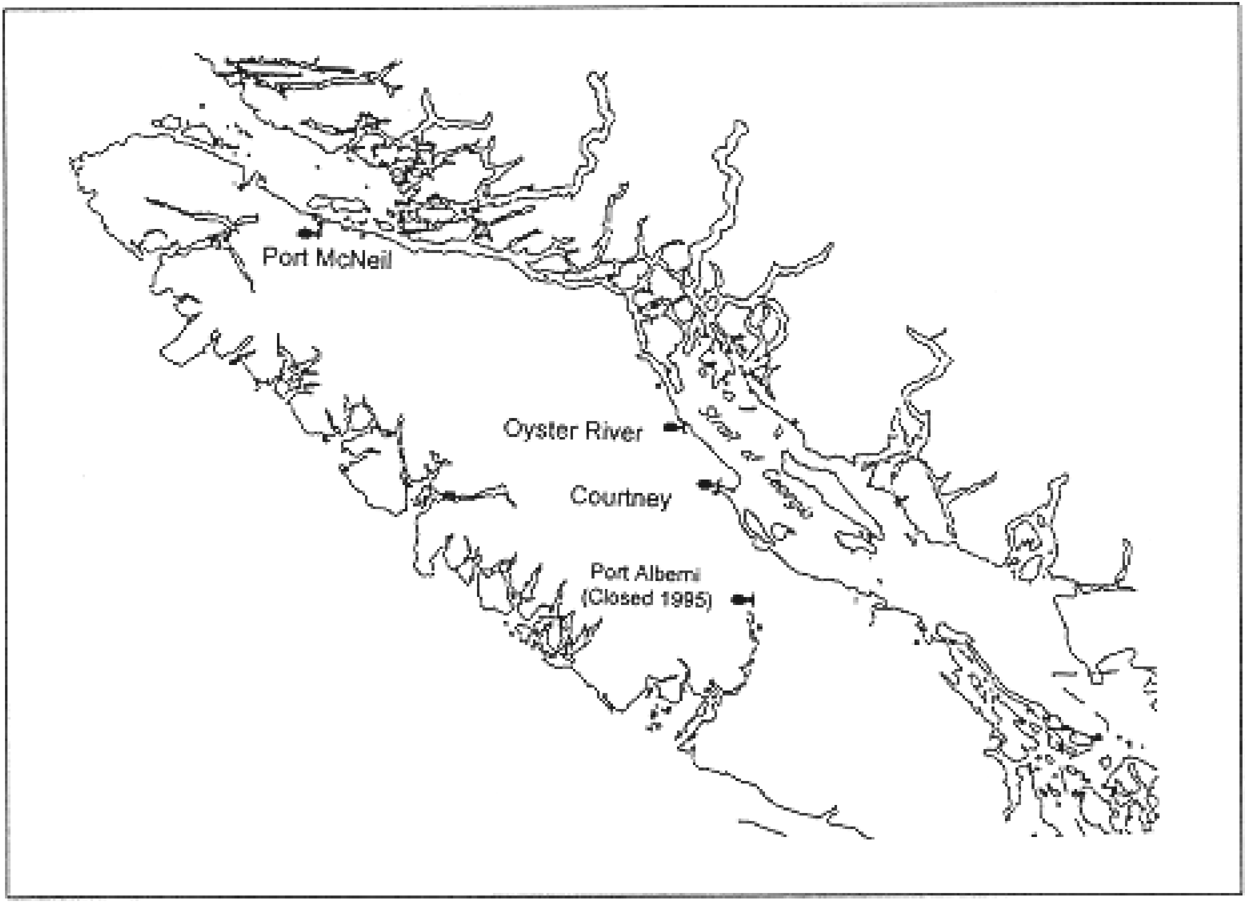
0.8
0.6
0.4
0.2
0.0
OFF
ON
OFF
ON
OFF
ON
PERIOD 1
PERIOD 2
PERIOD 3

Figure 8. Main disposal locations for dead fish from salmon farms in British Columbia.



Source: Winsby et al. 1996.

SALMON AQUACULTURE REVIEW

SITING OF SALMON FARMS

DISCUSSION PAPER

PART F

This paper was prepared on behalf of the Environmental Assessment Office by:
Catherine R. Berris Catherine R. Berris AssociatesVancouver, B.C.

PART F—TABLE OF CONTENTS

References:

Appendix B—Salmon Farm Case Histories:

Tables

LIST OF ABBREVIATIONS USED IN THIS PAPER

ACRD	Alberni-Clayoquot Regional District
ADD	acoustic deterrent device
AHD	acoustic harassment device
APC	Advisory Planning Commission
AUM	animal unit month
BCSFA	B.C. Salmon Farmers Association
BCWF	B.C. Wildlife Federation
CBCYC	Council of B.C. Yacht Clubs
CEAA	Canadian Environmental Assessment Act
COFRI	Coastal and Oceans Frontiers Research Initiative
CORE	Commission on Resources and Environment
CRIS	Coastal Resource Interests Studies
CSRD	Comox-Strathcona Regional District
DFO	Department of Fisheries and Oceans
EAA	Environmental Assessment Act
EIS	environmental impact statement
ESA	environmentally sensitive area
FAO	Food and Agriculture Organization (UN)
FFRC	Fish Farm Review Committee
FPC	Forest Practices Code
GBI	Georgia Basin Initiative
GESAMP	Group of Experts for Scientific Advice on Marine Pollution
GIS	Geographic Information Systems
ICLARM	International Center for Living Aquatic Resources Management
ICES	International Council for the Exploration of the Sea
IUCN	International Union for the Conservation of Nature
KTFC	Kwakiutl Territorial Fisheries Commission
LRMP	Land and Resource Management Plan
LUCO	Land Use Coordination Office
MAFF	Ministry of Agriculture, Fisheries and Food
MAIAC	Minister's Aquaculture Industry Advisory Council
MELP	Ministry of Environment, Lands and Parks
MOF	Ministry of Forests
MOM	Modelling-Operations-Monitoring
MOU	Memorandum of Understanding
MPA	Marine Protected Area
MSBTC	Ministry of Small Business, Tourism and Culture
NASCO	North Atlantic Salmon Conservation Organization
NPA	National Action Programme
PMHL	Pacific Marine Heritage Legacy
PICES	North Pacific Marine Science Organization
RC	Salmon Aquaculture Review Committee
RFFRC	Regional Fish Farm Review Committee
RIC	Resource Inventory Committee
SAR	Salmon Aquaculture Review
SMA	Shoreline Management Act (Washington)
SPARK	Strategic Planning for Applied Research and Knowledge
TAT	Technical Advisory Team
TFL	Tree Farm Licence

EXECUTIVE SUMMARY

This paper provides an overview of all factors related to siting, including biophysical and socio-cultural issues, site selection considerations, the context for coastal management in B.C., siting procedures in other jurisdictions, and current approaches to siting. Based on that information and analysis of the Broughton area, the paper assesses siting considerations and procedures and provides conclusions.

Information for the paper was derived from written materials and interviews. Because of the topic, much of the information is qualitative, and numerous statements are based on perceptions. These are qualified as such.

The biophysical issues related to salmon farm siting are described in relation to the four other Technical Advisory Team (TAT) papers being prepared for the Salmon Aquaculture Review (SAR). Those topics are described much more fully in the papers on escaped farm fish, fish health, waste discharges and aquatic mammals and other species. Some of the observations related to siting are that wild salmon stocks in close proximity to farms are likely to be at higher risk than those stocks inhabiting areas further away. Good siting choices combined with improved technology may reduce the likelihood of escape and the potential risk of impacts. Siting decisions also need to consider the potential spread of drug residues to wild food species, and features of wild species that would make them more susceptible to the effects of pathogens or parasites of farm origin. Siting is an important factor in minimizing environmental degradation in the vicinity of the farm location. It can also help to address concerns such as loss of wildlife, danger to the public and disturbance to other user groups which can result from farmers' attempts to protect their stocks from predators.

Socio-cultural issues have been grouped under six headings:

- Proximity effects are defined as the effects of farms on people when they are close to the sites, and they include noise, smell, visual impacts, decline in water quality, air pollution and garbage.
- Effects on communities include employment and related economic benefits, as well as the social and economic costs of conflict when controversy over siting occurs.
- Resource use conflicts have occurred because the particular biophysical characteristics sought for fish farms often overlap with those of other uses such as tourism and recreation, anchoring, fishing, navigation, and forestry.
- First Nations perspectives include a wide variety of concerns related to: the importance of resources to their physical and spiritual lifestyle, concerns about health of the stocks and the effects on the health of First Nations people, protection of aboriginal rights, the management of the industry, and an interest in involvement in the decision-making process.
- Public service benefits and risks include safety and transport provided by and to salmon farmers as well as public awareness programs.
- Process issues include concerns about regulations and procedures for siting and managing aquaculture operations.

Site selection considerations for salmon farming include biophysical siting criteria for chinook and Atlantic salmon preferred by the industry, e.g., temperature, salinity, dissolved oxygen, current speeds, depth, wind speed, wave height and acidity. In addition to these factors, farming operations require good water quality, suitable physical characteristics, adequate protection, appropriate biological factors, avoidance of marine mammals and sites for fallowing. There are also separate detailed criteria to determine appropriate lakes for salmon farming. Farms are being built to withstand more exposure and this is increasing the number of possible sites for growing larger fish. Potential new technology for salmon aquaculture at the prototype stage of development is the use of enclosed systems. These could reduce environmental impacts and further increase the geographical range of farming operations. Land-based systems of aquaculture are still too expensive to be feasible. In the future they may provide opportunities to reduce impacts on marine resources and users, although other types of impacts would need to be addressed.

Salmon farming operations need a sufficient concentration of farms within an area to sustain local support services for the farms. This also provides operators with the flexibility to use safer farming practices such as single-year-class sites and fallowing. Farms require security in relation to natural environmental conditions and human intrusions to protect the health and safety of the fish.

Socio-cultural considerations related to siting centre around identification of the areas important to other coastal users and the desires of user groups to protect those resources for their interests. The uses include residential, tourism and recreational, commercial fishing, archaeological, anchorages and navigation, and First Nations areas.

A number of international, national and provincial initiatives set the context for coastal management in B.C., and in some cases for management of the aquaculture industry. The most important of these are mentioned here. The International Union for the Conservation of Nature (IUCN) adopted a resolution on aquaculture at its recent Congress. The UN Food and Agriculture Organization (FAO) adopted a Global Programme for Action for Protection of the Marine Environment from Land-based Activities, which has national and provincial counterparts. The International Council of the Exploration for the Sea (ICES) has published extensively on the topic of aquaculture. A Canada/U.S. Marine Science Panel recommended strategic planning as the highest management priority.

The *Canada Oceans Act,* which has received Royal Assent, authorizes the development of a National Oceans Policy, and an Oceans Management Strategy is being developed. Federal and provincial agencies are developing a Marine Protected Areas Strategy for the Pacific Coast.

At the provincial level, The Provincial Land Use Charter and A Sustainable Environment Charter establish general principles for land use and environmental planning and management. The Gillespie Inquiry, the Ombudsman's Report, and the Minister's Aquaculture Industry Advisory Council (MAIAC) provided recommendations specific to aquaculture. The B.C. government is engaged in discussions regarding the development of a coastal strategy.

A brief overview is provided of siting procedures in Norway, Scotland, Ireland, Iceland, Washington, Maine, New Brunswick and Nova Scotia. Some of the common regulations are: requirements for an environmental impact statement (EIS); distance restrictions between farms, from critical habitat, and from Environmentally sensitive areas (ESAs); and specific limitations based on oceanography. Norway has a complex system for modelling flushing rates in order to predict the effects of organic loading.

Regulatory and approval systems for aquaculture are described in much more detail in Ann Hillyer's paper for the SAR. Aquaculture in B.C. is regulated by the Department of Fisheries and Oceans (DFO) at the federal level. The primary provincial regulatory bodies are the Ministry of Agriculture, Fisheries and Food (MAFF) and two parts of the Ministry of Environment, Lands and Parks (MELP): B.C. Lands and B.C. Environment, which have recently been merged. The Federal Aquaculture Development Strategy outlines federal principles for aquaculture development and a strategic plan. The Coast Guard within DFO is responsible for the protection of navigable waters under the authority of the federal *Navigable Waters Protection Act*, and any salmon farm that requires approval under that *Act* will be considered to be a project for the purposes of the *Canadian Environmental Assessment Act* (CEAA). The federal *Fisheries Act* prohibits the harmful alteration, disruption or destruction of fish habitat. DFO is currently developing guidelines for siting and operating aquaculture facilities.

The Federal-Provincial Memorandum of Understanding (MOU) divides the responsibilities for the administration and regulation of the aquaculture industry and gives the province the key role in regulating aquaculture. At the provincial level, MAFF and the Ministry of Crown Lands signed an MOU to define the respective roles of the ministries regarding aquaculture development and to clarify and streamline administrative processes.

Anyone wishing to operate a salmon farm on provincial Crown lands, including subaquatic lands, must obtain tenure of Crown lands for the purpose of aquaculture from MELP (formerly B.C. Lands). The B.C. Lands Aquaculture Policy contains siting and spacing guidelines for fish farms. Operators must also obtain an aquaculture licence from MAFF, which is based on evaluation and approval of an Aquaculture Development Plan. Aquaculture licences contain terms and conditions for farm management. Operating standards for fish farms have not yet been developed. Salmon farm operations must also comply with the provisions of the *Heritage Conservation Act*, which protects archaeological resources.

Local government may be involved in the siting of salmon aquaculture facilities through official community plans, zoning bylaws, and permits. Regional districts and the Islands Trust may also use rural land use bylaws. The Comox-Strathcona Regional District has enacted zoning bylaws which permit aquaculture uses on Cortes Island and Quadra Island, and a rural land use bylaw which does the same for Desolation Sound. The Regional District of Alberni-Clayoquot permits aquaculture in four designated zones.

The possible application of the provincial *Environmental Assessment Act* (EAA) to salmon farming activities will be considered following the SAR being conducted by the Environmental Assessment Office. A new piece of provincial legislation, the *Farm Practices Protection (Right to Farm) Act* has the potential to affect operational aspects of existing salmon farms in the future.

To begin the process of obtaining permission to operate a salmon farm on Crown land, an applicant applies to B.C. Lands. The application is referred for comments to other government bodies, including First Nations, and other interested parties. This report outlines the steps taken by each government agency in their review of applications, and describes their perceptions of the referral process. B.C. Lands reviews and assesses all comments made in response to referrals, a public notice, and consultation, and makes a decision. The objective is, given the available information, to determine if aquaculture is the highest and best use for the site.

If a salmon farm is found to be in trespass, the owner is charged with penalties and must rectify the situation. If B.C. Lands receives an application for a replacement tenure, it normally does not repeat the full referral process; however, if concerns about the tenure have been raised, a partial referral is conducted. Because of the large capital investments involved in establishing fish farms, there is an expectation by the industry and B.C. Lands that if farms are being operated in compliance with the terms of their tenure, replacement licences or leases will be granted.

When sites are decommissioned, B.C. Lands requires a statutory declaration that all improvements are removed. As part of the tenure agreement, farms post a performance security, which can be used for clean-up.

During the period of the SAR, approvals of new salmon farms have been suspended. Applications for replacement or amendment of existing tenures and aquaculture licences are referred to a Regional Fish Farm Review Committee of government agencies.

This report describes the primary information which is available to support site selection, evaluation, and approvals. There are several booklets which provide criteria for site selection. The major sources used to make siting decisions are the Coastal Resource Interests Studies (CRIS) and Biophysical Capability for Salmon Farming. The former, produced by B.C. Lands, is based on mapping by coastal interest groups who identified the areas important to their interests. Based on the information, a map was produced showing areas of Conditional, Limited and No Opportunity (coloured red on the maps) for finfish aquaculture. The latter, produced by MAFF, includes the primary criteria affecting salmon farm siting and a rating for aquaculture development. MAFF is currently working on a computer-based tool to model capability for aquaculture. The Land Use Coordination Office (LUCO) is compiling the Corporate Coastal Inventory and Information System, which includes extensive mapping of marine resources. DFO maintains an internet site with information on fisheries.

Monitoring of salmon farms can be undertaken to ensure compliance with standards, to evaluate standards, and to improve knowledge of impacts. B.C. Lands monitors sites for compliance with tenure boundaries, with visits occurring six months to three years apart. Mandatory monitoring of environmental effects was established through the Aquaculture Waste Control Regulations, with the intensity of monitoring based on three levels of production. A 1994 study of monitoring found problems with compliance of industry and response by government. Compliance with the terms of the aquaculture licence is monitored by MAFF, and within the past two years, MAFF began a regular monitoring program to check the environmental status of farms.

This paper provides a brief comparison between siting of salmon farms and siting of other uses of Crown land. Aquaculture is generally far more regulated than other coastal users. Salmon farming has never been subject to the no net loss policy of DFO because DFO considers aquaculture a temporary impact on resources. Grazing permits on Crown land are allocated based on assessment of the capability of resources to support cattle, but there are problems with the process and the results.

An analysis was conducted of the Broughton archipelago to better understand concerns, observations and results of siting procedures. There are 28 operating salmon farms in Broughton, almost all of which are owned by two companies. The first part of the analysis describes the perceptions of residents and users of the area. A local information collection exercise recorded primarily negative comments on siting, with concerns including perceived non-compliance with leases, hazards to navigation, trespass on upland areas, abandoned equipment, and negative effects on fishing, recreation sites and resources.

The Broughton area is considered to be of extremely high value for tourism and recreation. The Ministry of Small Business, Tourism and Culture conducted a survey of tourism operators in Broughton for the SAR. Included were lodges, marine charters, kayak tours, marinas and air charters. The number of clients has doubled over the last five years, with businesses reporting an average growth rate of 17% annually during that period. About 85% of the tourism businesses reported negative impacts from salmon farms, with most diverting their trips or operations away from fish farm sites. The negative impacts were attributed to effects on fish and wildlife, loss of access to important areas, visual impacts, and pollution (visual, noise and smell). Positive impacts from fish farms were reported by 35% of the tourism businesses (some operators cited positive and negative impacts), with these impacts attributed to fish farms being points of interest, tour opportunities, and providing safety.

Salmon farmers consider the Broughton to be a world class area for their industry. It is one of the best, if not the best, area for salmon farming in B.C. It is close to service centres. Ocean water flowing in from Queen Charlotte Strait is very clean, there is a narrow water temperature range, and the numerous islands, bays and inlets provide shelter. Because the companies in the Broughton manage defined geographical areas, they have enough sites to provide flexibility with their operations.

An analysis of Broughton fish farms in relation to CRIS red areas showed that two are completely in No Opportunity areas, three are partially in those areas, and one has only a residence in a red area. Applications for all of the above sites but one were received prior to the release of CRIS, and they were grandparented into not being subject to CRIS limitations.

A series of analyses was conducted to determine the extent of resource use conflicts. These are based on interpretations of data, some of which is very coarse, and the numbers should be taken as general indicators only. Depending on the method of analysis and the type of recreation use, the number of recreation sites affected by fish farms ranges from 5% to 20%. Half of the larger recreational use areas and routes are highly or moderately affected by farms, meaning that in approximately half of the Broughton area, one is aware of fish farms. An analysis of fish farms in relation to clam, crab, prawn and herring spawn areas and salmon and ground fish sport fishing areas shows that a relatively small proportion of the resources are physically affected by farm sites, although 10 prawn areas are affected.

Another analysis looked at the case histories of five fish farms selected to represent a range of conditions. The similarities among the farms are much more striking than the differences. All of the farms received at least one objection in the referral process. The analysis raised several concerns: identical responses on form letters from key agencies give the impression that detailed knowledge of each site may have been limited, information provided to the SAR indicates incorrect or missing information on resources and uses on the original applications (unconfirmed), and none of the files provide a rationale from B.C. Lands on the decision made.

The Broughton area is compared with other areas of the coast to identify likely target areas if the industry were to expand. The areas where salmon farming currently occurs may have some capacity for expansion, though conflicts with other resource users will likely be a limiting factor. The primary new areas with potential to support the industry are the Central Coast and Prince Rupert regions. The interest in the industry on the Central Coast is mixed.

The biophysical risk assessment of salmon aquaculture in B.C. is being conducted by the other four TAT authors. There are a number of possible reasons why the perception of socio-cultural impacts appears to be high in relation to the geographic extent of the industry: although the coastline is vast, many coastal users have interests in the same locations; although those directly affected by salmon farms are relatively few, the impacts when they have occurred have had a significant effect on the people concerned, particularly First Nations; some of the perceptions of impacts could be based on experiences of several years ago; salmon aquaculture is a relatively new use on the coast and typically traditional resource users have a difficult time accepting a new use; some people do not feel that the environmental impacts are well understood, and lack of understanding is often accompanied by concern; and concerns about the regulatory system and approval process also may affect perceptions about the industry as a whole.

This report does not attempt to evaluate the validity of perceptions. Rather, it documents them and also describes the current system for siting salmon farms in order to obtain a better understanding of the basis for the concerns.

The proximity effects of salmon aquaculture on permanent residents affect relatively low numbers of people, but the effects can be significant. Recreation and tourism users can avoid salmon farms to some degree, but the perceptions of impacts can be strong because of the importance of the quality of recreational experience often desired. Current procedures partially address proximity effects through the mandatory consent of upland owners and reference to CRIS mapping. MAFF also attempts to address some of these concerns in the aquaculture development plan terms. Some proximity effects remain unregulated.

The economic effects of aquaculture on communities are generally positive. The non-economic effects on communities overlap with proximity effects and resource use conflicts. Government regulations to address conflict are centred around the referral process. Although that process has improved in recent years, it is not a process which lends itself to consensus-building or conflict resolution.

The geographic extent of resource use conflicts varies for the different uses and areas, but perceptions of conflict are strong even for the uses where there appears to be a very small physical overlap. The high levels and steady increase in tourism use in the Broughton suggest that recreation, tourism and aquaculture are coexisting, although there remain impacts on recreation and tourism. Although the percentage of the commercial fishing resource affected is even smaller in the Broughton, the level of concern is likely related to broader environmental concerns as well as the irritations of losing favourite, highly accessible fishing spots or having fishing gear fouled by fish farm equipment. Impacts on shellfish resources are relatively limited in geographic extent; however, the potential risks of consuming contaminated shellfish are significant. It is expected that navigation impacts are also relatively limited in number, but where they do occur, they cause a high level of annoyance and potential cost or harm to other coastal users.

The approval process prior to CRIS studies did not adequately address resource use conflicts, and this impact was extended because of the grandparenting of applications. The issue of resource use conflicts brings up the question of equity in the allocation of Crown land. Because of the level of different types of use in many coastal areas, competition for space and conflicts are unavoidable. The major user groups all appear to feel that there is inequity in access to Crown land. There is a lack of interest-based, consensus-seeking planning processes, making it extremely difficult to address competing demands and to achieve an acceptable balance of uses.

The approval process for salmon farms did not sufficiently address First Nations concerns in the 1980s. First Nations are now highly concerned about aquaculture, and they want to be involved in the decision-making process.

One concern with site selection is the lack of legal or regulatory requirements which precisely define siting limitations with respect to environmentally sensitive resources. Various guidelines exist, but these are not requirements and there are no detailed criteria for defining resources such as salmonid streams, fish habitat, or shellfish beds. There are no guidelines for siting with respect to important wildlife areas or for areas used by red or blue-listed species. Concentrations of marine mammals, seabirds, waterfowl, raptors and shorebirds are documented as predators in the biophysical mapping for aquaculture, but these are not listed as species to protect from an environmental perspective.

Siting discussions with tourist operators and recreational user groups implied that salmon farming and recreation can coexist provided that salmon farms are sited and designed to blend with the surroundings, that fish and wildlife are not harmed, that farms do not impede access along or to the shore, that noise and pollution are minimized, that the best recreation areas are protected, and that the number and density of farms are within limits. These limits likely vary with the perceptions of specific individuals and user groups. At a certain level of either use, the capacity of the other use to expand will be limited. The marine tourism industry relies on the existence of some pristine areas with no industry, while in other locations tourism and aquaculture could coexist.

After considering biophysical requirements, industry needs, and the limitations resulting from environmental and socio-cultural factors, there may not be many additional sites for salmon farming meeting present criteria in some areas of the coast. The consideration of cumulative effects or carrying capacity is central to the practice of site selection. New technology could increase the sites with capability, and thereby reduce conflicts. Because fish farms are so sensitive to environmental conditions, they can be an early warning system of problems. Site selection currently suffers from a lack of direction.

Some concerns with the regulatory structure are the complex jurisdictions and regulations, the lack of coordination in coastal strategy initiatives, the lack of collaboration among agencies, and the lack of a broader structure for coastal planning and management.

A major problem facing siting for salmon farms has been the lack of appropriate coastal resource information at a regional scale or a site-specific scale. The CRIS mapping has useful information but is subject to a number of limitations. There is a lack of prescriptive plan designations based on biophysical, socio-economic, cultural and industry criteria as well as community input, which would make siting much more responsible and efficient.

Comments on the referral process include perceptions that it is too cumbersome and other views that it does not allow adequate time. If there were improved guidance for the location and management of salmon farms, the process could likely be streamlined. The primary comments on the referral process relate to the need for improved communication, public consultation, and dispute resolution. There is also concern about the ability of the agencies to adequately manage the industry and resources sustainably, given limited and declining government resources.

There is a significant level of agreement that the primary problem with decision-making is that the criteria and rationale for decisions have been unclear. Some public groups are unhappy with past siting decisions, and some public and government groups do not feel that their concerns were properly addressed. The industry is concerned about uncertainty of tenure. All of those concerns could be mitigated by clarifying regulations, decision-making criteria and performance standards.

Although the above concerns are significant, there are also positive features. There is now better information, most relevant interest groups are now contacted for referrals, and some planning efforts are underway. The majority of farms currently in place were sited before these benefits existed.

The recommendations of the SAR will be developed jointly by the TAT and EAO. This report provides a list of conclusions which could be used to guide the development of recommendations. The conclusions address needs for: following the principles and commitments of Canada and B.C. in siting, a provincial coastal strategy, integrated resource planning, an interim process for siting until planning has occurred, clear decision-making criteria and documentation, better information at four levels, maintaining information current, improved communication and collaboration among agencies and industry, improved consultation with the public, better regulations for environmental protection, relocation of salmon farms which have proven negative effects, more flexibility for the industry, responsible decommissioning of farm sites, an improved monitoring system, adequate resources for government, streamlining of processes and ongoing research and development of new technologies.

I. INTRODUCTION

This paper provides an overview of all factors related to siting of salmon farms. There are strong interrelationships among siting and seven other technical papers being prepared as part of the Salmon Aquaculture Review (SAR): the four papers regarding environmental issues (Alverson, Stephen, Burd and Iwama), a paper on the regulatory framework, a paper on other jurisdictions to be completed later (Hillyer), and a paper on the social and economic impacts (Shaffer). This paper summarizes the aspects of those papers that relate to siting in the course of describing and assessing salmon farm siting in B.C. This paper describes the issues, site selection considerations, the context for coastal management in B.C., siting procedures in other jurisdictions and current approaches to siting. Based on that information and analysis of the Broughton study area, the paper assesses siting considerations and procedures and provides conclusions.

In addition to the other SAR papers listed above, the primary information sources for this paper are listed below:

- information provided by members of the SAR Review Committee (RC) and submissions made by the public and RC members to the SAR,
- information provided by First Nations in two special meetings with them related to the SAR,
- paper on local information organized as part of the SAR,
- articles on issues, description, evaluation, commentary and information related to siting,
- articles and interviews related to the context for coastal management at the international, national and provincial levels,
- interviews with aquaculture industry, other industry, First Nations, coastal user groups and those involved in decision-making on siting for aquaculture and for other coastal uses,
- regulations and procedures for decision-making related to siting of aquaculture,
- regulations, processes and methods used to site aquaculture operations in other jurisdictions,
- information on the decision-making process for selected salmon farms derived from review of government files and maps, and
- analysis of maps of the Broughton area.

The information above is largely qualitative, i.e., there are few statistics available to support statements. Where possible, scientific and analytical information is used, but for some issues, the only information available is based on perceptions. This lack of “hard” information is not considered a primary deterrent, because, for the topic, analysis of qualitative information is a generally accepted practice. Statements in the paper which are based on perceptions are qualified as such.

II. ISSUES

A. BIOPHYSICAL ISSUES

The primary biophysical issues related to salmon farm siting are described below in relation to the four Technical Advisory Team (TAT) papers. These sections were prepared by the individual TAT authors (indicated below each subtitle) before they completed their risk assessment. For a review of the risks and conclusions associated with each issue, refer to the individual TAT papers.

Escaped Farm Fish

(Dayton L. Alverson and Gregory T. Ruggerone)

In the course of marine and freshwater salmon farming, smolts, sub-adults of various sizes and adult fish are lost due to operator error, predators, storms and vandalism. In addition to the reported major losses of coho, chinook and Atlantic salmon, there are chronic leakages of small numbers of farmed salmon that are unreported. Potential concerns related to these escapes include: those of an ecological character (competition and predation), potential genetic dilution caused by interbreeding of farmed Pacific salmon, which could render the progeny of wild stocks less fit in their endemic habitat, hybridization between Atlantic and Pacific salmon, colonization of an exotic species (Atlantic salmon) and transmission of diseases from farmed to wild salmon stocks or to other B.C. marine or freshwater species.

The potential for impacts to occur over large geographic areas is reflected by the capture of farmed Atlantic salmon from southern Puget Sound to Alaska. However, the SAR authors on this topic conclude that wild salmon stocks in close proximity to farms are likely to be at higher risk than those stocks inhabiting areas further away. Good siting choices combined with improved technology may reduce the likelihood of escape and the potential risk of impacts. Nevertheless, increased production levels on extant and potential new sites could lead to higher levels of escapes. Larger, older salmon may have a higher probability of surviving after escaping to enter freshwater spawning areas and show greater dispersion than farmed salmon that escape shortly after entering the grow-out cage. Finally, the potential impacts from escaped Pacific salmon could constitute a significant ecological and genetic risk if any “all Pacific salmon” marine farming mode was to occur.

Fish Health

(Craig Stephen and George Iwama)

Disease and its control has been a primary concern of salmon farmers since the inception of the industry. Diseases, which occur in both farm and wild fish, include those that are bacterial, viral, fungal and parasitic. Concern has been expressed that farm salmon may expose wild fish (salmonids and others) to disease and vice versa. The potential for disease to be transmitted between farm and wild species will vary according to the pathogen involved, the susceptibility of the host fish, and environmental factors influencing the number, movement and survival of pathogens and susceptibility of the host. Concerns exist that fish health management practices to control disease on fish farms may also impact wild stocks and the surrounding environment. The importation of Atlantic salmon gametes from eastern North America and Europe is of concern due to the possibility of inadvertent introduction of exotic fish diseases to the Pacific coast.

Each of the concerns relating to health issues requires that at-risk individuals or populations are adequately exposed to pathogens, parasites or chemical compounds of fish farm origin before an adverse effect can be realized. The probability of exposure to such agents can be affected by siting. This is most clearly seen when considering the impacts on other marine and aquatic resources of drug and pesticide use by salmon farms. Although the distribution of drugs in the environment is generally restricted to the area of deposition of feed and fecal wastes, siting guidelines have been established to minimize the opportunity for wild food species to be exposed to environmental drug residues. Research conducted in the Pacific Northwest as well as in Europe has demonstrated that some species can be found with drug residues beyond the current B.C. guidelines for siting near shellfish resources.

Siting decisions also need to consider features of wild species that would make them more susceptible to the effects of pathogens or parasites of farm origin or would affect the likelihood that a pathogen would be spread throughout the population. Wild salmonids will be more susceptible to developing disease after exposure to a pathogen when they are physiologically stressed at spawning or smoltification. Estuarine locations are not only sites where such stressed fish will spend time, but are also locations where salmonids will congregate, thus increasing their density which may in turn increase the likelihood of transmitting an infectious agent throughout the population. Populations that are further compromised by other negative population regulating factors such as habitat loss, food depletion and over-fishing may also be more sensitive to any incremental negative pressures that disease may create.

Waste Discharges

(Brenda Burd)

The issues about waste discharges relate to the effects of farms on the functional integrity of ecosystems. The primary waste materials from net-cages include uneaten food, fish faeces, and dissolved urea, ammonia, carbon dioxide and bicarbonate. Other direct net-cage outputs to the marine environment include vitamins, antibiotics, therapeutants, antifoulants and possibly cleansing agents. Smaller scale outputs from salmon farming operations may result from net-cleaning operations, disposal of morts, bleeding operations, offal disposal, sewage from farm sites and garbage disposal.

Increases in organic material above ambient levels can cause physiochemical changes in the sediment and water column leading to biotic changes. Levels which are greater than the assimilative capacity of the benthic environment may lead to: increases in nutrient levels, reduction in oxygen levels, biotic effects ranging from enrichment to defamation, reduced redox potentials and outgassing of carbon dioxide, hydrogen sulphide and methane from the sediments into the water column. Other potential water column concerns include hypernutrification of the water column resulting in increased production of phytoplankton, stimulation of toxic algal blooms and increased water column turbidity leading to shoreline degradation.

Investigations through the SAR indicate that the actual areal extent of sedimentation under salmon net-cages appears to be fairly limited in most cases. Sediment accumulation rates are more difficult to measure. Outgassing is rare in B.C. The effects of the gasses on fish are unknown, but they have been held responsible for negative effects on the farmed fish.

Occurrences of environmental degradation can be summarized as being the result of: inappropriate initial siting of the cage operation, overproduction for the assimilative capacity of the site, and/or poor husbandry practices. The environmental degradation which has occurred is reversible by natural processes. The time scale for this is not yet precisely predictable, but will occur within a few months to years of cessation of organic loading. The recovery time for fallowed sites will depend on: level and time span of production, bottom topography and currents, basin flushing time, and level or intensity of impact at the time recovery begins.

Aquatic Mammals and Other Species

(George Iwama, Linda Nichol and John Ford)

There are significant interactions between salmon net-cage culture operations in B.C. and a number of wildlife species. Aquatic mammals (both marine and freshwater), birds, aquatic invertebrates and other fish species comprise the major groups of animals. Aquatic mammals and birds prey on the fish in the net-cages and the salmon farmers attempt to deter those animals with a variety of devices ranging from dogs, predator nets and lines to specialized devices, called acoustic deterrent devices (ADDs) or acoustic harassment devices (AHDs), designed to scare and impose discomfort to marine mammals. Permits are issued by DFO for the use of these devices. Farmers can, and do, kill marine mammals to protect their stock. Permits from DFO are also issued for this purpose. While nets and lines strung across rearing containers are used to deter birds away from net-cages, many are killed by shooting. Large numbers of both aquatic mammals and birds are killed each year. The loss of such wildlife, the danger to the public, and the disturbance to casual and professional recreation activities are the basis for concern.

Aquatic invertebrates and wild fish are attracted to the vicinity of salmon farms by excess feed falling into the water and by increased primary production from the localized enrichment of the water by dissolved nutrients from feed and fecal wastes. There is a concern for the possibilities of disease transmission between farmed and these wild species, as well as for the potential accumulation of therapeutants and other farm chemicals in the tissues of these animals. These topics are covered in the sections described above.

Another issue is the effect that night lighting has on wild species. Lights over the net-cages after dusk extend the feeding time for the fish. One side effect of this practice is the attraction of other wild fish species to the net-cages. For example, there is public concern for migrating herring being attracted to, and becoming trapped in, the net-cages. This concern includes the possibility for the farmed fish to eat substantial numbers of wild fish.

Siting can address some of the above concerns by considering the stationary distributions and dynamic migratory patterns of the wildlife species of concern in the site selection process.

B. SOCIO-CULTURAL ISSUES

The description of socio-cultural issues is complementary to the paper on socio-economic issues being prepared as part of the Salmon Aquaculture Review. This paper only addresses the economic effects of aquaculture generally as they relate to socio-cultural issues. The focus here is on the social and cultural positive and negative effects of aquaculture on human populations.

Proximity Effects

Proximity effects are defined as the effects of farms on people when they are close to the sites. Proximity effects are most significant to residents because of the extent of exposure, but they also affect recreational and other coastal users. Some of the effects described may be related to previous farm practices. For example, oily residue from fish feed is apparently a concern no longer because of changes in feed technology.

Although there is little in the literature on the effects of salmon farms on nearby residents and no available statistics on the number of people affected, comments from local groups indicate that this is a serious concern. The conflicts stem largely from the fact that aquaculture is an industrial use, and that coastal residents in remote areas have sought locations which they expected to be apart from industry. While residential uses themselves reduce the perception of remoteness, effects of salmon farms on residents have been cited as noise, smell, blockage of views or detraction from scenery, decline in water quality (e.g., reports of oily scum on beach), air pollution (e.g., from generators), and garbage (e.g., plastic bags, polystyrene foam pellets). The extent and degree of impact varies with the size, location and management practices on the farms. The effects can be significant, especially in small bays or inlets. In B.C., this has arisen as an issue when farms are close to residential areas or recreational properties, e.g., Sooke basin, Gilford Village/Carrie Bay in the Broughton Archipelago, previous farms on the Sunshine Coast, and Cypress Bay in Clayoquot Sound. The proximity effects described are also perceived as concerns by various tourism and recreational users.

One component of proximity effects is the visual impact. The visual effects of aquaculture operations are considered because of the significance of tourism and recreation on the coast of B.C. and the importance of scenery to tourism and recreation groups. When focus groups with a range of coastal recreation and tourism users were asked about the resources most important to their activity, every group except for sport fishers rated scenery first. Sport fishers rated the presence of suitable fish first and scenery second (Ministry of Small Business, Tourism and Culture, 1990). Visual impacts are frequently cited as being of particular concern to small boaters and kayakers. Scenery is also important to residents and First Nations groups because those who choose to live in remote locations often value the scenic resources.

The visual effects of salmon farms are sometimes perceived as negative, particularly when structures are visually dominant. A study on Public Preferences for Scenic Resources in Clayoquot Sound (Hamilton, 1996) found that perceptions about fish farms were influenced by the visual prominence of the structure in the environment and the function of the facility and its perceived potential environmental impact. The Draft Clayoquot Sound Scenic Corridors Landscape Management Plan (Ministry of Small Business, Tourism and Culture, May 1995), (which has been indefinitely deferred by government), found that salmon farms have a range of visual impacts depending on the viewing distance, site placement, orientation, size and style of development and experiences sought by others. That report has an appendix on visual assessment guidelines for finfish aquaculture operations.

Effects on Communities

Salmon aquaculture provides direct and indirect employment on Vancouver Island and some areas of the Mainland. The RC of the SAR expressed questions and potential concern about the quality of employment, the location of the employment (a perception being that it appears to be primarily in the communities with more services), and a concern that siting may affect the tourism industry that could have the capability to provide more direct local benefits than aquaculture.

The preliminary results of the social and economic analysis of the impacts of salmon farming in B.C. indicate that direct employment from salmon farms was over 1,100 person years with the supplier industry providing 275 person years of employment in 1996. The direct employment is greatest in the Alberni-Clayoquot, Comox-Strathcona and Mount Waddington Regional Districts, with much of the supplier employment located in the Greater Vancouver Regional District and other parts of B.C. The average salary for direct employment was $32,000.00 in 1996. In Broughton, 21% of employees lived within the study area, and the remainder lived primarily in Port Hardy, Campbell River, Courtenay and Comox.

A summary of the community effects is that "local" employment is concentrated in the larger centres, such as Campbell River, Port Hardy and Port McNeill. The employment is relatively small compared to total employment, but it does provide some offset to declining resource industries. First Nations people hold 6% of total direct jobs, and they have no ownership interest in leases, farms or related businesses (excluding hatcheries).

Salmon farming has social and cultural impacts on First Nations, residents who live near salmon farms, commercial and sport fishers, and recreation and tourism participants, all of which are described in more detail elsewhere in this report. The impacts on First Nations are complex and difficult to measure. The effects on residents are relatively low in number, but where they do occur, they are significant. Effects on fishers are also difficult to measure, and the impacts appear to be more social and cultural than economic.

In addition to the issues described above, conflict over siting is important to consider as an issue itself. When there were controversial farms sited in the mid 1980s, some communities were adversely affected by the conflict. On the Sunshine Coast, for example, major battles among neighbours and an extraordinary amount of political attention were focused on the siting of fish farms.

Resource Use Conflicts

Some of the primary concerns with salmon aquaculture stem from competition with other resource users. There are traditional users of the B.C. coast who have become accustomed to frequenting the areas which satisfy their needs. The particular biophysical characteristics sought for fish farms often overlap with those of other uses such as tourism and recreation, anchoring, fishing, navigation and forestry. Part of the reason for this is because farm systems have not, until recently, been constructed to withstand a high level of exposure.

There have been significant conflicts between salmon farming and tourism and recreation. To clarify those terms, the World Tourism Association defines a tourist as anyone who travels more than 80 km from home or anyone who stays away from home overnight. According to that definition, most coastal recreational users are also tourists. In this report, the terms tourism and recreation are used interchangeably.

Recreational boaters and other mariners use protected bays for anchoring. Kayakers seek wilderness paddling areas and small pristine clearings with accessible shorelines and fresh water. Canoeists have particular concerns about salmon farms at river mouths and estuaries and near special canoeing areas such as tidal rapids and lakes. Fly fishers are particularly concerned about salmon aquaculture's effects on wild stocks. The B.C. Marine Trail Association is working on establishing a system of marine landing and camping sites a maximum of 10 nautical miles apart for paddlers and small boat operators. Scuba divers want to ensure that the prime diving areas, generally locations with good tidal exchange, are protected from environmental damage and barriers to access, and there are claims that fish farms have caused turbidity at dive sites. When recreational sites are used for a fish farm, the recreational values are often lost or reduced. This impact can extend beyond the fish farm site itself because of the effects on noise, smell, views and wildlife.

Although the B.C. coastline is vast, the competition has been increasing due to the relatively small number of suitable areas for the uses described and rising levels of recreational use. If salmon farms are located in sites with more exposure, the level of conflict may decline. In the future, if some farm operations are shifted onto land, certain marine conflicts may also be reduced, although new types of conflicts would likely arise.

Fish farms affect the perception of remoteness and this is a concern to recreational and resident groups. Recreation planners use a tool called the Recreation Opportunity Spectrum to describe the state of "naturalness, remoteness and expected social experience" on a scale ranging from primitive to urban (Ministry of Forests, 1997). The presence of fish farms, especially concentrations of them, in areas which are otherwise considered to be remote changes the recreational experience. This is significant for recreation and for the growing adventure travel and eco-tourism industries.

Commercial fishers have traditional and new fishing grounds which vary with the species and type of vessel, e.g., prawn and crab fishers, trolling and seining. Although a report on the subjects stated that conflicts between fish farm siting and commercial fishing have been limited (Macleod), the Broughton local information report cited a number of concerns by commercial fishers, including loss of favourite fishing locations. The most important physical concerns for prawn fishers involve proposed, current and abandoned anchoring systems (Macleod, 1990).

Fish farms also have effects on navigation and access to the shoreline. Although all applications are checked and required to minimize effects on navigation, some feel the system is inadequate and doesn't address site-specific issues. A number of people providing input to the SAR cited examples of fish farms cutting off access to land and water areas used for recreation and other purposes (Abram, Morton, Whyte). Examples were also provided of farms extending beyond their approved boundaries and posing hazards to navigation (local information report, Burrows). The use of bright lights at night of an unknown type has also been mentioned as a problem for navigation because they can make it difficult to see other features.

The forestry industry has a large number of sites which they use for sorting, loading and storing logs. In some cases, especially in the 1980s, fish farms have occupied these sites with cooperation agreements to provide access for forestry at specific times. This can sometimes be accommodated when forestry requires temporary use only, e.g., for two years.

Other uses which can be affected by fish farms are traplines, First Nations locations of interest, which are described in more detail below, archaeological sites and underwater archaeology resources, e.g., wrecks. Conflicts with upland owners are described under Proximity Effects.

First Nations Perspectives

The First Nations presented their perspective on salmon farming to the TAT in special sessions coordinated by the B.C. Aboriginal Fisheries Commission, in addition to participating on the RC and providing written submissions to the SAR (from B.C. Aboriginal Fisheries Commission, Kwakiutl Territorial Fisheries Commission, and Nuu-chah-nulth Tribal Council). Ann Hillyer's paper on the regulatory framework describes First Nations issues. First Nations are also developing, authored by Hugh Braker, a summary of jurisdictional issues from their perspective. The following represents a very brief summary of the known concerns at this time.

A broad First Nations concern is related to their spiritual belief that wealth is derived from the resources of the land and the sea. The health of the First Nations people is related to the health of the fisheries, and their first priority is restoring the wild salmon. A primary concern of all First Nations is therefore to ensure that salmon farms are environmentally and biologically safe and sound.

The aboriginal peoples in B.C. have been a part of the land, sea and resources of their territories for thousands of years. They cannot leave. If the resources disappear, First Nations as a people will disappear. Therefore, First Nations are uniquely vulnerable to any risk in the environment (B.C. Aboriginal Fisheries Commission submission).

Aboriginal people are much more susceptible to some particular diseases than the general public. First Nations are alarmed at the use of biologically active chemicals, such as antibiotics, especially in net-cages where these chemicals are released into the marine environment, where they can be ingested by animals and plants that are eaten by aboriginal people. The potential impact of these chemicals on the health of aboriginal people is unknown. Therefore, First Nations are opposed to the continued use of medicated feeds in marine net-cages (B.C. Aboriginal Fisheries Commission submission).

First Nations people are currently involved in treaty negotiations. First Nations have an interest in ensuring that land and resources are not alienated before treaties are finalized. Salmon aquaculture may interfere with aboriginal rights by interfering with access to fish resources through site location, affecting the quantity and quality of wild fish and shellfish resources, and contaminating of wild stocks (B.C. Aboriginal Fisheries Commission submission). First Nations are concerned that their rights to fish under Section 35 of the *Constitution Act* be protected.

Most First Nations are interested in involvement in the decision-making process, and want to have a principal role in the issuing, monitoring, enforcement and restoration of salmon aquaculture licences and sites in their territory. Some First Nations are also interested in socio-economic benefits, through either comanagement or employment for their people if the environmental effects are acceptable. The interest in this likely varies, with some First Nations promising to prevent fish farms in their territories if there is not comanagement (Alfred).

Specific concerns expressed by First Nations during the SAR, in addition to the major concerns described above, include:

- environmental concerns such as: effects on oolichan and wild salmon populations, predation on wild juvenile salmon from escaped farmed Atlantics, the impact of farm operations on the benthos and associated infaunal organisms, the effects of farms on the frequency and duration of algae blooms, and shooting at birds and mammals, with no First Nations consultation on the issuing of shooting permits,
- health concerns such as: disease transfer to wild stocks and fishers catching foreign “unattractive” fish,
- siting concerns such as: the density of farms in some areas, farms in traditional winter fishing grounds (protected waters), and potential restriction on or interference with the rights to fish for food, social or ceremonial pursuits, hunting or conducting of cultural activities, cultural and spiritual sites and traditional hunting and gathering sites,
- process concerns such as: lack of referrals to First Nations on licence replacements, lack of consideration of traditional ecological knowledge in decision-making, and the members of the Fish Farm Review Committee, which includes no First Nations, and in which the majority of members are perceived as aquaculture proponents, and
- other concerns such as: the use of lights for photoperiod modification, fish farm workers from outside the local area, challenging communications with the fish farming industry, the lack of remediation efforts for abandoned farm sites, and the “widespread chronic non-compliance” with regard to siting (KTFC submission).

These concerns are not limited to First Nations.

Public Service Benefits and Risks

Fish farms can be a significant resource providing safety and transport in remote areas. Farmers have been known to assist boaters in rescue missions and by allowing boaters to tie up to their floats. Fish farmers also use existing safety resources because they can have trouble, particularly in their boats, and require assistance. Statistics are not available because the Rescue Coordination Centre does not identify fish farmers in their incident reports, but contacts have indicated that these services are provided in both directions.

The perception of the value of fish farms for emergency support varies among coastal users. For example, the Council of B.C. Yacht Clubs is proposing that certain fish farms be designated as emergency stations, and some kayakers have appreciated assistance from fish farmers. Many kayakers, on the other hand, take pride in being self-reliant, and feel that these benefits do not make up for the negative effects of fish farms on their industry (Baert to SAR, Arcese, pers. comm.). Wilderness recreationists are trained to be self-sufficient, and that independence is an important part of the experience. In addition, crews at salmon farms are not necessarily trained to render assistance and they do not keep a look out because they are usually otherwise occupied.

In the past, there have been minimal and random efforts in B.C. to introduce the public to salmon farms, and this lack of public promotion has been particularly evident at the farm sites. Other jurisdictions have shown that opportunities exist for education as part of a tourist experience and some farms have an open door policy with respect to visitors. There are challenges related to the need to protect the fish from potential harmful substances and effects. For example, transfer of disease and escaped farm fish due to net tearing from boat propellers are potential problems related to visiting boats.

The B.C. Salmon Farmers Association has recognized the need for greater public communication and has undertaken initiatives in advertising and promotion, a web site, industry and government tours, meetings, school programs and community sponsorship of salmon enhancement. The failed operations and abandoned sites from the mid 1980s continue to influence many perceptions of salmon farming in B.C. Some siting decisions and industry practices have improved since that time and measures are in place to prevent reoccurrence of some problems in the future. The industry is interested in greater public knowledge and understanding of salmon farming.

Process Issues

Because familiarity with the regulatory and approval process can help in understanding process issues, this section provides an overview only. A more detailed analysis of process issues is provided in section VIII. F.

The process for siting salmon farms has been evolving and continues to do so. Numerous members of the RC made comments on the lack of careful management and enforcement of the industry up to the mid 1980s, and there has been a high level of controversy about the industry since that time.

Conflicts over siting have slowed because of the moratorium, but some members of public groups are still unhappy with the system of siting and managing farms, and there are perceived inconsistencies in the application and management of siting guidelines. Many people contacted perceive that farms continue to get licences where conflicts exist, and that government regulations are not followed. There are also concerns that licence renewals and applications for increased production are not subject to the same scrutiny as initial applications, e.g., they are not referred to all interest groups. There is a perception that the industry has such strong advocates in government that other uses such as tourism are disadvantaged (Baert to SAR).

Another process issue raised at the RC is the recovery of sites when aquaculture operations leave. While this presents an opportunity to research recovery rates on the ocean floor, there are questions about responsibilities for removal of infrastructure, including who pays for that.

III. SITE SELECTION CONSIDERATIONS

A. BIOPHYSICAL CONSIDERATIONS

There are clear biophysical factors to be considered in siting salmon farms, and the factors may change with advances in technology. This section describes those aspects of siting from the perspective of the industry. A discussion of other biophysical siting considerations is located in section VIII. C. of this report.

Capability for Salmon Farming

A variety of biophysical factors can be considered siting criteria for salmon farms (see Table 1). These are based on information provided by the B.C. Salmon Farmers Association (BCSFA) to the SAR. These are guidelines only, as particular combinations of factors may make a site acceptable and missing criteria can be mitigated by various husbandry practices. The regulatory agencies stress that the evaluation of capability is the responsibility of the proponent, and that MAFF will provide assistance in that process.

Table I: Fish Farm Biophysical Siting Criteria

FACTOR	CHINOOK	ATLANTIC	COMMENTS
Temperature Minimum	$>1^{0}$C 17^{0}C	$>0^{0}$C Maximum	$<20^{0}$C $<25^{0}$C surface temperature Optimum
Salinity	10-36 p/litre	0-34 ppl	concern with rapid shifts in salinity
Dissolved Oxygen Minimum		>5mg/litre	>4mg/l varies with time in feeding cycle
Current Speeds Average lowest		5-7 cm/sec	5 cm/sec measured at 15 m depth Highest
maximum	140 cm/sec	140 cm/sec	expensive to anchor, very short intervals
Depth—Minimum	20m	5m	less for Chinook if other factors optimum No
Maximum			
Wind Speed—Maximum		100 knots	
Waves—Maximum	3m	3m	technology dependent
pH		6.5-8.2	freshwater portion of life cycle

Certain sites provide a higher capacity to assimilate the effects of farms. Careful siting in these locations will also provide the most cost-effective solutions to salmon farmers. When salmon-farming was experiencing a high rate of growth in the 1980s, there was less knowledge of detailed siting requirements and rapid decisions were made by the industry and government in site selection (Ginetz, pers. comm.). Natural processes took their course and resulted in abandonment and relocation of farms. For example, in 1989 Sechelt Inlet had 17 farms, and because of high water temperatures, algae blooms and limited water exchange it now has seven operations.

The following is a summary of the biophysical siting criteria used by salmon farmers (BCSFA SAR submission). They feel that the factors which contribute to a clean and productive environment for optimal salmon farming also minimize adverse impacts from salmon farming operations:

- good water quality. The composition and characteristics of the water at a site must be suitable in several key respects including cleanliness, temperature, dissolved oxygen and salinity. It is important that the quality of the water be maintained. Salmon farms can provide information on deteriorating water quality and usually provide an advance signal of problems in an area. It is in their interest that the water quality be maintained. Salmon farmers require protection from other uses, such as residential, recreational and industrial, which may cause a deterioration in water quality. Generally, they seek an adequate distance from natural and anthropogenic sources of pollution. Temperature is also a key consideration because both warm and cold water have detrimental effects on the product. B.C. coastal inshore marine waters generally support a consistent and acceptable temperature range.
- physical factors. The site must have suitable physical characteristics including hydrology, currents and mixing patterns, depth, wave fetch, bathymetry and other bottom considerations such as appropriate substrate composition. Ideal sites are generally in areas where the bottom profile and water exchange characteristics lead to a regular flushing of the area beneath the farm operations.
- adequate protection. While well-flushed areas are desired, siting of farms in areas that are too exposed can lead to dangers in securing the farms. Some protection reduces the risk of farm damage from storms and heavy currents. Technology advances discussed below affect the level of exposure which can be tolerated. Until recently, most B.C. salmon farmers have been unwilling to locate in areas where wave heights in extreme conditions could exceed 2 m, but with certain technologies this limit is increasing to 3 m for larger fish.
- other biological factors. Salmon farms avoid areas which are susceptible to algae blooms and areas with an overabundance of fouling organisms. Site specific chemical and biological profiles are conducted in the evaluation of potential farm sites and the ongoing management of productive farm sites.
- avoiding marine mammals. To minimize predation, salmon farms avoid areas where predatory marine mammals congregate.
- sites for fallowing. To allow for good husbandry practices, it is necessary to have adequate sites to allow for rotation of stock among sites so that each site can remain fallow periodically as required.

Farms cannot be considered in isolation. There can be cumulative effects of several farms in an area or cumulative effects of farms and other uses combined.

Lakes have their own specific opportunities and constraints for aquaculture. The draft criteria for lakes appropriate for salmon farming (1994) are as follows:

- lake should be completely landlocked or, if not available, then it should have a migration barrier to anadromous fish on the outlet stream at or near tidewater;
- lake must be west of coast mountains or on Vancouver Island;
- size over 160 ha preferred unless there is acceptable flushing;
- lake should be oligotrophic;
- proposed fish production should not exceed a level that will cause the lake to exceed oligo-mesotrophy based on nutrient loading modelling exercises;
- undersides of cages must be at least 10 metres above lake bed;

- Waste Management Permit may be required in future;
- annual relocation of cages to a fallow site will be required;
- not acceptable in watersheds with endemic wild fish populations that are rare or endangered or considered unique by fisheries managers;
- lake should not be intensively stocked, angler effort should be low, advertising must occur, and there should be no conflict with extraction of water for domestic or other licensed use;
- kokanee or sockeye should not be present; and
- lakes with severe ice build-up or extensive free log movements should be avoided unless adequate measures are proposed to avoid escapes through damage from logs or ice.

Largely due to the challenge of finding lakes meeting all of the above requirements, there are only five lakes in B.C. which meet the criteria for commercial net-cage smolt-rearing sites, and three active operations. Georgie Lake west of Port McNeill has two farms and Lois Lake near Powell River has one operation. The roles of the regulatory agencies in siting farms in lakes are very similar to the situation in the marine environment. The Waste Discharges paper addresses the biophysical aspects of siting in lakes in some detail.

Changes in Technology

Biophysical considerations are changing as a result of improvements in technology and farming practices. Farms are being built to withstand more exposure, i.e., stronger currents and higher winds and waves, than they were several years ago. One example is a net-cage system called the polar circle. It uses large plastic circular tubes filled with flotation material, and there are guardrails which support the nets. This system can tolerate a wave height up to three metres, but each circle must be moored individually with up to eight anchor lines.

One of the major limiting factors is the ability of float-homes to withstand exposure, as various types of cages are being built much stronger than they were previously. Salmon farms in the Bay of Fundy, which do not have accommodation on site, are all more exposed than those in B.C. The exposure of B.C. salmon farms could likely be increased further, especially for larger fish. Smolts require the level of protection offered by existing salmon farm sites, but grow-out sites could likely be located farther offshore where there is cleaner water and less chance of conflicts with other coastal users.

Potential new technology for salmon aquaculture at the prototype stage of development is the use of enclosed systems. One of these is a bag system in which large watertight bags are set in the ocean, supported by existing float systems or some form of walkway. Water from 15 to 30 m deep is pumped into the bags and circulated to encourage the fish to swim, leading to firmer flesh. The shape of the bag allows for checking samples from the bottom which can ensure that excess feed is not being used. The waste at the bottom of the bag can be directed through a pipe to the desired location. Systems for collecting the solids from the waste are being investigated. Enclosed systems would eliminate some environmental concerns about fish farms such as predator access, and could reduce possibilities for effects on marine organisms and transfer of disease. They could also increase the number of sites where farms could potentially locate.

Land-based systems of aquaculture have also been receiving attention recently. Some systems are fully enclosed, and others which are open to the air are less expensive, but require more water. The general position of the aquaculture industry in B.C. is that land-based systems are currently much too expensive to allow for competition on the international marketplace. Worldwide, there have not yet been any land-based systems which are economically self supporting. Once recirculation technology is perfected and where there is an inexpensive source of power, land-based farming may become a more feasible option.

Advantages of some land-based systems could be: reduction in the potential for disease transfer, elimination of risks related to escaped fish, elimination of marine mammal predator problems and concerns about algae blooms, fewer limitations on the use of lights at night, significant reduction of impacts to existing marine life, significant reduction of competition with coastal users, and reduction of the need for certain resources such as boats, repair of farm damage from storms and maintenance of anchor lines and floating structures. On the other hand, land-based systems would introduce new potential impacts and possible conflicts relating to water supply, sewage, access, alteration of relatively larger areas and different site restoration potential.

One saltwater land-based system was attempted in Cedar, B.C., but the operation folded because of problems it encountered. The operation was expensive to construct and it involved piping water from and back to the ocean. The system offered advantages in relation to potential predators and it could be located in a more developed location than a floating fish farm. However, the use of ocean water and lack of treatment of the effluent provided no advantages in terms of disease or potential effects on marine organisms. It is very difficult to design a filtration system for sea water. The farm was sold by the company that developed the fish farm, and at the time of writing this report, the property is up for sale again. There is one experimental tank farm in Norway which uses triangular filters to treat salt water. The technology is very expensive.

Freshwater land-based systems are generally used in hatcheries and farms for trout and other species. Atlantic salmon can be raised to maturity in fresh water only, but the growth rates are generally not as high. One company has designed a system for farming Atlantic salmon (to 2 to 4 kilos) in fresh-water inland environments (Butler). They have detailed plans for farms in Wisconsin, Montana and Arizona, with construction starts planned for summer of 1997. The system is based on aquifers as a water source, and treatment and recirculation of 97% of the water. This is very different from the system attempted in Cedar, B.C., and the company projects that costs will be competitive with the production of salmon in Chile. The primary rationale for this land-based system is to raise fish close to the markets. The owner of the company comments that B.C. does not need land-based facilities at this time, but that it could be useful in the future as a supplement to attain higher levels of production.

There was one marine salmon farm in B.C., owned by Dom Sea, which relocated to Idaho and changed to a freshwater operation. That operation was raising coho to pan size, and has since gone out of business. The market for pan-size fish is very different from and not directly competitive with the market for larger salmon. Most of the freshwater farms raise pan-size fish, primarily trout.

B. OTHER INDUSTRY CONSIDERATIONS

In addition to needing appropriate biophysical conditions to promote fish growth and minimize environmental impacts, there are complicated variables which determine the number of sites required by salmon farmers within an area. The variables include the species of fish, market size and the value-added product to be delivered to meet market demand and specific contracts. The goal is to produce and deliver a fresh, high quality product to international markets in a timely fashion. The larger aquaculture companies develop a detailed management plan which includes maintenance of broodstock, fallowing, and, where possible, careful timing of operations at single-age-class sites.

The aquaculture industry requires infrastructure support in the form of a local support network to manage and service the farm sites. Examples of the infrastructure and support services needed include: cage manufacture and installation, live fish haulage, feed supply, underwater inspection and maintenance, net making and servicing, marine and land transport and service, processing, fuel supply, machine maintenance, boxing and packaging, labour pool, and professional, administrative and banking services. To achieve economies of scale that will allow the industry to improve its competitiveness, fish farmers require sites that will encourage the corresponding growth in support industries.

While salmon farmers tend to be located in areas that are fairly remote to have access to clean water sites, a sufficient concentration of farms within an area is required to sustain a locally based support service for the farms. Some have suggested four farms as the minimum (Needham, pers. comm.). These farms need to be linked through a management agreement or ownership by one company in order to provide flexibility in farming practices and opportunities to share infrastructure. If salmon farmers have access to a larger area or more sites instead of a limited number of defined sites, they can manage their farms with more flexibility using methods such as single-year-class sites and fallowing. This can provide for safer farming practices.

Fish farming is extremely sensitive to environmental conditions and intrusions. In addition to having a site which is relatively secure in relation to natural environmental conditions, farms must be managed to protect the health and safety of the fish. Farm perspectives on visitors vary. Some farms require all visitors to disinfect their footwear before walking on floats, while others are only concerned about potential contamination if people visit more than one farm in a day. Although boats can cause damage by introducing foreign organisms or net tearing from propellers, most escapes caused by boats result from harvesting operations at night.

C. SOCIO-CULTURAL CONSIDERATIONS

Because of the socio-cultural issues described early in this paper, there are many areas considered by some groups to be inappropriate sites for salmon aquaculture because of their values to other users. The Coastal Resource Interests Studies (CRIS) and the Outdoor Recreation Council identified these groups and the types of areas important to their interests. These are:

- settlements, including villages, subdivisions and recreational property,
- anchorages for recreational boaters and commercial use (e.g., fishers, tugboats), some of which have been designated Provincial Boat Havens,
- commercial fishing areas, including prawn fisheries, seiners, and bottomfish,
- shellfish fisheries,
- log handling sites, including marine areas used in helicopter logging operations,
- sport diving sites,
- kayaking and canoeing landing and camping sites and special routes,
- sportfishing areas,
- general recreational areas including beaches, bays, tidal rapids and special features such as waterfalls,
- parks and ecological reserves,
- wildlife viewing areas,
- scenic areas including narrow channels and areas with wilderness qualities,
- archaeological sites, on land (e.g., middens, village sites), in the inter-tidal zone (e.g., canoe skids, fish traps and petroglyphs) and subtidal (e.g., shipwrecks, inundated sites),
- areas important for navigation, especially through narrow channels, and
- First Nations areas of use and spiritual importance.

The location of aquaculture sites close to settlements has caused a high level of conflict in the past and currently. Examples of this are Sunshine Coast farms of the 1980s, and existing operations in Carrie Bay, Sooke Basin and Cypress Bay. Community conflict can have significant social and monetary costs. Perceptions and assessment of siting on recreational users are described in more detail elsewhere in this report.

IV. CONTEXT FOR COASTAL MANAGEMENT

A number of international, national and provincial initiatives set the context for coastal management in B.C., and in some cases for management of the aquaculture industry. These initiatives do not necessarily address siting in particular, but they are important to the discussion of aquaculture in that they provide the broad context for management, they are sources of information, and, to some extent, they set strategic directions at a senior government level.

A. INTERNATIONAL INITIATIVES

IUCN

The International Union for the Conservation of Nature (IUCN) held its first World Conservation Congress in Montreal in October 1996. The Congress adopted resolutions promoting marine protected areas, coastal and marine conservation and management, and protection of fisheries and marine biodiversity.

A resolution specific to aquaculture was adopted by consensus. The Norway delegation indicated that had there been a vote, they would have abstained. The following is the draft provisional version of the resolution. There may still be minor editorial changes including modifications to the note regarding Norway.

CGR 1.73

AQUACULTURE

AWARE that in recent years aquaculture has been repeatedly promoted as a solution to meet growing world food needs;

COGNIZANT that traditional forms of aquaculture can make, and have made a substantial contribution to food supplies in areas of the world where food needs are most acute;

CONCERNED that aquaculture as currently practised is often unsustainable, resulting in a various negative impacts;

ESPECIALLY CONCERNED that the rapid expansion in the development of intensive aquaculture for high value species such as salmon and shrimp can result in degradation of the environment and displacement of coastal fishing and farming communities;

RECOGNIZING the grave dangers posed by the introductions of non-native species;

NOTING that the FAO Code of Conduct for Responsible Fisheries, in Article 9, urges responsible aquaculture development;

BELIEVING that national and regional implementation of the FAO Code, the convention on Biological Diversity and other existing laws and policies must be pursued in a manner which ensures that unsustainable aquaculture is prohibited, before there is more irreversible damage, loss of biodiversity or harm to coast communities;

The World Conservation Congress at its 1st Session in Montreal, Canada, 14-23 October 1996:

1. URGES all States to:
   a) ensure that all aquaculture within areas of jurisdiction is responsible and sustainable;
   b) ensure that artisanal fisheries and dependent coastal communities are not adversely affected by aquaculture development;
   b) ensure the protection of mangrove forests, wetlands and other ecologically sensitive coastal areas,
   c) manage the responsible use, and minimize or prevent the pollution of fresh water supplies (including groundwater) that are important for drinking and for agriculture,
   d) ensure that the use of fish as feed for aquaculture is based on sustainable practices, given its importance as a source of food for people, and if such use occurs, aim to limit the spread of diseases and the introduction of alien species,
   e) ensure that the conversion of agricultural land to aquaculture use is subject to ecologically sound land use planning and where such conversion occurs, that negative ecological and social impacts are minimized,
   f) ensure that the ecological damage resulting from introductions of non-native species is prevented,
   g) ensure that abandoned or degraded aquaculture sites are ecologically rehabilitated with due regard, as appropriate, to the polluter pays principle;
2. REQUESTS the Director General, within available resources, to promote these objectives through IUCN members, Commissions and secretariat."

United Nations

There are a number of initiatives coordinated by the UN in which Canada participates. The Food and Agriculture Organization (FAO), Group of Experts for Scientific Advice on Marine Pollution (GESAMP) have produced a number of documents on coastal resources and effects of pollution.

In November, 1995, Canada together with over 110 other nations adopted the Global Programme for Action for Protection of the Marine Environment from Land-based Activities (GPA). It should be noted that marine aquaculture would fall within their definition of land-based activities, which is intended to mean human activities (Kangasneimi, pers. comm.). The duty to protect the marine environment from human activities was placed squarely in the context of sustainable development by the United Nations Conference on Environment and Development in 1992 (Agenda 21, of which Chapter 17 deals with oceans). In June, 1996, a Discussion Paper on Developing Canada's National Programme of Action for the Protection of the Marine Environment from Land-based Activities was prepared to set the stage for development of a corresponding National Programme of Action (NPA).

At the provincial level, to prepare for collaboration with the federal government, an Oceans Strategy Working Group chaired by the Ministry of Employment and Investment was formed. Members of the group include Environment Canada, DFO and the Province, and they are working on regional action programs in keeping with the objectives of the NPA.

Law of the Sea Treaty

The comprehensive Law of the Sea Treaty is in force because it has been ratified by the minimum number (60) of countries. When a country ratifies it, they are expected to pass domestic implementing legislation. The treaty contains obligations related to protecting the marine environment, protecting living marine resources and conserving anadromous fish stocks. Article 66 sets out the regime for management of anadromous species and provides that states of origin of anadromous stocks have the primary interest and responsibility for those stocks. Canada has not yet implemented domestic legislation that would make the treaty fully in force.

ICES

The International Council for the Exploration of the Sea (ICES), formed in 1902, is an intergovernmental marine science organization currently with 19 member countries. Its principal functions include promoting marine research, disseminating results of the research, and providing advice and information to regulators for the protection of the marine environment and for fisheries conservation. ICES has addressed issues related to marine aquaculture through its Mariculture Committee, which holds conferences every two years. ICES has developed a Code of Practice on the Introductions and Transfers of Marine Organisms.

The North Pacific Marine Science Organization (PICES) was formed in 1992 from the ICES model. To date, it has not had any involvement related to aquaculture but it could in the future.

ICLARM

The International Center for Living Aquatic Resources Management (ICLARM) is another international body that produces information on management of aquatic resources.

Georgia Basin Initiative

The Georgia Basin Initiative (GBI) is a cooperative structure which was established in 1994 at the request of the B.C. Round Table to promote a more sustainable future in the Georgia Basin/Puget Sound bioregion. It has multi-agency representation from B.C. and Washington and was intended to cut across jurisdictional boundaries. Initially the GBI had its own parliamentary secretary. It is now led by the Parliamentary Secretary to the Minister of Municipal Affairs and is part of the Ministry's Growth Strategies Program.

B.C/Washington Environmental Cooperation Agreement

A B.C/Washington Environmental Cooperation Agreement was established in 1992 to address transboundary environmental issues and to ensure coordinated action and information sharing. A number of task forces are focusing on specific aspects, one of which is the Puget Sound/Georgia Basin Task Force.

In 1993, a Marine Science Panel of three Canadian and three U.S. scientists was struck to report on the current condition of, and trends in, the marine waters shared by B.C. and Washington. The recommendations for actions in order of priority were: minimize estuarine wetland habitat loss, establish marine protected areas, protect marine animals and plants, minimize large freshwater diversions, minimize introduction of exotic species, control toxic wastes and prevent large oil spills. The highest priority management recommendation was to conduct strategic planning. Work groups have been set up to address the recommendations of the panel and are now working on action plans on topics such as habitat loss and marine protected areas.

Oil Spill Task Force

A States/B.C. Oil Spill Task Force has been operating since 1990. The members are B.C., Alaska, Washington, Oregon and California. Their purpose is to prevent marine spills and to promote and coordinate emergency preparedness and response. They are working on a coordinated base of information on environmental resources, which is described elsewhere in this report.

Pacific Northwest Environmental Directors

A group called the Pacific Northwest Environmental Directors has representation from Washington, Oregon, Idaho, Alaska and B.C. This group meets twice a year to share information and discuss bioregional issues of common interest. They have been conducting some work on regional indicators to describe the state of the environment.

NASCO

The North Atlantic Salmon Conservation Organization (NASCO) was established in 1982 to provide for the conservation, restoration, enhancement and rational management of Atlantic salmon stocks through international cooperation. Its members are Canada, Denmark, the European Union, Iceland, Norway, the Russian Federation and the United States. NASCO has developed a resolution on measures to minimize impacts from salmon aquaculture on wild salmon stocks. NASCO is opposed to the import of European stocks for aquaculture on the east coast of North America until scientific information confirms that the risk of adverse genetic effects on wild Atlantic salmon stocks is minimal. NASCO has adopted a zoning (geographic) and classification scheme for application of their protocols.

B. NATIONAL INITIATIVES

Oceans Act

The *Oceans Act*, which received Royal Assent in December, 1996, consolidates Canada's ocean related legislation. One part of this *Act* authorizes the development of a strategy and integrated management plans for estuarine, coastal and marine ecosystems, a National Oceans Policy for Canada. The *Act* is intended to involve stakeholders in developing specific mechanisms, planning, guidelines and standards required to bring about sustainable use of the oceans. This process could be relevant to the siting of salmon farms and other aquaculture operations.

An Oceans Management Strategy is being developed under the proposed Oceans *Act.* The Strategy will be based on the principles of sustainable development, integrated management and the precautionary approach. Integrated management plans mean that stakeholders, including federal departments, will not implement plans related to oceans without seeking collaboration of interested parties. It is intended to include provisions to establish agreements with provinces and other levels of government to better coordinate coastal area management. There are strong linkages between the scope of this strategy and the National Programme of Action mentioned above.

Marine Protected Areas

The Marine Protected Areas Strategy is a joint federal and provincial initiative to develop a Marine Protected Areas Strategy for the Pacific Coast of Canada. Agencies involved include Fisheries and Oceans Canada, Parks Canada, Canadian Wildlife Service, B.C. Land Use Coordination Office, B.C. Parks and the Ministry of Agriculture Fisheries and Food. Both the *Park Act* and the *Ecological Reserve Act* are presently used for protected area designations in marine settings.

New aquaculture operations are prohibited in existing provincial and federal marine protected areas (MPAs). Some of the newer MPAs designed boundaries to exclude existing operations, e.g., Broughton Archipelago Marine Protected Area. If new MPAs include salmon farms, the aquaculture operations may be required to relocate to outside the MPAs. The South Moresby and Pacific Rim federal park reserves include large marine areas where aquaculture is prohibited.

Most of the MPAs in B.C. are Provincial Marine Parks which were established as recreational facilities, for the protection of a specific species, or as marine components to terrestrial protected areas. Most of these areas are not "no take" zones for federally managed marine species so their protection of marine life and habitat is limited.

The Pacific Marine Heritage Legacy (PMHL), announced in July 1995, is another joint federal and provincial initiative. An essential element of PMHL is the fostering of marine conservation through partnerships with other levels of government, First Nations, and other interest groups along the entire B.C. coast.

C. PROVINCIAL INITIATIVES

The following paragraphs describe provincial initiatives which relate to planning for coastal areas in general or salmon aquaculture specifically. To set the context for the provincial initiatives, the government has adopted The Provincial Land Use Charter and A Sustainable Environment Charter. The Provincial Land Use Charter is based on a provincial commitment to protect the environment. It articulates the precautionary principle, the principle of full-cost accounting, the importance of nature for its own sake, the importance of development that reduces waste and makes efficient use of resources, the need to match land uses with the inherent capability of the land, the need for social equity, decision-making principles based on consensus-building, and the titles and rights of aboriginal peoples.

The Sustainable Environment Charter adopted by the Clark government sets out principles to guide government under the headings of: stewardship, sustainability, precautionary principle, pollution prevention, user pays, environmental equity, shared responsibility, and enforcement. Commitments to clean air and clean water are discussed in relation to the proposed introductions of the *Clean Air Act* and the *Clean Water Act.*

Gillespie Inquiry

A Commission of Inquiry into Finfish Aquaculture in B.C. was conducted in 1986 in response to public concerns about finfish aquaculture. Part of the government response to concerns was also to declare a moratorium on the issuance of new tenures. The inquiry, conducted by David Gillespie over 30 days, prepared a report on the impact of finfish aquaculture, reviewed government approval and monitoring procedures, and provided recommendations related to government support, information and education, native involvement, fish marketing and processing, marine environment, user conflicts and siting, advertising and referrals, production plans and diligent use, land tenure, and the provincial agency approval system.

All but one of Gillespie's 52 recommendations were implemented, either wholly or in part, including the completion of Coastal Resource Interests Studies. These are described in section VI. C of this report.

Ombudsman's Report

In 1988, the Ombudsman conducted a Review Of Aquaculture And The Administration Of Coastal Resources In B.C. The recommendations included: reconsideration of the statutory authority to provide clear coordinated authority for the administration of aquaculture possibly through enactment of an *Aquaculture Act;* development of a framework for integrated management of resources and activities in the coastal zone with appropriate enabling legislation; and the use of consensual dispute resolution techniques as official policy by all ministries to be available as an option for the resolution of aquaculture-related disputes.

MAIAC

In 1992, the Minister's Aquaculture Industry Advisory Council (MAIAC) was established to provide recommendations to the Minister of Agriculture, Fisheries and Food on how to ensure responsible development of salmon farming in B.C. Its final recommendations, distributed in May 1993, address wild and farmed fish interactions, lake cage culture, native involvement, communication and education, government roles and support, coastal zone management, environment, health and safety, and interactions with other coastal users. The recommendations on siting support the importance of locating farms at high quality sites and suggest that spacing be determined in consideration of environmental information and local consultation. Comments made during the SAR indicated that the recommendations were not based on consensus among all MAIAC members (McBride, pers. comm.).

B.C. Round Table

The B.C. Round Table on the Environment and the Economy was a joint body of government, industry and public organizations. Its mandate was to offer a process of consultation and to stimulate and foster sustainable development. It published a number of theme and background papers including Sustainable Land and Water Use (1991) and Towards a Strategy for Sustainability (1992). These documents cite lack of good information, lack of comprehensive legislation, and lack of integrated management as impediments to protecting the marine environment. They also discuss public requests for integrated coastal management plans to foster the sustainable management of the coastal zone.

SPARK/COFRI

The SPARK (Strategic Planning for Applied Research and Knowledge) Oceans Process (1993) developed a strategic framework for ocean industry, science and technology in B.C. Coastal resource management was recommended as an integral component of the strategic framework.

In response to the SPARK report, a group called Coastal and Ocean Frontiers Research Initiative (COFRI) was formed. The original goal of the group was to encourage industry and government to work together to promote major coastal research projects. Recently, COFRI has focused on research projects more directly related to coastal and fisheries management. In November 1996, COFRI sponsored a Forum on the Future of the West Coast of Ocean Science, Technology and Stewardship. The objectives of the workshop were to address: recent advances in ocean science, ocean priorities needing scientific analysis, and a strategy for addressing these critical issues.

B.C. Government Coastal Planning Strategy

A number of initiatives related to the potential for coastal planning in B.C. have taken place over the years, of which only the more recent ones are described. In 1993, a coastal resource strategy study was co-funded by the Ministries of Agriculture, Fisheries and Food; Environment, Lands and Parks; and Tourism, to explore the possibility of a strategy to address a number of pressing coastal resource management issues in B.C. The study process included a discussion paper, a workshop attended by over 60 government and interest group representatives, and a final report. The report contains suggestions for the development of a coastal resource strategy (Salasan, 1993).

Developing a coastal resource strategy was on the Commission of Resources and Environment (CORE) agenda for 1996 before CORE was disbanded. It now falls within the responsibilities of the Land Use Coordination Office (LUCO), and a coastal strategy workshop was held in June 1996. The agencies attending the workshop indicated that a coastal strategy for B.C. is still needed, that it should be developed right away, that existing government structures should be used, and that the strategy should be a policy document describing a vision for the coast and general policy statements. A small working group has been formed to develop a coastal policy position paper.

Forest Practices Code

In the Forest Practices Code (FPC) Riparian and Harvesting Guidebooks, aquaculture is considered a marine sensitive zone. The FPC cannot sanction the marine component of a plan as a higher level plan, as it does for the upland portion of LRMPs, since the FPC applies only to the forest land reserve. This underscores the need for a formal mechanism to sanction the marine component of plans such as the upcoming Central Coast LRMP.

V. SITING IN OTHER JURISDICTIONS

This section briefly describes some methods, processes and regulations used to site aquaculture operations in other jurisdictions. This is not an exhaustive review, as regulations are always changing, and the rationale for the regulations has not been outlined. Attention is focused on those regulations which could be relevant to B.C. as a comparison or as an example for our consideration. Some evaluation of the programs in other jurisdictions is included.

The requirements and guidelines of a number of jurisdictions are summarized in Table 2 (from Levings et al., 1995). Some of the common standards are: requirements for an environmental impact statement (EIS); distance restrictions between farms, from critical habitat and from ESAs; and specific limitations based on oceanography. The requirements for an EIS in other jurisdictions are not necessarily equivalent to the full EIA process under the CEAA or the *B.C. Environmental Assessment Act.*

Other criteria which are unique are as follows:

- Norway and Japan restrict ownership to support local people and those displaced from fisheries, respectively. No other countries restrict ownership.
- Some countries, including Ireland, Scotland and Chile, promote development in specific areas for social, economic and political reasons (Heen et. al. p. 218).

Table 2: Summary of Criteria used for Siting Salmon Farms at Eight Jurisdictions

Criteria	Site Between Sensitive Areas	Minimum Critical	Distance Ecologically Required	Distance Considerations Costal Use	Distance Similar	Oceanographic Criteria for	EIS or Re Low Tide	Zoning Farms	Boundry Fish Habitat	Depth
Maine	n.c.	n.c.	n.c.	²403m	²402m	n.c. in 'pristine' areas	yes	Yes; farms prohibted		
New Brunswick	²45m herring, weirs,	²8m within a Fed-	²300m limited by	²300m— environmentally	farms prohibited ally designated	Farm sites	no	no lobster ponds sensitive area	ally or Provinc- ecological or	
Ireland span	n.c. ings <0.1m s-1	n.c. production	²1 km considered	²1 kim or current read-	must be annual undefined	unsuitable if 80% fro aquaculture	yes, if	Yes; area must be designated over an	>100 t	time
Washington	n.c. (distance	depends currents	yes considered	²91m depth, production,	must be	graph relating Act applies	yes	Yes; Shoreline Management production	unkown)	on
Norway systems	n.c.	n.c. mouth of	²1 km(b) in certain	distance from LENKA scheme controlled	farms prohibited	accounted for in capacity	no	LENDA scheme to determine	salmon rivers	fjord
Scotland	n.c. has been prepared coast >12,000 m2	n.c. distance from required for fishing ground	²8 km(b) wildlife colories	²0.4 km loch characteristics	²0.8 km from lochs, m2, on open	catalgue of sea sensitive areas productive	yes; in out	Yes; farms prohibited in farms >6,000	a specific	
British Columbia	n.c. relaxed DFO tide-swept channels	20m are proposed	²3km—may considered	125 m(c) biophysical rating Canada	must be on the opposite	accounted for in mended by	yes when farms	Yes; CRIS scheme shore of	scheme	recom-
Iceland	n.c. mouth of salmon	n.c.	²2 km	distance from	n.c. streams contolled	n.c.	n.c.	n.c. 5km to 15 kim (d)		

a—>3 km between grow-out farm and broodstock farmb—closer siting possible between small farms, in open water or with management agreementsc—commercially or recreationally expoited shellfish beds; distance from salmon bearing stresms considered on a case by case basisd—if stream producing 100-500 salmon in last 10 yr, separation distance = 5 km, if stream producing >500 salmon in last 10 yr, separation distance = 14 km, but can be shortened to 5 km if local or sterile stocks usedn.c. = factor not considered as a criteria

#Source: Adapted from Levings et al, 1995.

Norway

A program called LENKA (Nationwide Assessment of the Suitability of the Norwegian Coastal Zone and Rivers for Aquaculture) was developed from 1987 to 1990 as a modelling and accounting system for the allocation of estimated ability of the marine environment to absorb additional organic loading. The program involved classification of coastal areas based on an assumed water exchange rate related to the topography and flushing characteristics. Constraints such as other uses were then considered in order to determine a net capacity. The result was assigned organic loading capacities to 500 geographically defined zones along the coast. Local authorities in a number of districts were using LENKA as recently as 1996 (MAFF comments).

A more recent program called Modelling-Operations-Monitoring (MOM) involves a more mathematical approach to modelling flushing rates. It uses a number of features for different geographic scales. In macro-scale modelling, topography is the dominant feature used. As the scale increases, the effects of tidal action and river runoff become more important in determining flushing rates. MOM is designed to assess the effects of organic loading, and it helps in the determination of carrying capacity for a particular marine basin.

Norway has site selection criteria and minimum distance regulations. The process for approval is that federal agencies, which have established environmental objectives, refer applications to local authorities, then the federal government approves sites. No formal approval of the municipality is required. Current siting criteria include a 20 km spacing from salmon-bearing streams (Fleming, pers. comm.). This is related to the unique hydrology on the Norway coast, where the salmon-bearing rivers are located at the heads of fjords. Another major difference between Norway and B.C. is that the tidal range in B.C. is several times larger than in Norway, giving B.C. much better tidal circulation and exchange in marine basins and through tidal channels (MAFF comments).

One of the weaknesses of LENKA was that the people involved in the analysis were not involved in implementation. Another criticism of aquaculture in Norway is that rapid development of the industry caused pollution problems and conflicts with other users.

Scotland

In Scotland, the Crown Estate office conducts main planning functions, approves and administers leases, consults with relevant parties, and charges rent for use of a site. The Scottish Office has main responsibility for coordinating regulations. The Scottish Office Environment Department is responsible for coordinating coastal policy, planning and environmental regulations. Analysis of potential conflicts is conducted and the cumulative effects of development are considered. Guidelines include a list of Very Sensitive Areas, recommended separation distances, thresholds for the formal environmental assessment of salmon farm proposals, and advice on the content of environmental statements. A comprehensive report on physical oceanography of lochs has helped in siting.

Washington State

In Washington state, applications for aquaculture are made under the *State Environmental Policy Act,* the Department of Natural Resources issues aquatic lands leases, and the county issues a permit under the *Shoreline Management Act* (SMA). The SMA sets out guidelines for the development of master plans to be created by local governments with extensive public hearings. Once aquaculture proposals are approved by state and federal authorities, power is shifted back to local governments which grant development permits in conformity with the plan. There are minimum spacing guidelines from habitats of special significance and between farms. Proposed farms must be described in an EIS. In 1990, an EIS of salmon farms in Puget Sound was completed.

The rigour of the regulations in Washington state has resulted in only 12 net-cage salmon facilities and three other tribal facilities. However, most of the biophysically appropriate coastline is in areas of human habitation and most of the issues around salmon farming in the state result from conflicts with upland owners (MAFF comments).

New Brunswick

In New Brunswick, the Minister of Fisheries and Aquaculture may designate lands as aquaculture land. All leases and occupation permits are then granted in designated areas. There are guidelines for water depth, current speed, site area, stocking density and site capacity, including guidelines for calculating an estimated site potential in terms of the number of fish and the percentage of a site that may be used for sea cages.

Nova Scotia

In Nova Scotia, applications are considered in a concurrent three-pronged review by:

- a committee of technical experts who focus on ensuring the proposed site is biophysically suited to the proposed culture species,
- the Aquaculture Review Network of federal and provincial representatives who carry out an impact analysis from the perspectives of their agency mandates, and
- either a public hearing in the local community or a Local Advisory Committee of stakeholders.

A single agency, the provincial Department of Fisheries, issues both the locational lease and the operational licence. There were 19 new fish farm operations authorized through this process in 1996 (Sweeney, pers. comm.).

VI. CURRENT APPROACHES

Three portions of this section, A. Regulatory System, B. Approval Process, and D. Monitoring are covered in much more detail in Ann Hillyer's report to the SAR. The information herein is derived largely from that report.

A. REGULATORY SYSTEM

The principal federal regulatory body is the Department of Fisheries and Oceans. The primary provincial regulatory bodies are the Ministry of Agriculture, Fisheries and Food (MAFF) and two parts of the Ministry of Environment, Lands and Parks (MELP): B.C. Lands and B.C. Environment. Although B.C. Lands and B.C. Environment have recently been merged within MELP, this report refers to B.C. Lands for historical context. The following are some key definitions which relate to the next portions of this report:

- regulation—a requirement enforceable by law
- policy—a requirement which may or may not be enforceable by law but which is sometimes related to obtaining necessary permits
- guideline—a recommendation which is flexible and usually non enforceable.

Federal Aquaculture Development Strategy

Because the federal and provincial governments each have authority over some issues related to aquaculture, jurisdiction over the regulation of aquaculture is divided between them. A Federal Aquaculture Development Strategy, 1995, outlines the federal role and a cooperative management framework for fostering aquaculture development, with the goal of facilitating long-term sustainable growth of the industry. The document outlines principles for aquaculture development and a strategic plan. In relation to this regulatory framework, the Strategy states that the federal government will undertake a comprehensive review of all federal legislation and any accompanying regulations to identify and remove constraints to aquaculture development, where appropriate.

The core implementation teams for the Federal Aquaculture Development Strategy are industry-government Aquaculture Implementation Committees with representation from industry associations, academia and relevant federal and provincial agencies and departments. The Committee in this region is considering whether amendments to the federal/provincial Memorandum of Understanding are needed.

Navigable Waters

The Department of Fisheries and Oceans is responsible for the protection of navigable waters under the authority of the federal *Navigable Waters Protection Act.* The Coast Guard is the government agency responsible for ensuring salmon farms comply with the provisions of this *Act.* Any salmon farm located on, under or over navigable waters or having improvements that are deemed to potentially impede navigation must have the site, the plans and the specific works approved under that *Act* prior to construction.

Any salmon farm that requires approval under the *Navigable Waters Protection Act* will be considered to be a project for the purposes of the *Canadian Environmental Assessment Act,* and the request for an approval will trigger at least a screening by the Department of Fisheries and Oceans for potential environmental effects. An environmental assessment is required under the federal *Act* if a federal authority such as Department of Fisheries and Oceans exercises a regulatory duty. The approval process required under the *Navigable Waters Protection Act* is the exercise of a regulatory duty.

Vessels towing are allowed anywhere at any time provided that they do not pose a safety hazard. This applies to fish farms so that during plankton blooms, it is permissible for fish farms to be under tow.

Federal Fisheries Act

The federal *Fisheries Act* prohibits the harmful alteration, disruption or destruction of fish habitat. Fish habitat is defined to mean spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes. A person will not be liable under this provision if that person alters, disrupts or destroys fish habitat under conditions authorized by the Minister of Fisheries and

Oceans or under regulations. The current revisions to the *Fisheries Act,* if brought into force, will permit delegation to provinces of certain habitat management responsibilities.

The Department of Fisheries and Oceans produced siting guidelines in 1986. Although these were never adopted, they have been used by local fisheries officers, and they were used in the development of MAFF guidelines. The DFO guidelines limit finfish aquaculture in the most important areas of fish habitat and fisheries. Sensitive fish habitat areas are as defined by Section 31 (5) of the *Fisheries Act.* Some of the draft DFO siting guidelines (currently under revision) which are not included in current guidelines are paraphrased as follows (DFO submission to SAR):

- no net-cages within 1 km of a minor stream populated by anadromous fish, within 3 km of the mouth of a major stream; distances may vary depending on wild fish populations; facilities which 5 km of such streams must have prior approval of Federal/Provincial Transplant Committee; zero tideline will be the start of the stream mouth for measurement purposes,
- no net-cages within 1 km of herring spawn areas designated as vital, major or important; for proposed sites within areas designated as sometimes important or minor, consultation with the local DFO office will be required,
- no net-cages over or within 50 m of sensitive fish habitat, including spawning, rearing, food supply and migration areas upon which fish and shellfish depend directly or indirectly to carry out their life processes, e.g., eel grass beds, kelp beds and rocky reef habitats.

The draft guidelines do not include all herring habitat, and they are unclear on whether salmon migration routes and salmon rearing areas are included. DFO promotes coexistence where possible. DFO also has a general guideline that if the water is deeper than 30 metres, impacts on habitat will be minimal.

The federal Department of Fisheries and Oceans currently is developing guidelines for siting and operating aquaculture facilities. These are expected to be completed within the next year. They will be used to assess referrals made to the department for new sites. They also are intended to assist potential salmon aquaculture operators in selecting potential sites for new salmon farms.

If authorization for harmful alteration, damage or destruction of fish habitat is issued under the *Fisheries Act,* this could be a trigger for CEA. Other triggers would include projects where DFO is the proponent or provides project funding.

The DFO No Net Loss policy does not apply to fish farms since DFO holds that properly located fish farms have no permanent impact on fish habitat.

Federal Provincial Memorandum of Understanding

In 1988, the federal government and B.C. signed a Memorandum of Understanding (MOU) dividing the responsibilities for the administration and regulation of the aquaculture industry. It gives the province the key role (with MAFF as lead agency) with respect to regulating aquaculture in order to avoid overlapping jurisdictions.

The MOU clarifies that the province has the primary authority to determine where and how aquaculture is to be done, whereas the federal government (with DFO as lead agency) retains responsibility for navigation, habitat protection and fish health. Among other introductory statements, the agreement states that Canada and B.C. wish to “advance the orderly growth and development of aquaculture” and “have substantial interests in the prudent development of an economically sound aquaculture sector and the facilitation of investment therein”.

The MOU addresses research and development, education and training, provincial licensing and regulation, federal regulation, coordination between the parties, dispute resolution, compliance and inspection, feed, egg supply, therapeutants and vaccines, and recording statistics. It also provides for the establishment of a Management Committee to oversee the management and implementation of the MOU.

Provincial Agreement for Aquaculture Development on Crown Lands

In 1990, the provincial Ministry of Agriculture and Fisheries and the Ministry of Crown Lands signed a Memorandum of Agreement titled Aquaculture Development on Crown Lands. The purpose of the agreement is to define the respective roles of the ministries regarding aquaculture development and to clarify and streamline administrative processes. It addresses the coordination of information, the form of aquaculture development plans, procedures for processing applications, public competition for aquaculture sites, tenure and licence administration, inspections, consultation for policy and regulatory issues and cooperation regarding planning. According to the agreement, MAFF and Crown Lands must agree to the Development Plans, including all aspects relative to siting, before tenure and licence will be issued. The agreement provides that Crown Lands is responsible for cancelling tenure for non-compliance with the terms of a licence of occupation or lease and MAFF is responsible for cancelling licences for non-compliance with conditions related to aquaculture operations, where such actions are necessary. It further provides that both Ministries will attempt to coordinate site inspections in connection with applications for or monitoring of tenures or licences.

Provincial Crown Land Tenure

Most salmon farms in B.C. operate on provincial Crown land. Title to the foreshore of tidal waters, the area between the high and low water line which is exposed at low tide, is vested in the province. Subaquatic lands such bays, harbours, estuaries and inland waters "within the jaws of the land" are within the boundaries of the province and thus under provincial ownership. The Strait of Georgia, the Strait of Juan de Fuca and Johnstone Strait are within the jaws of the land in British Columbia. The provincial Crown, therefore, owns the beds of these bodies of waters.

Anyone wishing to operate a salmon farm on provincial Crown lands, including subaquatic lands, must obtain tenure of Crown lands for the purpose of aquaculture. B.C. Lands is the lead provincial agency responsible for the administration and allocation of Crown lands in B.C outside of the Provincial Forest. Land is made available under the *Land Act* for salmon aquaculture under an investigative permit or two types of tenure: a licence of occupation, or a lease. An application fee of $107.00, including tax, must be submitted to the Lands Regional Office with the application for Crown land.

An investigative permit allows for the temporary use of Crown land for the purpose of determining the feasibility of developing a salmon farm in the area. It allows the prospective salmon farmer, for a period not exceeding one year, to occupy the Crown land to conduct an investigation of the area and its resources. There is a $500.00 fee for this permit which is payable in advance.

Either a licence of occupation or a lease is required before placement of net-cages or other site improvements required for salmon farming is permitted. A licence of occupation has a 10- year standard term, with the option of a replacement licence after half the term has expired. The annual fee for a licence of occupation is calculated at 7.5% of the zone land value, with a minimum annual rent of $500.00. There is a rental discount of 60% for the first three years of the initial term. A replacement licence of occupation also has a 10-year standard term with the option of another replacement licence after half the term has expired.

A lease is the longest form of tenure available and is the only tenure under which the fish farmer may obtain a registerable interest in land. A lease has a 30-year maximum term, with the option of a replacement lease after half the term has expired. The annual fee for a lease is 8% of the zone land value, with a minimum annual rent of $500.00. There is a rental discount of 60% for the first three years of the initial term. A replacement lease also has a 30 year maximum term with the option of another replacement lease after half the term has expired.

B.C. Lands Aquaculture Policy

B.C. Lands identifies a number of siting and spacing guidelines in its Aquaculture Policy. These include the following:

- applications will not be accepted in areas fronting and 1 km seaward of provincial parks and ecological reserves;
- all marine finfish lease and licence applications will be:
  - 3 km from an existing finfish lease or licence with consideration given to existing lease or licence applications, existing investigative permits and existing investigative permit applications;

  - 1 km from the mouth of a salmonid stream;
  - 125 metres from an existing shellfish lease or licence, with consideration being given to an existing application for shellfish tenure; and
  - 125 metres from a wildstock shellfish bed considered important based on the joint recommendation of the Ministry of Agriculture, Fisheries and Food, the Ministry of Environment, Lands and Parks, and the Department of Fisheries and Oceans;
- the spacing distance between a marine finfish lease or licence and a salmonid stream may be increased upon the joint recommendation of the Ministry of Agriculture, Fisheries and Food, the Ministry of Environment, Lands and Parks, and the Department of Fisheries and Oceans;
- the marine finfish spacing distance may be increased in respect to shellfish applications and tenures if concerns are received from adjacent shellfish farmers or applicants, if recommended by the Ministry of Agriculture, Fisheries and Food;
- the marine finfish spacing distance may be increased in relation to wildstock shellfish beds upon the joint recommendation of the Ministry of Agriculture, Fisheries and Food and the Department of Fisheries and Oceans; and
- the spacing between freshwater finfish leases and licences must be at least 1 km.

The Regional Director of B.C. Lands will consider relaxation of the finfish spacing guidelines if an application demonstrates that the proposal is technically sound and acceptable environmentally and socially. Normally the existing farm owner must concur in writing to agree to the relaxation of the 3 km guideline.

There are no spacing requirements for investigative permits. Where there are investigative permits between fish farms and limited opportunities for any additional fish farms in that area due to spacing guidelines, the Regional Director may issue leases or licences to existing investigative permit holders only, issue leases or licences through public competition among the existing investigative permit holders, or issue leases or licences by direct offer or public competition.

If the tenure is expected to affect the right of access of a riparian or upland owner, the applicant is required to obtain the written consent of the upland owner for the proposed use, for the duration of the tenure. Applicants for a licence of occupation or lease are required to notify in writing adjacent tenure holders and landowners within one kilometre in either direction of the proposed salmon farm and about 300 metres inland.

Aquaculture Licence

As well as obtaining approval for the physical location of a salmon farm, anyone who carries on the business of salmon aquaculture in B.C. must hold a licence to operate a salmon farm issued under the provincial *Fisheries Act*. The signal to MAFF that a farm is in operation is the introduction of fish to the site. MAFF is the provincial body responsible for the administration of licences for salmon aquaculture operations under the authority of the B.C. *Fisheries Act* and the Aquaculture Regulations.

An application for a new licence or a renewal of a licence is made to the Minister of Agriculture, Fisheries and Food. A licence, when granted, is valid for one year from the date it is effective. A separate licence is required for each salmon farm location.

For salmon farms located on provincial Crown land, the Aquaculture Development Plan submitted to B.C. Lands is forwarded to MAFF for approval during the review of the application for tenure. However, if the proposed salmon farm will operate on private land or land not administered by B.C. Lands, an Aquaculture Development Plan must be submitted to MAFF along with the application for an operating licence.

Terms and conditions contained in licences for salmon farming include the following provisions, requiring the licence holder to:

- comply with its approved Aquaculture Development Plan,
- obtain an approved amendment to its Aquaculture Development Plan for an increase in production greater than 20% or for a change in the mode of operation,

- raise only the species listed in the licence, after obtaining all necessary authorizations for import and transplant,
- take reasonable precautions to prevent escape and report escapes that occur,
- employ reasonable practices for preventive predator control and disease control,
- keep and make available records to verify compliance with the terms of the licence, the Aquaculture Regulation and the provincial *Fisheries Act.*

MAFF has broad discretion to establish controls on fish farms through terms and conditions of the aquaculture licence. The Minister is authorized to suspend or revoke a salmon farm licence, in addition to all other available penalties, if the holder violates a provision in the *Fisheries Act*, the regulations or a condition of the licence. Before suspending or revoking the licence, the Minister must conduct an investigation. The Minister also must hold a hearing if requested to do so by the licence holder.

For some time it has been contemplated that standards for the operation of different types of aquaculture facilities would be developed by MAFF in consultation with the industry and other government agencies. For instance, written materials explaining the terms of an aquaculture licence make reference to the development of operating standards to deal with issues such as preventive predator control, preventive disease control and disease treatment. These could be expanded to include siting issues such as visual and noise impacts, use of adjacent upland areas, etc.

Operating licences issued under the provincial *Fisheries Act* could then be made subject to compliance with those operating standards. Although some work has occurred in the development of operating standards, there are no standards in effect at present. The need to determine normal farm practice for the purposes of the *Farm Practices Protection (Right to Farm) Act,* discussed below, may accelerate completing these operating standards. However, it is not clear if they will be regulatory standards or guidelines.

MAFF will consent to the transfer of a licence when there is a change of ownership if the following conditions are met:

- the site has not been reassigned within one year,
- the site is being used diligently,
- the site is currently licensed by the branch, and
- the assignee or new owner agrees to operate the salmon farm according to the existing approved development plan.

Heritage Conservation Act

Fish farm operations have the potential to conflict with archaeological resources protected under the provisions of the *Heritage Conservation Act.* Most coastal archaeological sites are located on upland areas close to the shoreline. Some, such as canoe skids, fish traps and petroglyphs, are found within the inter-tidal zone, and others, such as shipwrecks, are subtidal.

The *Heritage Conservation Act* provides for the protection of objects and land, including land covered by water, that have heritage value to British Columbia, a community or an aboriginal people. Heritage value is defined as the historical, cultural, aesthetic, scientific or educational worth or usefulness of a site or object. The *Heritage Conservation Act* protects archaeological sites through designation as provincial heritage sites or through automatic protection by virtue of being of particular historic or archaeological value.

Protected archaeological sites may not be altered without a permit. Permits are also required to conduct archaeological impact assessments, for the systematic recovery of archaeological data from sites, and for unavoidable impacts from development activities. Penalties include fines up to $50,000 for an individual and $1,000,000 for a corporation. The *Act* is binding on government, and in matters of heritage conservation, the *Act* takes precedence over other legislation.

Local Government

Local government also may be involved in the siting of salmon aquaculture facilities. The authority of local government includes planning and regulation of the use and development of land, including areas of Crown land or water surfaces where leases or licences of occupation have been granted. Under the *Municipal Act,* local governments may state, in their official community plans, broad objectives, policies and guidelines respecting present and proposed land uses and development. These may be implemented using zoning bylaws, permits and other instruments. Regional districts and the Islands Trust also may use rural land use bylaws for planning and regulation of land, including the surface of water. The power to regulate includes the power to prohibit any use or uses in any zone or zones.

The B.C. Lands Aquaculture Policy provides that the siting of all aquaculture tenures will be consistent with local government bylaws.

Some local governments have enacted zoning bylaws with specific provisions relating to aquaculture. For example, the Comox-Strathcona Regional District, an area in which a number of salmon farms are located, has electoral areas that have adopted bylaws reflecting different approaches to zoning for aquaculture.

The Cortes Island Zoning By-Law designates four types of aquaculture zones, two of which permit active aquaculture (which includes salmon farming) over large coastal areas. Both zones permitting active aquaculture require that no structures prevent access by an upland owner to water or over the surface of water to navigable areas. The two zones have different requirements regarding the size of the farm sites (maximum site area of 12.15 hectares or 8.1 hectares). The zone permitting the smaller sites adds a spacing maximum of one finfish aquaculture site per three kilometres of shoreline with a minimum separation of one kilometre between finfish aquaculture sites.

Zoning for the electoral area of Quadra Island, also in the Comox-Strathcona Regional District, has followed a different approach. The Quadra Island Official Community Plan Bylaw, 1996 sets out policies for fisheries and aquaculture which expressly recognize the importance of the aquaculture industry as well as the need to ensure protection of sensitive areas and consider the impact on the environment, other uses and the community. The policies also state that the management, protection and enhancement of foreshore values can be most effectively accomplished through direct and active consultation between the appropriate government agencies and the community.

The Quadra Island Zoning By-Law permits active aquaculture in one of its zoning designations over very specific coastal locations. These locations reflect the areas where salmon farms were already located at the time the zoning was adopted. A proposed new salmon farm site in any other area would require a change in zoning to active aquaculture, a process that would involve a public hearing.

Electoral area J in the Comox-Strathcona Regional District has adopted a Rural Land Use bylaw for Desolation Sound which also includes a designation for active aquaculture. The bylaw states that active shoreline developments will be reviewed on a site-specific basis through open communication and referral between the community and all government agencies whose interests may be affected. It also provides that temporary aquaculture permits will be considered if certain conditions are met, including returning the site to its original condition if aquaculture zoning does not occur, with security to guarantee completion of the rehabilitation of the site.

The Regional District of Mount Waddington includes the Broughton Archipelago, the study area for the Salmon Aquaculture Review. The general zoning bylaw for the Regional District of Waddington does not designate aquaculture zones, nor does it restrict finfish farming. The Official Regional Plan contains only general language about commercial development and nothing specific to salmon farming. The Malcolm Island Official Community Plan establishes an aquaculture policy to exclude finfish farms unless located on land.

The Regional District of Alberni-Clayoquot permits aquaculture in four designated zones. Three of the designated zones permitting aquaculture allow upland aquaculture only. The fourth zone permits both upland aquaculture and foreshore and water-based aquaculture. Zoning requirements for all zones permitting any form of aquaculture provide that nothing is to be done that will become an annoyance or nuisance to the surrounding areas by reason of unsightliness, the emission of odours and noise including generator or pump noise and the use of floodlighting.

The Regional District of Alberni-Clayoquot initiated and coordinated the development of the Barkley Sound Planning Strategy. The Strategy designates aquaculture priority areas in recognition of the high suitability for such uses, but does not limit aquaculture elsewhere. The Strategy also recommends that sites which are particularly suited to aquaculture be reserved, that existing salmon farms be maintained, and that conversion of existing fish farm leases to non-aquaculture uses not be permitted.

Provincial Environmental Assessment

The possible application of the provincial *Environmental Assessment Act* (EAA) to salmon farming activities will be considered following the SAR being conducted by the Environmental Assessment Office. It will be necessary to determine if the provisions of the *Act* will apply to new and expanding salmon aquaculture operations and, if so, whether all farms will be subject to review or only those that exceed a particular threshold size.

The purpose section provides that the *Act* should:

- promote sustainability,
- provide for a thorough and integrated assessment of the environmental, economic, social, cultural, heritage and health effects of projects,
- prevent or mitigate adverse effects,
- provide an open review process, and
- provide for public participation.

If the *Act* applies, a reviewable project may undergo one, two or three stages in the review process: the Application phase, the Project Report phase and the Public Hearing phase. Not all projects proceed through each of these phases.

The application stage involves presenting available information about the project and project setting, with preliminary identification of potential effects, issues and proposed mitigation measures. The typical steps in preparing an application include: an outline of the project concept and description, including alternative sites; preliminary consultation with government and non-government groups; collection and analysis of available data on environmental, economic, social, cultural, heritage and health conditions in the vicinity of the project; and an overview analysis of key issues, major data gaps, and the programs proposed to fill those gaps.

If a project proceeds to the second phase, the Project Report stage, section 22 of the *Act* provides a list of issues that may be required to be addressed in a project report, including but not limited to issues such as:

- why the site was chosen and a description of alternative sites considered,
- the existing environmental and other characteristics that may be affected,
- the potential for direct and indirect effects,
- potential impacts on the exercise of aboriginal rights,
- health issues,
- the potential for accidents with adverse effects, and
- data to assess the probable cumulative effects.

A project committee, comprising of representatives of various government agencies and First Nations, provides advice, analyses and recommendations on projects throughout the review process. It is also possible for a public advisory committee to be established under the *Act* to advise and make recommendations to the project committee on matters of public concern. Throughout the review process the public has guaranteed opportunities for comment within timeframes set in a regulation.

The *Act* also allows for category assessments so a whole category of reviewable projects could be reviewed and specifications developed that would be used in the individual assessments of projects. Proponents would be required to include these specifications and provide information required for the entire category in applications for review of a particular project.

Farm Practices Protection (Right to Farm) Act

A new piece of provincial legislation has the potential to affect some aspects of salmon farming in the future, including aspects related to operating practices. The F*arm Practices Protection (Right to Farm) Act*, passed in 1995, provides a number of measures to protect agriculture in British Columbia. It applies only to existing farms. If the requirements of the *Act* are followed on a farm operation, a farmer cannot be sued in nuisance for any odour, noise, dust or other disturbance resulting from the farm operation and a farmer cannot by injunction or other court order be prevented from carrying on that farming operation. Under the *Act,* farm operations include aquaculture as defined in the provincial *Fisheries Act* when carried on by a party licensed under that *Act.*

For a salmon farmer to be entitled to the protections noted above, the farm operation must be conducted according to normal farm practices, under a valid aquaculture licence issued under the *Fisheries Act,* and in compliance with other legislation and land use regulations.

Instead of bringing an action in nuisance, it is possible to bring a complaint about odour, noise, dust or other disturbance from a farm operation to the Farm Practices Board, which is established by this *Act.* The Board will determine whether or not the practice complained about is a normal farm practice. If the Board finds that it is a normal farm practice, it must dismiss the complaint. If the Board finds it is not a normal farm practice, it must order the farmer to cease the practice or modify it to be consistent with normal farm practice.

The *Farm Practices Protection (Right to Farm) Act* also amended the *Municipal Act* with provisions that may affect local government's regulation of aquaculture operations when the *Act* applies to aquaculture. First, the Minister of Agriculture, Fisheries and Food may establish standards to guide local government in the preparation of rural land use bylaws, zoning bylaws and bylaws related to this *Act.* Second, the Lieutenant Governor in Council may declare by regulation that specific new provisions of the *Municipal Act* prevent and enable a local government to enact certain bylaws with respect to aquaculture. Third, there are requirements for checking consistency among local bylaws and provincial regulations.

If a salmon farm has a valid aquaculture licence, when a local government wishes to make bylaws affecting that farm it will have to determine whether these new sections of the *Municipal Act* apply to it and, if so, will have to obtain the approval of the Minister of Agriculture, Fisheries and Food before adopting new bylaws which would affect that farm.

The Ministry of Agriculture, Fisheries and Food currently is developing operating standards that would be used, in part, to determine what constitutes normal farm practice for aquaculture under this *Act.*

B. APPROVAL PROCESS

Application and Referral Process

To begin the process of obtaining permission to operate a salmon farm on Crown land under a licence of occupation or a lease, an applicant identifies a foreshore area, places a posting notice at a conspicuous point on the upland, and submits to the regional office of B.C. Lands a notice of intention to apply for a disposition of Crown land. The notice describes the area by way of a legal description or a distinctive geographic feature. The applicant for a licence of occupation or a lease may be required to provide public notice of the application, if the Minister of Environment, Lands and Parks considers it in the public interest.

An application for a lease or licence of occupation, but not an investigative permit, must be accompanied by an Aquaculture Development Plan. Included in the Aquaculture Development Plan is detailed information about matters such as: the location, the area required, biophysical and operational characteristics, the species to be grown, the specific type of operation, the volume of production, water quality factors, facilities layout, schedules of improvements and production, factors relevant to site capacity, and other coastal users in the area.

The application is reviewed for completeness and referred to other government bodies, First Nations and other interested parties, who are invited to comment on the application. Referrals normally are made to the following:

- Ministry of Agriculture, Fisheries and Food, regarding the technical feasibility of the proposed operation and the biophysical capability of the site to support the proposed operation;
- B.C. Environment, regarding the potential environmental impact and the monitoring requirements;
- Department of Fisheries and Oceans, regarding the impact on wild fish stock and fish habitat;
- Environment Canada, regarding water quality issues;
- Coast Guard, regarding any navigational hazards;
- Ministry of Forests, District Office, regarding impacts on coastal logging or forest recreation;
- Local government authorities, regarding local planning and zoning requirements and the degree of public acceptability;
- Ministry of Small Business, Tourism and Culture, regarding coastal tourism;
- First Nations, regarding any possible infringement on aboriginal rights;
- other interest groups, regarding the interests of other groups potentially affected (where Coastal Resource Interests Studies have been undertaken, applications are referred to groups which have expressed interest in an area); and
- Parks Branch, regarding possible impacts, but only where the proposed salmon farm is close to a recreational area, or a proposed or existing ecological reserve or park.

The following are the tasks undertaken by the key referral parties and B.C. Lands in their review of applications. Issues raised by the agencies contacted are noted.

Department of Fisheries and Oceans

Salmon farm referrals are sent to the Aquaculture Coordinator and the Habitat Branch of DFO. Applications are reviewed to determine their potential effects on fisheries resources and commercial and sport fishing. An office review using maps and inventory data is conducted first. If there are questions or a lack of data, field staff are contacted. The Habitat Branch provides their referral comments directly to B.C. Lands. Before 1988, DFO issued aquaculture licences. A dive survey by DFO or the applicant was a required part of the process. Now DFO staff are reviewing rather than approving applications.

There are diverse responsibilities and perspectives within DFO and fish farm applications are not generally referred to other specialists such as those dealing directly with marine mammals, shellfish or herring. For example, applications are usually brought to the attention of the marine mammal group by B.C. Environment. This has caused concern because fish farms have been approved in sensitive marine mammal habitats.

Generally, DFO notes that the trend will be towards better information and consultation than occurred in the past. There are still significant gaps in information such as the effects of different loading densities on the environment. The process also currently suffers from a lack of flexibility in farm tenures and a lack of guidelines adopted by all agencies.

Environment Canada

The Environmental Protection Branch of Environment Canada reviews salmon farm applications with respect to water quality issues and effects on habitat. They review the site location on maps and computer data bases, and check the improvement plans for items such as the structures, pilings and privy. The agency has a checklist, and the appropriate items are checked off for each application. Fish farm applications are rarely opposed. The referral process is considered acceptable. Environment Canada would like an immediate letter back upon approval of applications.

Coast Guard

When the Coast Guard is asked to comment on an application for a salmon farm, they review it in relation to navigation criteria:

- will the farm impede navigation and the normal activity and ability to manoeuvre?
- will the farm affect riparian rights, e.g., the ability to access property?
- will the farm affect other uses, e.g., anchorage, boat launch, fishing?

If there is deemed to be no substantial interference with navigation (Section 5(2) of the *Navigable Waters Protection Act*), farms are considered exempt from the provisions of the *Act.* When this occurs, which it does in the majority of cases, the Coast Guard cannot impose conditions on the farm and there is not as much checking. The degree of interference is difficult to measure, and there has been debate about whether any farms should be considered exempt. If the farm does present a substantial interference with navigation, a licence is required under Section 5 (1) and an environmental impact review under the *Canadian Environmental Assessment Act* is triggered.

The Coast Guard sometimes field checks the sites of applications. They also contact user groups such as First Nations or Council of Marine Carriers if they have questions about potential effects on users. Once farms are in place, they are checked on a random basis. As there are only two officers for all of B.C. and the Yukon, they may check farms when they are passing by, but they primarily respond to complaints.

The Coast Guard is indifferent as to whether farms are located in a channel versus a bay. Channel locations are considered acceptable provided that boats can go safely around the farm with reasonable clearance.

Ministry of Agriculture, Fisheries and Food

When MAFF receives an application as a referral from B.C. Lands, they first double check whether the farm is in a CRIS No Opportunity area. If it is, they inform B.C. Lands immediately to determine if they want to continue with the referral. MAFF then conducts the following tasks:

- check of biophysical suitability studies for aquaculture rating and notes,
- check of marine charts for 3 km spacing, bathymetry, potential conflicts with protected areas, First Nations, tourism and other users,
- check of development plan for completeness and accuracy,
- assessment of technical aspects of development plan including equipment proposed,
- assessment of biophysical characteristics of the site including depth and flow, using a spreadsheet model which predicts sediment anoxia under the farm based on proposed fish biomass and site characteristics, and
- check of most sites (about 80%) by boat.

The MAFF analysis of development plans determines whether or not the site biophysical attributes can support a salmon farm of the physical size and production level and using the species and culture technology proposed. Based on this analysis, MAFF establishes the maximum site production and can set licence conditions as needed, including the type of net-cage equipment and anchoring systems, in order to minimize risks of damage to the farm and any consequent negative environmental impacts.

If the plan appears to be overambitious, that is related back to the company, negotiation occurs, and a revised development plan may be submitted. Some additional details about MAFF’s review process are described in section V. A. of this report. MAFF typically spends two and a half days reviewing each application.

There are various perceptions within MAFF about the referral process. MAFF staff acknowledge that the process has become very difficult for B.C. Lands because of the enormous pressure from three primary agencies: B.C. Environment, MAFF, and First Nations. Some MAFF staff perceive that B.C. Lands has become more likely to disapprove sites recently because of the concerns which are raised. MAFF points out that a number of different agencies duplicate the same review process. There are also concerns about consistency in criteria used by the agencies involved, e.g., there is no agreement among MELP, DFO and MAFF on the definition of a salmon stream.

B.C. Environment

Two branches within B.C. Environment review salmon farm applications: Environmental Protection Branch and Fish and Wildlife Branch.

The Environmental Protection Branch focuses particularly on waste management concerns, but because the ministry is short-staffed, they have been asked to cover broader environmental concerns as well. When they receive a salmon farm application, they conduct an office review first, checking maps, marine charts, CRIS maps and inventory maps to identify environmental resources, bottom configuration, currents and flushing. It a site fails the office review, they do not support it.

When problems are not identified in the office review, they field check sites if possible. One concern is that they do not have enough staff or resources to inspect every site. In the field, they check for high use by salmonids or other bait fish, high priority habitats such as eel grass beds or bull kelp beds, the degree of exposure, and other resources such as eagle nests. Staff then evaluate the proposed production in relation to the receiving environment.

The Environmental Protection Branch has a number of concerns about the referral process. One is that each application is for a fixed level of production and they are requested to support or oppose the application. This is a concern because sometimes a lower level of production would be acceptable on a site, but the current process does not allow for interaction and negotiation directly with the proponent.

Another concern is that the Environmental Protection Branch requires site-specific information on currents in order to assess applications, and that information is not regularly required from proponents. In some cases, current information at one depth is acceptable, and in some situations, they require data from more than one depth. There are presently no guidelines for determining when the more detailed information is required.

The development application includes a checklist of biophysical characteristics of the site. B.C. Environment would like a complete mapped inventory of biophysical resources and existing use in an area within about 2 km of the proposed farm. This would speed and improve the evaluation process.

Another challenge in the review process is determining the upper threshold for expansion. Generally if there is sediment build-up and anoxia under a farm, expansion is not approved. Agreements with MAFF on an acceptable level of deposits would facilitate the evaluation of expansion plans.

A generally acceptable goal of fish farming supported by government, interest groups and industry is that operations be sustainable, but there are presently no documented criteria for measuring that. Other industries with a point source of discharge use an initial dilution zone to set limits on pollution. A comparable tool for measuring impacts is required for salmon farms, perhaps using the footprint under the pens as an initial dilution zone. This could then be used to set environmental objectives and criteria.

Sometimes there is disagreement among agencies on a farm application. The Environmental Protection Branch would like to see a better dispute resolution process to address disagreement. This is particularly important because the level of production is now managed only by MAFF, whereas it used to be part of the tenure agreement with B.C. Lands. B.C. Environment cannot cause MAFF to deny a licence, and they have no means to control pollution if an operator has a licence from MAFF.

The referral process for siting of fish farms is one of the only opportunities that MELP has to review the company's development plan and comment on operations. They need to know at this stage in the review how the operation is planning for environmental protection. The establishment of environmental management systems designed to identify risk and the options available to reduce or eliminate risk greatly enhance the operator's ability to meet these challenges.

Another concern expressed by the Environmental Protection Branch is that MAFF will only take direction from the agency with a direct mandate for management of a species. For example, if a proposed site is near a seal haul-out and B.C. Environment requests a predator net, MAFF refers the comment to DFO. A predator net is only required by MAFF if DFO requires one.

The Environmental Protection Branch would like to see presentations from the proponent directly to the Regional Fish Farm Review Committee (RFFRC). They noted that the RFFRC is functioning well but that there isn’t legislation to support some of their activities.

In addition to referrals on siting, the Environmental Protection Branch follows a referral process when processing waste management permit applications.

The Fish and Wildlife Branch reviews applications to determine potential effects on fish and wildlife, acknowledging that they only have jurisdiction over upland resources. They seek to identify proximity to streams, waterfowl concentration areas, migration routes, eagle nesting areas, and other habitats such as bear use areas. They are concerned about escaped farm salmon and their potential effects on freshwater ecosystems. They check inventory data and make contact with field staff as required. Reviews of applications are more thorough than they were in the past.

Some of their concerns with the process revolve around the level of bureaucracy involved, though it is felt that the RFFRC has improved communications. They would like to know more about the environmental management systems and technology proposed by applicants. For example. B.C. Environment is not familiar with the new technology being proposed for more exposed marine locations.

B.C. Environment commented that the current regulatory process is an approval process, and that environmental protection is difficult without an environmental planning and management process which includes defining ecologically sensitive and high productivity sites.

Archaeology Branch, Ministry of Small Business, Tourism and Culture

The Archaeology Branch has requested B.C. Lands to refer to them any applications with an upland or intertidal component. They do not know if they are sent all of these applications or not. The Archaeology Branch has received complaints about use of the upland and foreshore by fish farms for activities such as damming a creek, location of a storage structure, or garbage disposal. These activities may or may not be approved.

When the Archaeology Branch receives an application, they refer to their inventory to check for recorded archaeological sites. If there are no recorded sites and the area has been adequately surveyed, the branch will indicate that it has no objections to the application. If the area has potential for archaeological resources and has not been previously surveyed, an archaeological assessment, in accordance with the British Columbia Archaeological Impact Assessment Guidelines, is normally requested as part of the approval process. Whether this is required of the applicant or not has varied among B.C. Lands Districts.

Tourism Branch, Ministry of Small Business, Tourism and Culture

Salmon farm applications are reviewed in relation to the Coastal Tourism Resource Inventory to determine if there are existing uses or facilities near the site, and to identify the tourism capability. Digital aerial photography of the coast is also checked. The impact of the farm on existing or potential tourism operations is then evaluated. Sites which are of high value for tourism are often the locations desired for salmon farms.

A relatively large percentage (about 50%) of the sites requesting expansions or additions are in areas which would not have been approved by MSBTC originally. Since the farms are in place, only the incremental effect of the expansion on tourism is evaluated.

Since MSBTC sits on the Fish Farm Review Committee (FFRC), their comments on the referral process were in relation to that committee. They commented that there have been challenges in establishing effective working relationships among the agencies, but that the FFRC now functions well. One concern is that the FFRC rarely speaks directly to proponents, and that if that occurred there would be more opportunity to work interactively to reduce concerns about the application.

Ministry of Forests

The various forest district offices have slightly different ways of approaching referrals. Generally, applications are reviewed to determine whether the farm will affect: access to adjacent upland; any upland forestry activities such as logging, road building, silviculture, siltation or herbicide application; areas for log dumping, booming or storage; or forest recreation sites. Fish farm applications tend to apply for areas that are used for log handling. Various staff within forest district offices such as the Small Business planner, TFL planner and Recreation Officer are consulted as appropriate. Timber licence holders are also sometimes contacted.

Generally the referral process is considered acceptable. One MOF office has a concern with the quality of the mapping submitted, indicating that the smallest acceptable scale is 1:20,000. Another office expressed concern about the amount of time required for referrals, and had one suggestion that farms apply for future expansions at the time of the initial application to minimize the need for an additional referral.

First Nations

Referrals to First Nations are sent to the tribal council or individual First Nations. One major challenge is getting referrals to the right person. According to First Nations representatives, referrals should be sent to the tribal council and the individual First Nation. Government has had trouble identifying the appropriate contacts.

First Nations review applications are based on their knowledge of the site area. Some First Nations indicated that they have the local knowledge required to identify proximity to food gathering sites, reserves and historic use sites. Others indicated a lack of resources and information available for research and evaluation of applications, and a need for completion of traditional use studies.

The 30-day response time is a problem for First Nations. They consider the time inadequate to reach the appropriate people and provide the relevant information, given their current resources.

First Nations also expressed mistrust about referrals and a lack of confidence that their comments would be heeded.

Regional Districts

The regional districts have different approaches and perspectives on the referral process for salmon farming.

The Mount Waddington Regional District comments on salmon farm referrals from a zoning perspective primarily. Aquaculture is generally allowed as an agricultural use, so the regional district has been permissive in its approach. They suggest that the proponent contact the upland owner or timber licence holder and the regional district staff refer applications to the area director responsible. Until about four years ago, there were no apparent problems with this approach. More recently, the level of conflict has made it difficult for the regional district to restrict its comments to the zoning perspective. They believe that the referral process is very difficult for the salmon farming industry and that there are few procedures which support the industry, one comment being that CRIS mapping is no longer used.

The Comox-Strathcona Regional District (CSRD) has a zoning bylaw or a rural land use bylaw in most locations, so they check applications for conformance with those bylaws and send them to the area director responsible. On the west coast where they do not have zoning, or if there is no prezoning or prior support for aquaculture, they generally oppose applications unless there is a bylaw amendment. The regional district is working towards having an integrated resource and land use plan for the west coast which would identify where aquaculture could occur.

The CSRD's greatest concern with the referral process is that the regional district is often consulted very late in the process. They would like to see a single application for fish farms starting with the regional district, with copies to B.C. Lands and MAFF, so that the three review processes could occur simultaneously. The regional district is most in touch with public perceptions and so the CSRD would like to be in a proactive rather than a reactive role.

The Alberni-Clayoquot Regional District (ACRD) reviews applications from a technical perspective to determine whether they conflict with any bylaw or study they have participated in, e.g., Barkley Sound Study, CRIS. They also refer to an aquaculture site catalogue identifying sites with high potential, prepared by their own economic development staff. The ACRD forms a preliminary conclusion, then sends the application to the Advisory Planning Commission (APC) for the area. The APC comments are brought to the Board by the area director, and through considering the staff comments and the APC views, they make a decision. Some applications require rezoning, in which case they are given conditional approval. Disapproval of sites can be based on conflicts with other users, or impacts on fisheries resources using local knowledge as a source.

The ACRD has several concerns about the referral process. Consulting with the APC involves a three-to-four-week turn-around so the 30-day comment period is insufficient. The ACRD has had problems obtaining complete information about applications, such as the development plan, and they are unable to make appropriate comments without full documentation of proposals. The third problem they have had is Crown Lands amending the terms of licences without consulting the regional district. Items with local bylaw implications have been changed without their input.

B.C. Wildlife Federation

The B.C. Wildlife Federation (BCWF) was contacted in this review because they have been included in the referral process for many years. A review of fish farm tenure files at B.C. Lands found comments from BCWF on every file opened. When the BCWF receives a referral, they check a complete collection of maps including parks plans, coastal plans, CRIS maps, and reports from Economic Development Commissions. They also contact their members who are familiar with particular areas, proponents and biologists.

The BCWF is disillusioned with the referral process and is not sure if their comments make a difference. Through their close contacts with government, they feel that staff in various ministries, especially the biologists, are frustrated by their lack of resources and inability to check sites and conduct adequate monitoring.

B.C. Lands

B.C. Lands reviews applications for completeness and compliance with siting guidelines and other siting policies. The application is checked in relation to the tenure administration system, the eligibility of the applicant, reference maps, legal description, and the Crown Land Registry Application System.

B.C. Lands usually visits proposed sites, at least by air. The site evaluation includes review of public beach access, natural hazards, contamination, potential impacts on other users, impacts on resources and physical processes, scenery, spacing, other potentially higher economic uses and concerns raised by referrals or the public. All comments made through referrals and the public notice are assessed. B.C. Lands checks inventory maps and tries to verify information received. They often contact agencies again to request further information or discuss comments received from other parties. They also ask the applicant to contact concerned groups directly to attempt to resolve concerns. One of the challenges for B.C. Lands has been to find referral contacts who respond to requests, are knowledgeable about the information required, and are willing to contact others who may have relevant information.

After completing this evaluation process, B.C. Lands makes a decision. The referral process is intended, in part, to determine the biophysical suitability of the proposed site for salmon farming and to assist in both the identification of potential adverse effects of allocating Crown land for a salmon farm and the prevention or mitigation of potential effects. The objective is, given the available information, to determine if aquaculture is the highest and best use for the site. B.C. Lands will usually disapprove an application if referrals identify significant concerns, but an application is not necessarily disapproved if there are some negative referrals and public comments.

Information derived from the B.C. Lands Tenure Administration System in January 1997 summarizes the current status of tenures and applications since 1986, which is when record-keeping in this system began. The system could include multiple tenures for one site, because as soon as a new application is received it is recorded as a new item.

Tenure Summary

Tenure Type	Active	Cancelled	Expired
Licence of Occupation	122	192	54
Investigative Permit	1	39	489

Application Summary

Tenure Type	Cancelled	Disallowed	Offered and Accepted
Licence of Occupation	93	263	309
Investigative Permit	100	205	472

New and replacement dispositions of Crown land normally are made by a direct offer to an applicant in response to an application from an individual party. However, in some circumstances, such as where there are competing applications for aquaculture for the same parcel, new dispositions are made by public competition. If competing applications over the same parcel are for different uses, such as salmon farming and log handling, the disposition of the Crown land will be determined on the basis of the highest and best use of the land as decided by the Regional Director of B.C. Lands, in consultation with other appropriate agencies.

When the site is approved, the regional office of B.C. Lands offers a prospective salmon farmer the appropriate form of tenure, allowing site development, capital works, schedules of improvements and other steps to establish the aquaculture operation. The tenure is subject to rent, performance security, and conditions which must be met prior to signing the document. Other interested parties also are advised. The application is forwarded to the Crown Land Registry Branch for a formal update of the reference map.

Tenure Violations

If a salmon farm is found to be in trespass, i.e., in a location without a licence or lease or extending beyond the boundaries of the licence or lease, the owner is immediately contacted and the situation is discussed. The farmer is requested to move the farm and to apply for an amendment if the approved tenure location is unacceptable. Double the normal rent is charged for the period that use occurred outside the tenure.

If a tenure holder does not realign the farm to within the boundaries or apply to amend the area of the tenure and the development, trespass procedure is initiated if all other avenues for resolution fail. There is no formal budget for trespass, so only if this is a major item will it undertaken and funded.

Replacement Licences or Leases

If B.C. Lands receives an application for a replacement licence of occupation or replacement lease, it normally does not repeat the full referral process followed at the time of an application for new tenure. However, a referral of the application for replacement tenure would be made to:

- an agency that had expressed a concern about an issue within that agency's responsibility, during the time of the previous tenure,
- an agency responsible for an issue of concern where that issue had been brought to the attention of B.C. Lands by another party during the existing tenure period;
- to the appropriate First Nations, in cases where there could be an impact on the aboriginal rights of those First Nations; and/or
- to the members of the Regional Fish Farm Review Committee.

Because of the large capital investments involved in establishing fish farms, there is an expectation by the industry and B.C. Lands that if farms are being operated in compliance with the terms of their tenure, replacement licences or leases will be granted. There is no guarantee that a replacement tenure will be issued. Applications for replacement can be made any time after half of the tenure period has elapsed. In unusual circumstances when issues are unresolved, B.C. Lands can issue a licence of occupation for less than the standard term.

Decommissioning

When sites are decommissioned, B.C. Lands requires a statutory declaration that all improvements are removed. As part of the tenure agreement, farms post a performance security, which can be used for clean-up. For operators who are members of the B.C. Salmon Farmers Association, the security bond is $25,000.00. For smaller independent farms, it is often $10,000.00. Unfortunately, even $25,000.00 is often inadequate for clean-up.

Some decommissioned farms have removed all improvements and supplied the statutory declaration. When farms go into receivership, B.C. Lands deals with the receivers. In the situations where farms have gone into receivership, accomplishing an appropriate level of clean-up has been more difficult.

Moratorium During Action Plan

In April, 1995, the province announced the Action Plan for Salmon Aquaculture. The Action Plan includes a review of provincial finfish aquaculture policy and the environmental review, under the *Environmental Assessment Act,* of salmon aquaculture issues.

The Action Plan triggered the suspension of approvals of new salmon farms for the duration of the policy review and the environmental assessment. It also set up an interagency review process to review and make recommendations on applications for replacements and amendments to existing salmon farms. This interagency process is the Regional Fish Farm Review Committee (RFFRC). The one RFFRC set up at Vancouver Island Region attempts to address the needs of all three regions involved in aquaculture. If needed, technical staff from the Kootenays and Lower Mainland Regions participate by conference call.

While no decisions will be made during this period on approvals or disallowances of applications for new tenures, applications are being accepted and held by B.C. Lands. These are not processed beyond checking the status of the area. Applications in CRIS No Opportunity areas are not accepted.

During this period, salmon aquaculture tenure and aquaculture licence holders may apply to replace their existing tenures or apply for administrative amendments to existing tenures and aquacultue licences. Administrative amendments are defined as:

- minor boundary changes;
- increases to production on existing sites and area expansion under exceptional circumstances only;
- exchanging or cancelling an existing site where there are exceptional environmental or operational concerns and the exchange or cancellation cannot be postponed until completion of the fish farm review;
- pen number and size changes; and
- species change.

During the period of the provincial aquaculture review, all applications for replacement or amendment of existing tenures and aquaculture licences must be referred to a Regional Fish Farm Review Committee for consideration. Each Committee is chaired by a representative of B.C. Lands and has members representing the following organizations:

- Ministry of Environment, Lands and Parks, Environmental Protection Program
- Ministry of Environment, Lands and Parks, Fisheries Program
- Ministry of Agriculture, Fisheries and Food, Licencing, Inspection and Field Services Section
- Ministry of Small Business, Tourism and Culture
- Department of Fisheries and Oceans
- Environment Canada, Environmental Protection Service

The role of the Committee is to review and make recommendations on applications for replacements, administrative amendments to existing sites, and amendments to aquaculture licences arising from changes in species or in production capacity. The terms of reference of the RFFRC were expanded in 1996 to include: consideration of First Nations infringement issues; access to MELP and MAFF executive for guidance as required; and consideration of production increases on a site-by-site basis.

Final decisions rest with the approving agencies. The Committee scrutinizes applications to determine possible environmental impacts. It can require applicants to submit studies that could include biophysical assessments, environmental impact assessments, and studies reporting on possible impacts on local government, First Nations, sport or commercial fisheries. The work of the Committee may involve consultation with industry.

C. INFORMATION SUPPORTING SITING

This section describes the primary information which is available to support site selection, evaluation and approvals. Some are these documents provide information only; others set policy direction for land allocators. Information booklets published before 1986 have not been reviewed primarily because they appear to have been replaced with newer publications.

Resource Inventory Committee

The Resource Inventory Committee (RIC) consists of representatives from various ministries and agencies of the Canadian, B.C., and First Nations governments. RIC objectives are to develop a common set of standards and procedures for provincial resource inventories. RIC has prepared two reports on coastal resources: a Coastal Resource Inventory Review (Howes, 1992) which provides an assessment of the status of coastal inventory programs in B.C.; and Coastal Information Resource Inventory (Harper et.al., 1993), which includes a lists of coastal data sets, a survey of user interest in coastal resource data, and a priority list of common resource data of interest to a wide range of users. These reports have confirmed that current coastal resource management and land use planning are hampered by the lack of province-wide coastal and marine information.

Biophysical Criteria for Siting Salmon Farms in B.C.

This booklet, published in 1987 by the Aquaculture Association of B.C. and MAFF, identifies factors to consider when siting a salmon farm and how siting should respond to those factors. It is a document targeted towards those who are new to the industry. It is somewhat out of date because the criteria are based primarily on chinook.

B.C. Salmon Farming Manual Site Selection Handbook

This booklet (Pennell, 1992) published by MAFF identifies factors to consider when siting a salmon farm and how siting should respond to those factors. The publication describes the major oceanographic zones of B.C.

Environmental Management of Marine Fish Farms

This booklet (Ministry of Environment, 1990) summarizes environmental practices and regulatory procedures required by the B.C. Ministry of Environment for marine finfish aquaculture operations.

Guidelines for Siting Aquaculture in Lakes

This document was prepared by MAFF and MELP in consultation with DFO, and is in draft form only. It identifies criteria for lakes which may be candidates for aquaculture.

Local Government Planning for Coastal Finfish Aquaculture Development

Published in 1987 by MAFF and the Ministry of Municipal Affairs, this booklet outlines local and senior government roles in relation to planning for finfish aquaculture, requirements of the industry and local planning options, and it describes the approvals process.

Coastal Resource Interests Studies

Coastal Resource Interests Studies (CRIS) were conducted by B.C. Lands from 1987 to 1992 for the Sunshine Coast, Western Georgia Strait, Johnstone Strait, Broughton, Nootka-Tofino and Kyuquot-Quatsino. Coastal interest groups were requested to submit mapping at 1:50,000 scale indicating areas which were critical and important to their interests with the understanding that finfish aquaculture would be directed away from areas critical to other interest groups. The map submissions from the interest groups were compiled onto one map, and based on a model with variations for each study area, a map was produced showing areas of Conditional, Limited and No Opportunity (coloured red on the maps) for finfish aquaculture.

CRIS maps for the Sunshine Coast, Broughton, Nootka-Tofino and Kyuquot-Quatsino are in digital form but they are not used in that form by B.C. Lands. All of those digital maps except for the Sunshine Coast are available from the Crown Land Registry. The Sunshine Coast Regional District has the digital copy of its CRIS map.

Work on the Broughton CRIS project was undertaken in November and December of 1989. The final product was released to the public on April 20, 1990.

Biophysical Capability for Salmon Farming

Mapping of the B.C. coast according to its biophysical capability to support salmon farming was conducted by MAFF from 1989 to 1995. The mapping is at scales of 1:50,000, 1:125,000 and 1:250,000, and the information is complete for the coast except for the Gulf Islands and Indian Arm. All of the mapping will soon be available in digital form.

The biophysical mapping includes the primary criteria affecting salmon farm siting, including: temperature, salinity and turbidity, oxygen saturation, phytoplankton and diseases, currents (too strong or weak), biological net foulants, slope stability (upland or underwater), depth, substrate, navigation hazard/visibility, exposure, snowfall/ice cover/avalanche, pollution and predators. Based on those factors, a rating for aquaculture development is provided.

Aquaculture Modelling System

A computer-based tool to support aquaculture siting by assessing the local and regional impacts of aquaculture operations is under development by MAFF. The components modelled include:

- hydrodynamics which simulates the temporal and spatial variations in water level and the depth integrated velocity based on equations of continuity and momentum,
- water quality which determines the spatial and temporal variations from a material source or deficit (e.g., ammonia, pesticide, oxygen depletion),
- sedimentation which models the dispersal of particulate carbon, and
- fish growth which is used primarily to determine the volume of material to be used as input to the water quality or sedimentation components.

The system has a graphic user interface for input and display of information. A pilot model is being developed for the Broughton Archipelago.

Corporate Coastal Inventory and Information System

The Land Use Coordination Office (LUCO) has the mandate to manage government information about the B.C. coast. Referred to as the Corporate Coastal Inventory and Information System, the components include:

- a video tape program with video tapes of the shoreline for: all of Vancouver Island except Brooks to Cape Scott, all of Georgia Strait, all of Johnstone Strait, and the south portion of Midcoast. The tapes are catalogued, and some are edited. Some are digitized on compact disks and linked to the coastline.
- a digital base map of the coast including bathymetry at 1:40,000 georeferenced to SPOT satellite data.
- digital coastal resource information including about 50 themes on biological features, biological resources (e.g., fish, wildlife, vegetation), human use (e.g., settlement, marinas, recreational use such as dive sites, ferry routes, aquaculture operations, closures), First Nations (restricted access), and Special status (e.g., tenures, ownership).
- other digital data sets that drive the Coastal Oil Spill Inventory, e.g. wave energy, oil residency, monthly shoreline sensitivity, environmental and economic importance rating. The product includes a hard copy Atlas and a user interface.
- spill trajectory (tidal currents) data set.
- a regional coastal information data set at 1:250,000 including: bathymetry, coastline, current, bottom sediment, depth polygons, bottom configuration; this information was used to develop and verify 12 marine ecosections.
- information that supports the Vancouver Island Land Use Plan including an integrated data set of resources, present use and zoning generalized to 1:250,000; and CORE plan marine units. A government plan still being finalized will be included in the information when it is complete. The marine planning units will be accompanied with a description of resources and general objectives.
- information to support the Central Coast Land and Resource Management Plan (LRMP). LUCO is compiling and undertaking inventory of coastal resources for the upcoming LRMP process.
- research is in progress to define Marine Ecosection subunits which will be the marine equivalent to biogeoclimatic zones on land. The subunits are based on temperature, salinity and primary productivity data, which exists for Juan de Fuca and Georgia Straits, and other resource information listed above.
- the coastal resource information system. That is a multi-media system for storage of cadastral data used to support research, analysis for planning, resource management and oil spill response. The information in the system includes GIS, Oracle data base, video, statistical programs and remote sensing. These have been linked with custom programming, and there is a special user interface for oil spills.

Herring Spawn Atlas

The Department of Fisheries and Oceans maintains an atlas of herring spawn areas divided into six categories based on their importance. The atlas is updated every one to two years and is available from DFO in its district offices upon request.

Land Use and Coastal Plans

A number of plans for coastal areas have been conducted by regional districts, and there are also zoning bylaws which include the marine area. The primary regional initiatives which have included planning for aquaculture are as follows:

- The Barkley Sound Planning Strategy was conducted by the Alberni-Clayoquot Regional District in 1994. Area designations for a variety of marine uses, including aquaculture, were prescribed. The products of the plan include digital data on land and foreshore use, recreation and scenic features, environmental features and area designations.
- The Sechelt Inlets Coastal Strategy was completed by the Sunshine Coast Regional District in 1990. It includes an area designation plan for marine areas, including aquaculture designations, and a digital data set at 1:50,000 including resource information derived from CRIS, existing use, land status and the area designation plan.
- A planning study of Nootka Sound has been proposed by the Regional District of Comox-Strathcona. The project is in the planning stages. It will use the provincial data base being prepared by LUCO to the degree possible.
- Some regional districts have developed zoning bylaws for aquaculture. Examples of this occur on Cortes Island, Quadra Island, and in Desolation Sound.

Tourism Resource Inventories

Tourism Resource Inventories have been conducted by the Ministry of Small Business, Tourism and Culture from 1992 to 1995 with ongoing updating. There are inventories of the B.C. Coast, Vancouver Island, Southwest Mainland and Northwest Mainland. The tourism inventories include a digital data set at 1:250,000 of resources important for tourism including physical features, biological resources, scenery and existing use.

Department of Fisheries and Oceans Internet Site

A number of Fish Habitat map products are maintained by DFO on an internet web site (http://habitat.pac.dfo.ca/heb/fhiip/maps1/htm). Most of the maps include base information such as shoreline, rivers and lakes, map sheet references and some jurisdictional boundaries. A MapGuide Viewer can be downloaded, allowing for viewing and printing specific information in defined areas. The map products include:

- digital maps of the Streamkeepers Urban Habitat Atlas (Squamish), FISS-BC Watershed Atlas (Vancouver Island), and B.C. North and South Coastal Resources Atlas (the data partner for south coast maps is LUCO),
- Vancouver Island Atlas, which includes obstructions, hatchery and release sites and instream locations of 10 species of salmonids,
- south coast maps illustrating areas of commercial fisheries for 17 species, recreational fisheries for seven species, hatchery and release sites, and fish and shellfish farms, and
- north coast maps illustrating areas of commercial fisheries for 9 species, recreational areas for fisheries and crabs, Native fisheries, and hatchery and release sites.

Central Coast Land and Resource Management Process (LRMP)

The planning process for this very large study area is just beginning, and will likely take two years to be completed. A Planning Framework Discussion Paper was produced in July 1996. The mapping scale will be 1:250,000, and the result of the process will likely be a map showing six zones similar to those in other LRMPs. There will be extensive agency and community involvement, and the plan will be based on consensus to the degree possible. Discussions are underway on whether or not the plan will include the marine area.

Protected Areas Strategy

A strategy to identify and designate protected areas in B.C. has been underway for a number of years. As a contribution to the Central Coast LRMP, a Central Coast Gap Analysis Team is working on identifying new protected area study areas. Existing fish farms have been excluded as potential areas for consideration.

Stream Classification Systems

Stream classification systems are not currently used in the siting of aquaculture operations, but they could be useful because the resources of different streams are highly variable. There are a number of stream classification systems that are based on different perspectives.

The Forest Practices Code includes a system described in the Fish-stream Identification Guidebook. There are two broad categories of streams: fish streams and non-fish streams, based on the occurrence of certain fish species. Fish streams (classes S1 to S4) are streams or specific reaches of streams that are known to contain at any time of the year anadromous salmonids, freshwater game species, threatened or endangered fish or regionally important fish; and which are less than 20% average gradient flowing directly into a fish-bearing stream as defined above, the Pacific Ocean or a lake known to support fish. The four classes relate to stream width: S1 are greater than 20 m, S2 are 5 to 20 m, S3 are 1.5 to 5 m, and S4 are less than 1.5 m wide. Non-fish streams include classes S5 (greater than 3 m wide and S6 (less than 3 m wide). Within these classes, the system includes collection of additional detailed information.

The Ministry of Environment, Lands and Parks has a watershed coding system for hierarchical numbering and cataloguing of watersheds, streams and lakes, described in A Guide to the Hierarchical Watershed Coding System for B.C. (Water Management Branch, 1988). It is more suited to inland systems.

The Clayoquot Sound Scientific Panel for Sustainable Forest Practices developed a classification system for streams which is described in Sustainable Ecosystem Management in Clayoquot Sound: Planning and Practices (1995). That system is based on the geomorphology of channels.

There are several other listings of rivers which relate to cultural factors. The Canadian Heritage Rivers System and the B.C. Heritage Rivers System identify rivers considered to have heritage values. The Outdoor Recreation Council maintains an annual listing of the top 10 endangered rivers based on nominations submitted by the public.

Another proposed river designation scheme is being proposed under the *Fish Protection Act*. Rivers which are considered ‘provincially significant’, heritage, or ‘at risk’ would receive designations by way of Order in Council.

MELP has noted that small streams with wild populations may be as important as large streams in terms of their sensitivity to the siting of fish farms. Any classification system and recommendations related to it must take this into account. MELP also notes the importance of field assessments in classifying streams.

D. MONITORING

Monitoring of salmon farms is discussed in detail from a regulatory perspective in Ann Hillyer’s paper and from a biophysical perspective in Brenda Burd’s paper. A summary is presented here.

Monitoring of salmon farms can be undertaken for a variety of purposes, including to:

- ensure that salmon aquaculture activities and practices comply with prescribed standards,
- determine whether the regulatory standards are appropriate for the intended objectives, such as protection of the environment, and
- improve the basis for understanding the mechanisms that cause changes or impacts in the ecosystem in which a salmon farm operates.

Monitoring can help in understanding environmental changes which could be used to develop measures of site assimilation capacity and data to improve siting regulations and decisions. B.C. Lands monitors compliance with tenure requirements. Farms are generally examined by air to ensure diligent use, that the farm is within the approved boundaries, and that the farm conforms with its approved aquaculture development plan for layout and the numbers of net-cages. While staff attempt to inspect each site once or twice a year, due to budget constraints some sites are only inspected every two to three years.

If a salmon farm is not complying with the terms of its tenure, B.C. Lands notifies the licence holder immediately and identifies the infractions. Where the conditions of the tenure are not met, the tenure may be cancelled. When B.C. Lands is informed of potential infractions, they investigate as soon as they can, but as stated above, staff and budget resources are limited.

The level of compliance on farms varies. It likely is improving as the industry becomes more established and farms are held by large corporations. Some members of the public have perceptions that there is significant non-compliance but conditions for farms often change and the public may not be aware of the changes, e.g., there are frequent amendments to tenures.

Mandatory monitoring of environmental effects was established in 1988 by MELP through the Aquaculture Waste Control Regulations, with the intensity of monitoring based on three levels of production. Cross (1994) summarized monitoring requirements, compliance and response by the provincial government. The information provided to MELP by the industry was incomplete (less than 50% response in all categories) with questionable data quality. Cross also found that MELP did not process all monitoring submissions, was not aware of non-compliance, and did not acknowledge receipt of submitted monitoring information or respond to failures to comply. In addition, the data were not being analyzed by MELP and returned to fish farmers so that any problems could be traced and acted upon when necessary. Cross and Kingzett (1994) recommended consolidation of all existing monitoring data of reliable quality and revision of the monitoring program. This has not been done to date.

Compliance with the terms of the aquaculture licence is monitored by MAFF. Within the past two years, MAFF began a regular monitoring program to check the environmental status of fish farms, with the intent to visit every farm site at least once, and those with potential problems several times. They use a remotely operated vehicle with a camera system to take videos of the area below salmon farms. The data is currently being analyzed. General MAFF inspections of farms are reported to occur twice each year. MELP also have recently been conducting extensive surveys of fish farms in the Broughton Archipelago, Clayoquot Sound and Sooke Inlet.

One of the problems with monitoring and regulation of the industry has been inefficient communication between MAFF and MELP. For example, when production increases are given by MAFF, this information often doesn’t reach MELP for some time. Cross and Kingzett (1994) found that several farms had reported an increase in production and feed usage which would change them to another category for waste discharge, but they had not been issued waste management permits by MELP.

In 1995, MELP announced it was reviewing the environmental monitoring requirements for fish farms with a view to developing a new long-term monitoring program. The submission of various data and the requirement for a sediment accumulation survey by diver or by sediment trap are no longer required (Oldham letter dated April 11, 1995).

The Kwakiutl Territorial Fisheries Commission (KTFC) was involved in environmental assessments with Stolt Seafarms and the province as well as other dive surveys. Their monitoring activities have documented the following samples of non-compliance (see KTFC submission for more detail):

- operation close to a tradition shellfish beach,
- waste build up to 0.5 km from cages with slow recovery after 10 months,
- cages outside of lease area,
- unlicensed use of fresh water, and
- abandoned nets and debris on the ocean floor, in some cases scattered at distances from the original operations.

Monitoring of salmon farms in lakes needs to be done monthly because temperature and other conditions can change so dramatically with the seasons. Because of the complexity of interactions, it is necessary to understand the dynamics of a lake system thoroughly before its use for aquaculture (see Brenda Burd’s paper).

E. B.C. REGULATIONS FOR COMPARABLE USES

A comprehensive review of regulations and processes for siting comparable uses would include other coastal uses and agricultural uses of Crown land. That type of review is far beyond the scope of this study. This section briefly reviews several uses and approaches to siting them in relation to siting for aquaculture.

The process for siting other uses in coastal areas is generally much simpler than for aquaculture. The proponent applies for a right to use an area and submits plans of their proposal. The plans are reviewed, referred to other agencies, and a decision is made. Aquaculture requires a Development Plan with much more detail on their operations than other coastal users. Aquaculture also requires approval for any significant changes to the terms of the tenure, e.g., changing an anchor line, one new cage.

One regulation which has never been applied to aquaculture is the DFO no net loss policy for impacts to fish habitat which requires compensation for any habitat lost. This requirement is applied to other uses, particularly on land and intertidal areas. DFO does not apply the no net loss policy to aquaculture because aquaculture is considered a temporary use.

The primary agricultural use of Crown upland is grazing. B.C. Lands previously issued grazing leases, but range tenures are now allocated by the Ministry of Forests under the *Forest Act.* Land allocation is determined on the basis of the capability of the land to support cattle. Capability is calculated using a measure called animal unit months (AUMs), which is based on the weight of dry feed that one cow eats in one month. This is a grassland concept and it works well in grassland areas. Currently, much of the rangeland is in areas which have been logged, and the calculation of AUMs is more difficult to determine. There are concerns about rangeland allocation in B.C. In some areas, particularly the south of B.C., there is extensive competition for range tenures, and competition between reforestation and grazing uses. Concerns have also been expressed by environmental groups that the management system has led to over-grazing.

VII. BROUGHTON CASE STUDY

A. DESCRIPTION

The Broughton area, often called the Broughton Archipelago, is composed primarily of a large number of islands between the mainland coast and Vancouver Island, northeast of Port McNeill. The study area for this project also includes a portion of the east coast of Vancouver Island and some large inlets and fjords which extend generally north and east from the archipelago. The archipelago has a low population located in several small settlements and First Nations villages. Port McNeill on Vancouver Island, with the adjacent populations in Alert Bay, Telegraph Cove, Port Hardy and Sointula (on Malcolm Island) form the major service centre for the area.

The Broughton area, within the Kwakiutl traditional territory, has a rich history and ongoing culture for the First Nations people. With Eurasio-Canadian settlement, the area became an important commercial fishing area, and forestry was another mainstay of the economy. As the population in B.C. has increased and outdoor recreation has become more popular, the Broughton area has evolved into a major destination for all types of boaters and outdoor enthusiasts. In 1992, the Broughton Archipelago Marine Park was established.

Since the late 1980s, the salmon aquaculture industry recognized the Broughton area as being highly suited for their needs. Numerous small companies filed applications for investigative permits, and the industry was introduced in the area. There are now 28 operating salmon farms in Broughton, almost all of which are owned by two companies, each with a distinct geographic range. Since the moratorium on salmon aquaculture, any new applications have been on hold. There are currently nine applications for salmon farms in the Broughton area being held by B.C. Lands. The Ministry of Agriculture Fisheries and Food has identified between six and 12 sites which they consider to be biophysically capable of supporting salmon farms (but not necessarily without resource use conflicts).

B. PERCEPTIONS ABOUT BROUGHTON

This section outlines perceptions expressed by members of the RC, the public and user groups on the Broughton Archipelago.

Local Information Report

As part of the SAR, the EAO assisted a Subcommittee and a local coordinator in collecting local knowledge and observations on the Broughton area. Four widely advertised open houses were held in the study area, observation sheets were completed by local people, then the results were compiled by the EAO. There were 36 observations related to fish farm siting.

The concerns cited most frequently in the observation records were salmon farms being located outside of their lease areas, and farms causing hazards to navigation. Other observations were as follows:

- fish farming has had a negative effect on fishing, affecting fishers of prawn, crab and other species by occupying favoured spots or impeding access to preferred locations;
- farms have negatively affected areas where artists were taken to paint, camping locations, anchorages, access to beaches and archaeological sites;
- farms have been located within salmon migration routes and too close to clam beaches;
- there have been a significant number of unlicensed improvements and trespasses on the upland such as storage of garbage and equipment; and
- improvements from past farming operations have not been removed.

Tourism and Recreation

The Broughton area is considered to be of extremely high value for tourism and recreation, particularly because it is interesting and diverse, it is primarily undeveloped, and it is located close to major populations. Tourism operators generally say there are already too many farms in Broughton. It is recognized that the Broughton is considered an important area for fish farming and for tourism and recreation.

The Broughton area has a reputation for excellent paddling. It is also fairly saturated for kayaking because during the warm season, the limited number of camp sites are full (Arcese, pers. comm.). Kayakers would prefer there to be no salmon farms. One of their primary concerns is noise. They claim to hear gunshots regularly, dogs barking, numerous large noisy boats, and loud generators and mechanical feeders which they can hear for up to 1.5 hours of paddling. While they still use the Broughton area extensively, they feel that farms have affected the quality of their trips. There are fewer whales and porpoises, which they perceive to be linked to the AHDs. They previously used a lot of bays that are now farms, too close to farms, or used by farmers for recreation with unsightly gear, e.g., temporary structures. The kayakers take pride in being self-reliant and do not feel that the safety services which could be provided by farmers outweigh the negative effects.

The operators of wildlife viewing and nature tours used to go into Broughton more than they do now. The primary reason is the lower numbers of whales, dolphins and porpoises. One major operator reported that passengers appear to have little interest in fish farms, and their guides tend to pass farms as quickly as possible since nature appreciation is the goal of the trips (Mackay, pers. comm).

The Council of BC Yacht Clubs (CBCYC) perspective is that farms in the Broughton are not too dense now, but that they wouldn't like to see a large increase. They appreciate the support services which result from having people living and working on the coast (e.g., gas docks, stores), and have proposed that fish farms be established as marine emergency shelters and stations. The group provided a number of recommendations on fish farm siting in Broughton to the review, including avoidance of farms near protected areas, residential subdivisions, within Provincial Boat Havens, and in channels where they could impede access.

Other recreational users have indicated that the Broughton is a world class recreation area and that salmon farming should be phased out of the area (Pillman, submission to SAR).

In order to better understand the effects of salmon farming on recreation and tourism, a survey was conducted of 29 tourism businesses which use the Broughton Archipelago (Ministry of Small Business, Tourism and Culture, 1997). Included were fishing lodges, campgrounds, resorts, marinas, charter boats and kayak and scuba operators. Five of the 29 companies operate year-round, while most typically operate from May to September. Each business served an average of over 1,000 visitors in 1996, with trips ranging from one day to over a week. On average, over half of the visitors' time was spent in the Broughton. The number of clients has more than doubled over the last five years, with businesses reporting an average growth rate of 17% annually during that period.

About 85% of the tourism businesses reported negative impacts from salmon farms, with most diverting their trips or operations away from fish farm sites. The majority of negative impacts were attributed to effects on fish and wildlife, the loss of tourism access to important areas, reduction in wilderness character, visual impacts, noise and pollution. Positive impacts from fish farms were reported by 35% of the tourism businesses (some operators cited positive and negative impacts), with these impacts attributed to fish farms being points of interest, providing tour opportunities and providing safety.

Salmon Farming

Salmon farmers consider the Broughton to be a world class area for their industry. It is one of the best, if not the best, area for salmon farming in B.C. It is close to communities which can be service centres on Vancouver Island. Ocean water flowing in from Queen Charlotte Strait is very clean, there is a narrow water temperature range, and the numerous islands, bays and inlets provide shelter. The area also has a relatively large amount of glacial runoff and this seasonal fresh water influx is particularly good for smolts. Because the companies in the Broughton manage defined geographical areas, they have enough sites to provide flexibility with their operations. Fish farmers are concerned about the impacts from other resource users, particularly related to pollution. They also have commented that recreational users sometimes disturb their peace with loud music and voices.

C. ANALYSIS OF BROUGHTON

The purpose of analyzing siting in Broughton is to better understand what problems have occurred and what basis there is for the concerns that have been expressed. The analysis looks at the interrelationships between fish farm sites and CRIS red zones and between fish farms and resources and uses, and it reviews the case histories of five farms. The actual impacts of farms on resources are not addressed here (see other TAT papers).

CRIS Analysis

The Review Committee requested that an analysis of the number of fish farms in No Opportunity areas of CRIS be compiled for Broughton. There are currently 28 farms in the Broughton CRIS area, which is slightly different than the Broughton study area defined for the review. Of those farms:

- two are completely in No Opportunity areas (Potts Bay, Eden Island),
- three are partially in No Opportunity areas (Bonwick Island, Watson Cove, Sargeaunt Pass); and
- one additional farm has only a residence in a No Opportunity area (Carrie Bay).

Applications for all of the above sites were received prior to the release of CRIS except for Potts Bay. Potts Bay was accepted as a broodstock site only (a few large fish used for egg collection). It is now proposing to switch to a smolt introduction site. The site had an Investigative Permit in 1987/88 (before CRIS) that expired. A new application was received in 1991. The application was fully referred and approved by all agencies including those whose interests resulted in the No Opportunity designation. B.C. Lands has indicated that they made a mistake approving the site.

Resource Use Conflict Analysis

A number of analyses of map information were conducted to better understand the extent of conflict between salmon farming and other resource users and resources. This analysis is based solely on geographic overlap. Maps illustrating the resource uses and resources in relation to fish farms are in Appendix A. Although numerical analysis of the conflicts was conducted where possible, there are limitations related to the accuracy of the data, and these numbers should be considered as general indicators only. The analysis also provides no information on the relative importance or quality of the resources and use areas affected.

One of the primary sources of information for the analysis was mapping provided by the Land Use Coordination Office (LUCO). The data was mapped on 1:40,000 scale marine charts. That information is considered draft as it is currently undergoing a quality control review. The mapping of fish farms was obtained from MAFF and it is based on 1:50,000 scale mapping of the tenure boundaries. All of the mapping was obtained in digital form and the analysis was conducted in a computer geographic information system.

Because the primary resource use conflicts in the Broughton are between aquaculture and recreation, several different analyses were conducted to determine the interrelationships among those uses. Those analyses are followed by others which address fisheries resources.

General Recreation Sites

This analysis looks at the interrelationship between recreation sites and existing salmon farms. Information on recreation sites was derived from CRIS critical and important designations for anchorages and all recreational uses except sport fishing, and from provincial boat havens. Sport fishing was excluded because it does not have the same level of conflict with aquaculture as the other recreational uses. The Broughton Archipelago Marine Park was included in the analysis because it includes important recreation sites, some of which are affected by adjacent fish farms. The study area for this analysis is the Broughton CRIS boundary, which is smaller than the boundary of the SAR case study area.

A map was produced of these areas showing for each polygon in order of priority: provincial boat haven, critical for recreation in CRIS, and important for recreation in CRIS (see map in Appendix A). For example, if a polygon is a boat haven and a critical CRIS area, it was coloured as a boat haven. The map based on this analysis was plotted and the coloured areas were then divided into recreational use "units". These are areas partially enclosed by land and separated visually from other areas, e.g., a bay or a section of a channel.

An analysis was then conducted of the recreation units "affected" by fish farms (see Table 3). A unit was considered affected if the farm is within the unit or relatively close to and highly visible from the unit. The recreation units were counted in each of the three categories. There are often 2 or more map categories within a unit, and the category was selected according to the priorities stated: provincial boat haven, critical for recreation in CRIS, and important for recreation in CRIS. The units affected by fish farms were tallied the same way.

Table 3: Recreation Units and Fish Farms

	Recreation Units	**Number Affected by Fish FarmS**
Provincial Boat Havens	10	
Critical Recreation Areas	73	17
Important Recreation Areas	21	3
Total	**104**	**20**

This analysis is subject to the limitations described for the CRIS data and the rough analytical method. It provides a general indication only of the extent of the impact of fish farming on recreation in the Broughton.

Anchorages

Information on anchorages used for recreation and by many other coastal users was obtained from LUCO (see Table 3). The sources of their information were Coastal Tourism Resource Inventory, MOF recreation data, Outdoor Recreation Council, CHS marine charts, Docks and Destinations, and Council of B.C. Yacht Clubs. There are 134 anchorages within the SAR study area. There are five fish farms within an anchorage, and an additional six farms are highly visible from an anchorage, e.g., directly across a channel, immediately adjacent.

Kayaking Routes

A map showing kayaking routes through the Broughton area was obtained from LUCO. Their information was obtained from kayaking guidebooks and the Coastal Tourism Resource Inventory (MSBTC). There are 400 lineal km of kayaking routes, and 10 fish farms are located along these routes.

Kayaking Stopping Sites and Staging Areas

A map showing kayaking stopping sites and staging areas through the Broughton study area was obtained from LUCO. Their information was obtained from kayaking guidebooks, the Coastal Tourism Resource Inventory (MSBTC), and the Ministry of Forests. Thirty-six sites and two fish farms are located directly adjacent to these sites.

Scuba Diving Areas

A map showing scuba diving areas through the Broughton study area was obtained from LUCO. Their information was obtained from guidebooks, parks maps and map books. It was not possible to measure the size of the diving areas or the number of dive sites because the areas are mapped as large polygons which include islands. There are nine fish farms within or near scuba diving areas.

Major Use Areas and Routes

Another analysis was conducted of the major use areas and routes in the Broughton (Table 4). These are primarily the locations labelled on maps as sounds, channels and passages. Some of the largest inlets were also included.

These locations are used for recreation and other forms of commercial and residential transportation. The number of fish farms in each area or route was counted, then each of these locations was analyzed to determine the effect of fish farms on the experience of travelling through the area. The resulting rating of high, medium, low, or not applicable was based on the number of the farms and their level of visibility in relation to the size of the area.

Table 4: Effect of Fish Farms on Major Use Areas

Major Use Areas and Routes	**Number of Farms**	**Effect on Experience**
Drury Inlet	0	N/A
Wells Passage	2	H
Grappler and Mackenzie Sound	0	N/A
Sutlej Channel	3 visible	L
Labouchere passage	0	N/A
Kingcome Inlet	0	N/A
Simoom Sound	2	H
Tribune Channel	2	M
Knight Inlet	1 visible	L
Sargeaunt Pass	1	M
Call Inlet	0	N/A
Havannah Channel	3	H
Chatham Channel	0	N/A
Clio Channel/Baronet Passage	0	N/A
Springs Passage	2	H
Sound west of Beware passage	2	H
Sound west of Knight Inlet	2	M
Retreat Passage	2	H
Arrow Passage	1	M
Fife Sound	2 & 1 visible	H
Greenway Sound	2	M
Nowell Channel	0	N/A
Nickoll Passage	0	N/A

Summary

H — 7

M — 5

L — 2

N/A — 10

Total — 24

#This analysis is subject to the same limitations as the one described above. It essentially indicates that in approximately half of the Broughton area, one is aware of the presence of salmon farming. Linking the routes together, it was determined that it is not possible to travel through the Broughton area without passing fish farms.

Relationship of Recreation Use to Biophysical Capability for Salmon Farming

Initially, another analysis was going to be conducted comparing recreation areas with biophysical capability to support salmon farming. The biophysical mapping rates coastal areas as good, medium, poor or not acceptable, and the units on the maps are quite large. The Ministry of Agriculture, Fisheries and Food indicated that even poor sites could be considered for fish farms because the ratings are based on chinook salmon and because detailed studies could show specific sites within an area rated poor to have farming capability. The analysis would therefore show large portions of the Broughton area to have salmon farming capability. Because the recreational sites also cover significant areas, it could be determined without conducting the analysis that the overlap between biophysical capability for salmon farming and recreational interest would be significant.

Clams

A map showing clam areas in the Broughton study area was obtained from LUCO. Their source was the DFO Pacific Biological Station. There are 151 clam areas, and six fish farms are within 125 m of those areas.

Prawns

A map showing prawn areas in the Broughton study area was obtained from LUCO. Their source was the DFO Pacific Biological Station. There are 48,600 ha of prawn areas and 10 fish farms are within those areas.

Crabs

A map showing crab areas in the Broughton study area was obtained from LUCO. Their source was the DFO Pacific Biological Station. There are 6,850 ha of crab areas, and four fish farms are located within those areas.

Herring Spawning

A map showing herring spawning areas in the Broughton study area was obtained from LUCO. Their source was the DFO Pacific Biological Station. There are 284 km of herring spawn areas and one fish farm is within one of those areas.

Sport Fishing for Salmon

A map showing salmon sport fishing areas in the Broughton study area was obtained from LUCO. Their source was the DFO Pacific Biological Station. There are 32,500 ha of salmon sport fishing areas, and three fish farms are within those areas.

Sport Fishing for Ground Fish

A map showing ground fish sport fishing areas in the Broughton study area was obtained from LUCO. Their source was the DFO Pacific Biological Station. There are 4,300 ha of ground fish sport fishing areas, and three fish farms are within those areas.

Wild Salmon Resources

The interrelationships of salmon farming and wild salmon are addressed in other TAT papers. Mapping submitted by a local fisher with extensive knowledge of the area (Proctor submission to SAR) indicates that there are mature salmon coming in to the Broughton area along almost all of the major water courses (DFO has not mapped migration routes of salmon in this area). Proctor's map also shows salmon schooling areas and chinook nursery areas, and it identifies Fife Sound as the major migration corridor. Contact with DFO (Russell, pers. comm.) indicated that there are salmon fry going out along all waterways. Because of the extent of their range, a significant number of salmon farms are located along salmon migration corridors. No numerical analysis of the interaction has been conducted to date and this will depend on the conclusions of the other TAT members regarding interrelationships of fish farms and salmon resources, as well as verification of map data.

Table 5: Summary of Analysis of Information from LUCO

CONFLICTS WITH FISH FARM	TOTAL RESOURCES
Anchorages5 fish farms within an anchorage	134 Anchorages6 fish farms across from anchorges
Kayaking Routes10 fish farms along kayak routes	400 km of kayaking routes
Kayaking Stopping Sites and Staging Areas2 fish farms next to stopping staging sites	36 Camp sites within the study area
Scuba Diving Areas9 fish farms in or near Scuba diving areas	No measure possible
Clams6 fish farms within 125 metres of a clam area	151 clam areas
Prawns10 fish farms within Prawn areas	48,600 ha of prawn areas
Crab4 fish farms within Crab areas	6850 ha of crab areas
Herring Spawning1 farm within a herring spawning area	284 Lineal kms
Sport Fishing for Salmon3 fish farms within sport salmon areas	32,500 ha of Sport salmon areas
Sport Fishing for Ground Fish3 fish farms within sport ground fishing areas	4300 ha of Sport ground fishing areas

Case Histories

In order to obtain a better understanding of the salmon farm siting process and results in the Broughton, case histories were prepared for five fish farms. The farms were selected to represent a range of conditions. For example, based on the comments of the RC, some of the more and less controversial sites were selected. The farms also represent a variety of conditions in terms of: location in CRIS red zones, location in Broughton, timing of installation, ownership, and resources and uses potentially affected.

The review of the five farms involved going through files on each farm at B.C. Lands and MAFF offices. All significant correspondence was noted, answers to siting questions on Development Plan application forms were documented, and forms summarizing the history were prepared. For the detailed information on each farm, refer to the summary forms in Appendix B. The following paragraphs provide an analysis of the case histories.

The information in the files provides information on licensing but does not provide a complete case history of the farms. For example, information on escapes or disease occurrences on farms are recorded in other files, and not necessarily in the files reviewed. Zoning on the form relates to local government zoning, not CRIS designations. The similarities among the five case histories are significantly more striking than the differences. Similarities are as follows:

- all of the farms applied for investigative permits between August, 1987 and November, 1988,
- all of the farms appear to have applied for licences of occupation between February, 1988 and July, 1989 (in some cases, this date was not indicated in the files),
- for the three farms with dates provided, it took 13 to 14 months from the time of application until approval was received for a licence of occupation,
- all of the farms applied to grow Atlantic salmon or modified their licences to allow for Atlantic salmon between 1990 and 1994,
- all of the farms changed ownership at least once,
- four of the farms requested and received amendments to their boundaries at least once,
- all of the farm applications indicate that predators are present (likely true for all of B.C.),
- all of the farms cite negative responses or no answer to the biophysical and spacing questions, i.e., history of plankton blooms, water pollution, aquatic plants and animals; and proximity to salmonid stream, native reserve, park/eco reserve, boat anchorage, shellfish bed, and fish habitat,
- four cite no use by recreational boaters and four indicate no use for commercial fishing,
- all farms received at least one objection in the referral process, often from the B.C. Wildlife Federation, for habitat and commercial fishing reasons,
- all of the applications were advertised, usually around the time of application for a licence of occupation, and
- four of the farms have indications of problems in the files, e.g., three had trespass notifications, one had a plankton bloom.

A number of concerns were raised by the information and lack of some information in the files:

- A number of agencies provided identical responses on form letters in response to all or most of the referrals. They would indicate approval subject to conditions, and the conditions outlined were the primary guidelines of the agency. For example, DFO letters would cite conditions as being minimum 125 m from shellfish harvesting beds, compliance with all waste disposal regulations, and accordance with *Fisheries Act*. These letters give the impression that the qualifiers may have been used because of a lack of complete resource information on the sites.
- Information provided later and through the RC indicates that there was significant incorrect or missing information on the original applications. There is no way of knowing whether this information was unknown or deliberately excluded. It is interesting that the B.C. Wildlife Federation, and none of the agencies, often reported these conditions originally. A submission to the RC indicated that several of the applications did not acknowledge presence of resources, such as salmon schooling area, crab, seal lion, seal haul-out; or site history and use, e.g., anchorage, recreational use, commercial fishing, and plankton blooms (Proctor). The scope of this review did not allow for confirmation of the information.
- On two of the applications DFO originally objected, and on another they requested a biophysical assessment. On all three applications, DFO changed their referral to support. The files do not indicate the reasons for the change.
- None of the files provide a rationale from B.C. Lands on the decision made. The impression on reviewing the files is that if all of the government agencies (but not the interest groups) supported an application, B.C. Lands granted tenure. There were no attempts, especially on the early applications, to address concerns raised by other organizations such as the B.C. Wildlife Federation. On later applications, the proponent was sometimes requested to resolve concerns directly with organizations expressing objections.

D. COMPARISON TO B.C. COAST

The current distribution of salmon farms in B.C. is currently as follows:

- major concentrations in Broughton, Clayoquot Sound and Discovery Islands,
- moderate concentrations on Sunshine Coast, Queen Charlotte Strait, Kyuquot Sound and Esperanza Inlet,
- low numbers in Barkley Sound, Gulf Islands and Quatsino Sound.

Generally, there is little opportunity for expansion of marine fish farm operations on the south-east portion of Vancouver Island because of warm water, algae blooms and the density of residential and recreational use. As stated elsewhere in this report, a significant number of farms previously located on the Sunshine Coast were abandoned or relocated. With new technologies, however, there may be limited opportunities along the south coast in the future.

The other areas where salmon farming currently occurs may have some capacity for expansion. The salmon farming industry supports infill because it allows for expansion using existing infrastructure. The major limiting factor to expansion of the industry in areas of current use is likely the conflicts with other resource users. The RC heard particularly about conflicts and concerns in Broughton, Clayoquot Sound and Comox-Strathcona Regional District.

The primary new areas with potential to support the industry are the Central Coast and Prince Rupert regions. The major constraint for the industry is transportation and servicing, which add to the cost of the product, but with a sufficient number of farms, support can be arranged. There were previously two operations near Prince Rupert, but this was likely not enough, and they went out of business at a time when the industry was in upheaval for various reasons.

Several calls were made to determine the level of interest in salmon farming in the Central Coast. The Central Coast Regional District opposed salmon farm applications in the past and has a concern about Atlantic salmon. While they are interested in encouraging economic development, the Board is apprehensive about aquaculture, especially with respect to environmental impacts

(Mikkelson, pers. comm.). The Heiltsuk First Nation has mixed feelings about salmon farming. Although they are interested in economic development, they are also concerned about environmental impacts such as disease (Humchitt, pers. comm.). The Kitasoo First Nation, which has a very large territory, previously had a salmon farm and runs a small processing plant. They are interested in involvement in the salmon farming industry in their area provided that they have a key role including control over siting (Greba, pers. comm.).

VIII. ASSESSMENT

The regulations and guidelines for aquaculture have been developed over several years to address environmental and socio-cultural considerations. It is difficult at this stage to classify any of them as mitigation measures. This section therefore assesses the regulations as they exist, without distinguishing any of them as mitigation measures.

A. BIOPHYSICAL

The biophysical risk assessment of salmon aquaculture in B.C. is being conducted by the other four TAT authors in their papers on escaped farm fish, fish health, waste discharges and aquatic mammals and other species. Because of the timing of submission of the papers for public comment, there was no ability to summarize the biophysical risk assessment related to siting in this paper. Please refer to the other four papers.

B. SOCIO-CULTURAL

This section addresses the socio-cultural issues described earlier in this report and the relative impacts of aquaculture with regard to these issues. It is not possible to quantify the impacts because of the lack of hard data. This topic is also difficult to analyze because it is partly expressed through perceptions, and emotions with regard to aquaculture run high. The section also discusses the degree to which existing regulations address these impacts.

It is interesting to compare perceptions about aquaculture with the actual geographic extent of the industry. The B.C. coast is approximately 27,200 km long. There are about 120 fish farm tenures and about 75 active grow-out sites. An extremely small percentage of the coastline is therefore occupied by salmon farms.

There are a number of possible reasons why the perception of socio-cultural impacts appears to be high in relation to the geographic extent of the industry:

- although the coastline is vast, many coastal users have interests in the same locations, i.e., those close to population centres offering protection, fresh water, accessible shorelines, etc.
- although in relation to the total number of coastal residents and users, those affected by salmon farms are few, the impacts when they have occurred have had a significant effect on the people concerned, and these effects have been proportionally much higher for First Nations people because of the First Nations populations in salmon farming areas,
- when the industry experienced a rapid expansion in the 1980s, it was far less regulated and managed than it is currently, and some of the perceptions of impacts could be based on experiences of several years ago,
- salmon aquaculture is a relatively new use on the coast and typically traditional resource users have a difficult time accepting the presence of a new use in areas which they have used for a long time,
- comments to the SAR indicate that some people do not feel that the environmental impacts are well understood, and lack of understanding is often accompanied by concern, which is easily extended to every aspect of the industry, and
- concerns about the regulatory system and approval process also may affect perceptions about the industry as a whole.

This report does not attempt to evaluate the validity of perceptions. Rather, it documents them and also describes the current system for siting salmon farms in order to obtain a better understanding of the basis for the concerns. In the conclusions, this report highlights areas where further improvements are required.

Proximity Effects

The proximity effects of salmon aquaculture on permanent residents affect relatively low numbers of people but can be significant. Effects on recreation and tourism users are more complex. These users can choose to avoid salmon farms to some degree because they are mobile, but in some regions they cannot avoid all farms unless they are willing to restrict their range. The perceptions of impacts can be strong because of the importance of the quality of recreational experience often desired.

The regulations address proximity issues in several ways. The application process includes mandatory contact and consent from the upland owner when the tenure is expected to affect the right of access of the owner. CRIS mapping is used to guide proponents away from areas which are of interest to other coastal users or to resolve potential conflicts with those interest groups.

Proximity effects are also addressed less formally. Although there are no formal guidelines for minimizing visual impact, MAFF advises proponents to design fish farms to minimize visual impact. Some effects such as production of garbage have been improving with better husbandry practices.

Some proximity effects remain unregulated. There is no requirement to contact upland owners who may be within visual or audible range of a proposed site. There are no guidelines or regulations governing noise or smell.

Effects on Communities

The economic effects of aquaculture on communities are generally positive. There is employment provided at average wages, and although the number of jobs is relatively small compared to total employment, it does provide some offset to declining resource industries. In addition to the direct and key supplier employment provided to the industry, there are additional economic benefits to service industries in general, e.g., grocery stores, banks, professional services.

The non-economic effects on communities overlap with proximity effects and resource use conflicts. In addition, conflicts over siting can be costly. When controversial farms were sited in the mid 1980s, some communities were socially and economically affected by the conflict.

Government regulations to address conflict are centred around the referral process. Although that process has improved in recent years in terms of the groups contacted and repeat contacts, it is not a process which lends itself to consensus-building or conflict resolution.

Resource Use Conflicts

Resource use conflicts generally occur in relation to the density of fish farms in an area. As noted in section VII. D, there are three areas with relatively high concentrations of farms, four areas with moderate concentrations, and three regions with low numbers. Conflicts with the forest industry appear to be have been resolved through the existing approval process. Conflicts with recreation, fisheries and navigation were described by participants throughout the SAR.

The Broughton Archipelago, as a high concentration area for fish farms, was evaluated as a case study to determine the extent of the conflicts. The geographic extent of conflict varies for the different uses, but as for proximity effects, perceptions of conflict as expressed to the SAR are strong even for the uses where there appears to be a very small physical overlap.

Depending on the method of analysis and the type of recreation use, the number of recreation sites affected by fish farms ranges from 5% to 20%. Although the majority of recreation sites are not affected by salmon farms, given the possible reasons for perceptions described near the beginning of section VIII.B, it is not difficult to understand the level of concern about the conflict. The information analyzed does not identify the relative importance of the sites affected.

Half of the larger recreational use areas and routes are highly or moderately affected by farms, meaning that in approximately half of the Broughton area, one is aware of fish farms. The overall character of the Broughton area has changed because of the industry. While previously it was relatively quiet and unpopulated, the permanent presence of industrial activity has reduced the feeling of remoteness. While the industry is of interest to some user groups (35% of tourism operators), it is a negative effect to a larger number of groups (85% of tourism operators). The high levels and steady increase in tourism use shown through the survey (MSBTC) suggest that recreation, tourism and aquaculture are coexisting, although impacts on recreation and tourism remain. A large portion of the operators citing negative effects of aquaculture (88%) diverted their activities away from fish farms or relocated.

Impacts of aquaculture on fishing include both commercial and sport fishing of various species including shellfish. Fish farms directly affect a relatively small portion of fishing locations because of the large areas used for fishing salmon, ground fish, crab and prawns. The level of concern is likely related to favourite, highly accessible fishing spots being lost to fishing. The fouling of fishing gear caused by fish farm equipment which is not removed from unused sites can also cause significant irritation to fishers. Impacts on shellfish resources are relatively limited in geographic extent; however, the potential risks of consuming contaminated shellfish are significant.

The effects of fish farms on navigation have not been quantitatively evaluated. Because of the efforts of the Coast Guard and B.C. Lands, it is expected that these are also relatively limited in number, and some cited navigation hazards may be a result of trespass beyond tenure boundaries. Where navigation impacts do occur, they cause a high level of annoyance and potential cost or harm to other coastal users.

The approval process as conducted before the CRIS study was undertaken did not adequately address resource use conflicts. Because of the grandparenting of applications submitted before CRIS was completed, this situation extended into the early 1990s. Since then, CRIS has been the primary tool for addressing resource use conflicts. B.C. Lands no longer accepts applications for salmon farms in CRIS red areas, and they do significantly more consultation to address potential resource use conflicts than they did previously but, because of the moratorium, it is difficult to assess the effects of the improved procedures.

The issue of resource use conflicts brings up the question of equity in the allocation of Crown land. This becomes a relevant issue only after potential biophysical impacts have been adequately addressed. Because of the level of different types of use in many coastal areas, competition for space and conflicts are unavoidable. The major user groups all appear to feel that there is inequity in access to Crown land. Without interest-based, consensus-seeking planning processes, it is extremely difficult to address competing demands and to achieve an acceptable balance of uses. Broad strategic direction from government is also required to ensure that decisions respect overall goals.

There is an inherent challenge in attempting to address resource use conflicts through the referral process. It would be much more effective to deal with them as part of integrated resource planning for all uses on a regional, rather than a site specific basis. Some of the conflicts could also be addressed more effectively if there was better mapping of existing resources available to and provided by fish farmers, and if monitoring was more thorough.

First Nations Perspectives

The effects of salmon farming on First Nations are highly complex and particularly difficult to quantify. The concerns overlap with all of the other issues described, i.e., proximity effects, effects on communities, resource use conflicts, and public service benefits and risks. Therefore, the assessment of those issues also applies to First Nations. In addition, First Nations have concerns related to their aboriginal rights, their health, their interaction and dependence on resources, and the fact that fish farms are being located within their territories.

The approval process for salmon farms did not sufficiently address First Nations concerns in the 1980s. This was likely due to a combination of factors including: lack of referral, referral to the wrong person inadvertently, lack of effective communication with First Nations, and lack of response by First Nations.

First Nations are now highly concerned about aquaculture, and they perceive that they still are not being appropriately served by the decision-making process. While First Nations vary to some degree in their perspectives on the industry, they all desire involvement in the decision-making process.

Public Service Benefits and Risks

The public service benefits and risks associated with salmon farming are also difficult to quantify. It is suspected that they are relatively few in number, but that when they do occur, they have a major effect on the people involved.

Existing regulations and processes do not address this issue, and this is likely not a regulatory matter. There are initiatives which industry could undertake to improve public perceptions and public service benefits associated with the industry.

C. SITE SELECTION

The ability of site selection procedures to locate sites with the biophysical capability to support salmon farming and associated risk assessment are addressed in the paper on waste discharges (Burd). This section provides some analysis of site selection procedures and impacts in relation to protection of environmental resources and interactions with other users.

There are locations on the B.C. coast which are important as habitat for fish and wildlife, but there are no legal or regulatory requirements which precisely define siting limitations with respect to those resources. The B.C. Lands Aquaculture Policy includes guidelines that recommend protection for salmonid streams and shellfish beds. The MAFF application guidelines add protection for marine fisheries habitat such as herring or cod spawning and salmon holding and rearing areas. Neither the B.C. Lands Policy nor the MAFF guidelines precisely define criteria for identifying the resources described. The federal *Fisheries Act* also defines fish habitat generally.

There are no defined criteria for identification of environmentally sensitive areas and existing guidelines do not address all of the concerns expressed by participants in the SAR. For example, there are no guidelines for siting with respect to important wildlife areas or for areas used by red- or blue-listed species. Concentrations of marine mammals, seabirds, waterfowl, raptors and shorebirds are documented as predators in the biophysical mapping for aquaculture, but these are not listed as species to protect from an environmental perspective.

The analysis of conflicts with resources and observations submitted to the SAR indicate that the existing guidelines have not been followed in a significant number of cases. Although guidelines are discretionary, there are no procedures for determining when flexibility can be granted, and there are no requirements to provide a rationale when a decision is made not to follow a guideline.

The impacts and potential risks of locating salmon farms in areas which are important to tourism and recreation are difficult to quantify. The Broughton tourism survey showed that although some operators relocated to other areas, tourism use is high even in an area where significant conflicts are expressed. While it is known that many tourism and recreational user groups prefer a pristine environment in their destination areas, some also appreciate the importance of a diverse economy.

The general impression from discussions with tourist operators and recreational user groups is that salmon farming and recreation can coexist provided that salmon farms are sited and designed to blend with the surroundings, that fish and wildlife are not harmed, that they do not impede access along or to the shore, that noise and pollution are minimized, and that the number and density of farms are within limits. These limits likely vary with the perceptions of specific individuals and user groups. The most important requirement from a recreational user's perspective is that farms only be located in areas with low recreation use and potential (Pillman submission).

In considering the coexistence and balance between salmon farming and recreation, it is important to acknowledge the economic aspects of both uses. The economics of aquaculture are relatively well understood. The financial benefits of recreation and tourism are also significant, as indicated in the MSBTC submission and survey. There is an interrelationship between the two because of their respective space requirements and impacts on each other. At a certain level of either use, the capacity of the other use to expand will be limited. The marine tourism industry relies on the existence of some pristine areas with no industry, while in other locations tourism and aquaculture could coexist.

After considering biophysical requirements, industry needs, and the limitations resulting from environmental and socio-cultural factors, there may not be many additional sites meeting present criteria in some areas of the coast. This will be particularly true in the areas where there are already significant concentrations of farms and in areas where recreational use is high.

The consideration of "cumulative effects" or "carrying capacity" is central to the issue of site selection. To responsibly allocate public resources, it is necessary to determine, to the degree possible, the capacity of the natural environment to assimilate wastes and the tolerance of tourists to the presence of industry and other uses, including tourism. These thresholds are difficult to determine, and past approaches appeared to consider resources infinite and impacts unlikely.

New technology could increase the number of sites with capability, because of technologies which can enable farms to withstand more exposed sites and areas where plankton blooms have historically occurred. For example, if fish farms focused more on sites in wide channels and less on bays, conflicts with recreational and settlement uses could be reduced.

Fish farms can be a useful monitor of environmental conditions. Because of the sensitivity of the fish, farms can serve as an early warning system of environmental problems such as disease or pollution. Salmon farms are currently the only monitors of environmental water quality in many remote sites because they regularly check water temperatures, nutrient levels, oxygen concentrations, and plankton blooms and the impacts of these on fish health.

Site selection suffers from the lack of direction. With no plan that designates preferred areas, aquaculture is sited in an ad hoc, reactive manner. The current system does not include proactive planning which would allow for establishing objectives, evaluation of options, consensus-building and analysis of potential salmon farming areas in relation to other use areas on a regional basis.

D. REGULATORY STRUCTURE

An assessment of the regulatory structure is presented in Ann Hillyer's paper. Because of the timing of submission of the papers for public comment, there was no ability to summarize the assessment of the regulatory structure in this paper. This section provides a summary of some primary concerns with the regulatory structure. Additional comments related to regulations are made in portions C and E of this section of the report.

There are many jurisdictions involved in managing salmon aquaculture, their respective roles are sometimes overlapping, and the responsibilities and regulations are complex. B.C. is not unique in this respect. Other countries have similar structures and even the international organizations with interests in coastal management are complicated and overlapping. The complexity of the agencies and regulations does pose a challenge for managers and for the industry.

At the provincial level, there are several coastal strategy initiatives which are all separate. The intergovernmental group is chaired by Ministry of Employment and Investment, the coastal strategy for B.C. is being coordinated by LUCO, and there are related initiatives under the authority of the Fisheries Secretariat. Each of these initiatives has a different set of assistant deputy ministers, which limits coordination and efficiency.

The agencies responsible for managing aquaculture have experienced difficulties in collaborating with respect to the industry. This has occurred among the three levels of government (federal, provincial and local), and it also has taken place among provincial ministries. The lack of collaboration has impeded information sharing, analysis and decision-making in the past. There are indications that collaboration may be improving, especially as a result of the Fish Farm Review Committee.

The lack of a broader structure for coastal management and planning which could provide guidance for the siting of aquaculture and other uses is a major issue. There is no coast-wide strategy which defines goals and objectives for B.C.'s coastal zone. There are few plans which set community-based, environmentally sound objectives, policies and designations for future use of coastal areas.

E. INFORMATION SOURCES

A major problem facing siting for salmon aquaculture has been the lack of consistent available data sets on coastal resources. To assist in identifying the most appropriate locations for aquaculture, there is a need for mapping which combines biophysical, socio-economic, cultural and industry criteria. Prescriptive plan designations based on those criteria and community input would make siting even more responsible and efficient.

In addition to a lack of regional resource information, data has consistently been lacking on sites under consideration. For example, there is no comprehensive information on the resources which exist at and near sites before the farm is introduced. This requires more than a cursory overview because some resources, such as geoduck beds, sea urchin and sea cucumber habitat, require dive surveys. This type of information is critical to responsible decision-making and to serve as a benchmark for monitoring.

There are information sets that have become available since the moratorium which have not yet been used for siting. The need for a coordinated, corporate system of information on coastal resources is well documented in B.C., and LUCO is working towards that objective. To be useful in the siting process, the data must be easily available at a reasonable cost.

Mapping scale is an important issue. Because of the need to map resources over the entire B.C. coast, much of the mapping is being conducted at small scales, e.g., 1:250,000. It is important to understand that regional mapping scales are only suitable for regional planning, and that much more detailed information is required for siting a fish farm.

The following two sections provide an assessment of the two primary sources of information which have been used for fish farm siting.

CRIS

The CRIS mapping provides a valuable source of information on coastal interests at the time it was prepared (1987 to 1992, 1989 in Broughton). It is important, however, to recognize the limitations of CRIS for application at this time:

- the information is out of date, primarily because use of the coast and knowledge of environmental resources have increased since the maps were prepared; there was no requirement or process for updating the information and there was likewise no mechanism for enabling the information to be superseded by subsequent data or processes;
- the maps are merely a reflection of areas of the coast where user groups expressed interests and where resources were known to occur; they therefore do not address the appropriateness of each area for these uses relative to aquaculture, nor do they show designations which could be interpreted as a plan or a summary of consensus; the implication is that access to public resources will be allocated based solely on the patterns of past use;
- the small scale of mapping means that there could be areas of interest which are not reflected and that there could be areas acceptable for aquaculture which are near or within areas classified as No Opportunity ("red area"); and
- No Opportunity areas were not defined based on planning principles; for example, a farm could be next to a red area and have the same effects as if it were inside the red area.

Another issue related to CRIS arises out of the CRIS process rather than the information directly. Fish farms which had filed applications before CRIS was released were grandparented in, i.e., they were not subject to the CRIS limitations. Because of this policy, quite a few farms were approved in No Opportunity areas after the CRIS study was completed. This is a major concern for people who contributed to the CRIS process because they were unaware of the number of applications and the fact that they would be grandparented, and were left with the perception that their input was not treated respectfully.

Biophysical Capability for Salmon Farming

The salmon farm capability maps summarize the biophysical requirements and constraints for siting. They have been an extremely useful tool in some cases. Generally, the industry knows more than the information on the maps in areas they are familiar with, e.g., in the Broughton where company farms are distributed by area. The mapping provides useful information in areas where familiarity and experience are low.

Although the maps provide a relative ranking of capability for salmon farming, they do not provide information on the assimilative capacity of sites or regions. That information has not been generated in B.C.

F. APPROVAL PROCESS

The following summary of expressed concerns has been grouped according to key topics. As evidenced by the headings, the concerns include regulations and information in addition to the referral and decision-making process. The comments on information were included here, in addition to the section above, because these comments relate specifically to information flow during the referral process.

Government Concerns

The detailed concerns government agencies have regarding the referral process are described elsewhere in this report. The following is a summary of their concerns.

Regulations

- lack of flexibility in tenures, e.g., to vary production levels and fallow sites (RFFRC now has some ability to vary production levels)
- lack of common guidelines approved by all agencies, e.g., for information required with application, for approval of sites, for approval of replacements, for measuring sustainability
- lack of common definitions, e.g., no agreement among MELP, DFO and MAFF on what constitutes a salmon stream
- no means for recourse by MELP if a farm is considered to be polluting

Information

- government agencies do not always have the resource information to adequately assess applications, a concern expressed particularly by some First Nations
- not enough information is provided with applications, e.g., detailed mapping, mapping of adjacent resources, detailed current information, description of technological systems proposed, and some referral agencies indicated that they do not receive a copy of the development plan with applications
- there are gaps in information, such as the effects of different loading densities on the environment

Referral Process

- referrals not being directed to the appropriate person, a concern expressed particularly by some First Nations
- local government is contacted too late in the application process, and amendments to tenures are sometimes approved without their input
- more time than the 30-day comment period is required for a responsible evaluation and response
- need for improved communication, e.g., promptly informing agencies when applications are accepted
- need for more cooperation, consultation and improved working relationships among agencies (this has improved for members of the Fish Farm Review Committee)
- lack of interaction directly with the proponent, a comment expressed by members of the Fish Farm Review Committee
- need for a dispute resolution process to address disagreements among agencies
- significant duplication of effort in the review of applications
- the high volume of referrals at times

Decision-making

- recommendations made as part of the referral are not always followed by B.C. Lands, e.g., need for an archaeological assessment
- B.C. Lands only considers comments from the agency with the direct mandate to manage a resource
- limited resources for site inspections to evaluate sites

Public Interest Group Concerns

The following are some common concerns and perceptions on the referral and siting process expressed by public (non-government, non-industry) members of the RC and other participants in the referral process:

Regulations

- resources to protect are not clearly identified, e.g., no mention of red- or blue-listed species

- while numerous government documents have described the need for coastal planning and management, there have been minimal efforts to undertake this

Information

- no habitat mapping is available to facilitate identification of important resources

Referral Process

- public comments are not given due consideration
- the approval process has not been modified to include recommendations from the Ombudsman's Report, especially those regarding public participation
- public are supposed to comment on socio-cultural issues only; does not account for local knowledge
- concern about not being contacted regarding licence replacements
- concern about relocation of farms without public input
- expansion of facilities with no approval
- inaccurate information on applications not checked
- conflict within DFO causes problems, i.e., they have a mandate to protect fisheries resources and also are supposed to promote the aquaculture industry
- government advocates for aquaculture, DFO and MAFF, tend to dominate over other concerns
- government agencies do not have the resources to adequately fulfill their mandates, e.g., DFO has minimal staff for ensuring protection of fisheries on the coast and cannot inspect, evaluate, monitor and manage aquaculture sites to ensure that fisheries are not being affected

Decision-making

- guidelines are often not followed, e.g., B.C. Lands Aquaculture Policy spacing guidelines, CRIS No Opportunity areas
- varying approaches among different B.C. Lands staff and regions
- siting decision-making and approval principles are not well defined
- problems with sites—cutting off access to a recreation feature or the shoreline, conflict between habitat issues and farm (e.g., seal and sea lion rookery, herring, salmon migration routes, salmon-bearing streams), farms beyond lease area, blocking navigation

Salmon-farming Industry Concerns

The salmon farmers also have concerns about the approval process, and their perceptions are as follows:

Regulations

- the current system, especially during the moratorium, does not provide salmon farmers with the flexibility they need to follow the best husbandry practices available, such as adjusting the location of the site to adapt to changing environmental conditions (e.g., fallowing), market timing and production efficiencies
- the current system does not provide opportunities for adaptive management; one of the tools salmon farmers recommend for achieving this is performance-based standards

Referral Process

- although time guidelines for decision-making apparently exist, decisions are often not timely, and this is a problem because salmon farming follows critical time paths
- dispute resolution mechanisms in the referral process are inadequate so consideration of applications can be blocked without apparent cause
- the process does not ensure equitable access to resources for salmon farming

Decision-making

- the decision-making criteria are unclear
- there is uncertainty related to tenure, and this is difficult because salmon farming has a production cycle of several years requiring certainty of access to good sites for a reasonable length of time to allow for investment and employment decisions; a 10-year term on a licence of occupation is not considered adequate unless there is an assurance of successive renewals if the conditions of the licence are met.

Commentary

There has been debate during the SAR about the validity of some of the above concerns. It is likely true that some of them are based on past experiences and that the system has changed since those perceptions were acquired. Certainly, the system of regulations, information, referrals and decision-making has changed since the mid 1980s. On the other hand, in order to improve the system, it is important to consider the existing conditions that could contribute to those concerns and solutions which could address them.

The comments on the regulatory system highlight the conflicting interests in more regulation and more flexibility. Some believe that common regulations for environmental protection supported by all agencies would reduce impacts of the industry, while others think that flexibility and adaptive management would be a preferable approach.

The comments on information highlight the need for site-specific resource information and complete development plans to be submitted to all agencies to facilitate their evaluation of proposals. There has also been a lack of broad resource information to allow for evaluation of relative importance.

Comments on the referral process include perceptions that it is too cumbersome and other views that it does not allow adequate time. If there were improved guidance for the location and management of salmon farms, the process could likely be streamlined. The primary comments on the referral process relate to the need for improved communication, public consultation and dispute resolution. There is also concern about the ability of the agencies to adequately manage the industry and resources sustainably, given limited and declining government resources.

There is a significant level of agreement that the primary problem with decision-making is that the criteria and rationale for decisions have been unclear. Some public groups are unhappy with past siting decisions, and some public and government groups do not feel that their concerns were properly addressed. The industry is concerned about uncertainty of tenure. All of those concerns could be mitigated by clarifying regulations, decision-making criteria and performance standards.

Although the above concerns are significant, there are also positive features. The knowledge, processes, and information bases for siting farms have been improving. The majority of farms currently in place were sited before these benefits existed. Because of the moratorium, the current status of systems has not been tested. There is now better information, most relevant interest groups are now contacted for referrals, and some planning efforts are underway. The international literature appears to place British Columbia at a relatively high level in terms of our management of the industry.

IX. CONCLUSIONS

The recommendations of the SAR will be developed jointly by the TAT and EAO. This section provides a list of conclusions which could be used to guide the development of recommendations.

1. Recommendations need to be developed according to the principles and commitments of Canada and B.C. These include: The Provincial Land Use Charter and A Sustainable Environment Charter, which articulate the precautionary principle, the principle of full-cost accounting, the importance of nature for its own sake, the importance of development that reduces waste and makes efficient use of resources, decision-making principles based on consensus-building, stewardship, sustainability, pollution prevention, user pays, and the titles and rights of aboriginal peoples; the IUCN, which passed a resolution regarding sustainable aquaculture; and the Federal Aquaculture Development Strategy, which promotes sustainable aquaculture.
2. A provincial coastal strategy is needed to set out principles and objectives for coastal planning which can be used to guide decision-making.
3. Integrated resource planning is needed to designate areas for specific types of uses such as environmental protection, recreation and tourism, settlement, and industry. Ideally these plans would be developed regionally and be based on thorough resource information and consensus-based planning including federal, provincial, local and First Nations governments, industry and interest groups.
4. Until the above is in place, there needs to be a process which approximates it to address siting. Some of the preferred principles of the process include involvement of all key parties, use of the best information available, consideration of applications in groups where possible, and consideration of other resource uses at the same time.
5. There needs to be a system which ensures that decision-making criteria are clear, and which documents the rationale for siting decisions where plans do not exist.
6. There is better information required at four levels: regional coastal information such as the data being developed for the Corporate Coastal Inventory and Information System, which needs to be easily available at a reasonable cost to anyone requesting it; complete resource information for proposed sites extending out some distance (to be determined) based on site and dive surveys; information obtained from site inspections by government staff or their assigned representatives; and collection and analysis of data which could lead to the determination of carrying capacity in different locations and conditions.
7. Information needs to be updated as conditions change, e.g., mapping of other resource interests needs to be maintained current, and biophysical capability analysis for salmon farming needs to consider changes in technology.
8. A process for improved communication and collaboration among agencies and industry during planning and management is needed, including a dispute resolution process.
9. A process for effective consultation with the public is needed for planning and management.
10. The system needs to be improved to ensure that environmental protection, First Nations concerns, and proximity effects are addressed during planning and management. This would include protection of fisheries and habitat resources, and management of noise, smell, upland modifications, and visual impacts. This system, which may include regulations, guidelines and/or performance standards, needs to have the support of all agencies.
11. Consideration needs to be given to relocating salmon farms which have significant negative effects on environmental resources and/or other resource users.
12. Regulations need to provide more flexibility for the industry to manage their stocks using adaptive management.
13. There needs to be a system to ensure that fish farm sites are decommissioned in an environmentally and socially responsible manner.

14. An improved monitoring system is needed involving benchmark data, detailed monitoring requirements, ensured compliance, analysis of the data, reporting of results, and responses in regulations and decision-making.
15. Government agencies need to have adequate resources to evaluate potential sites, ensure that operations are appropriately monitored, and manage the industry.
16. The above systems need to be developed so that they are streamlined, minimizing time requirements.
17. There needs to be ongoing research and development of new technologies.

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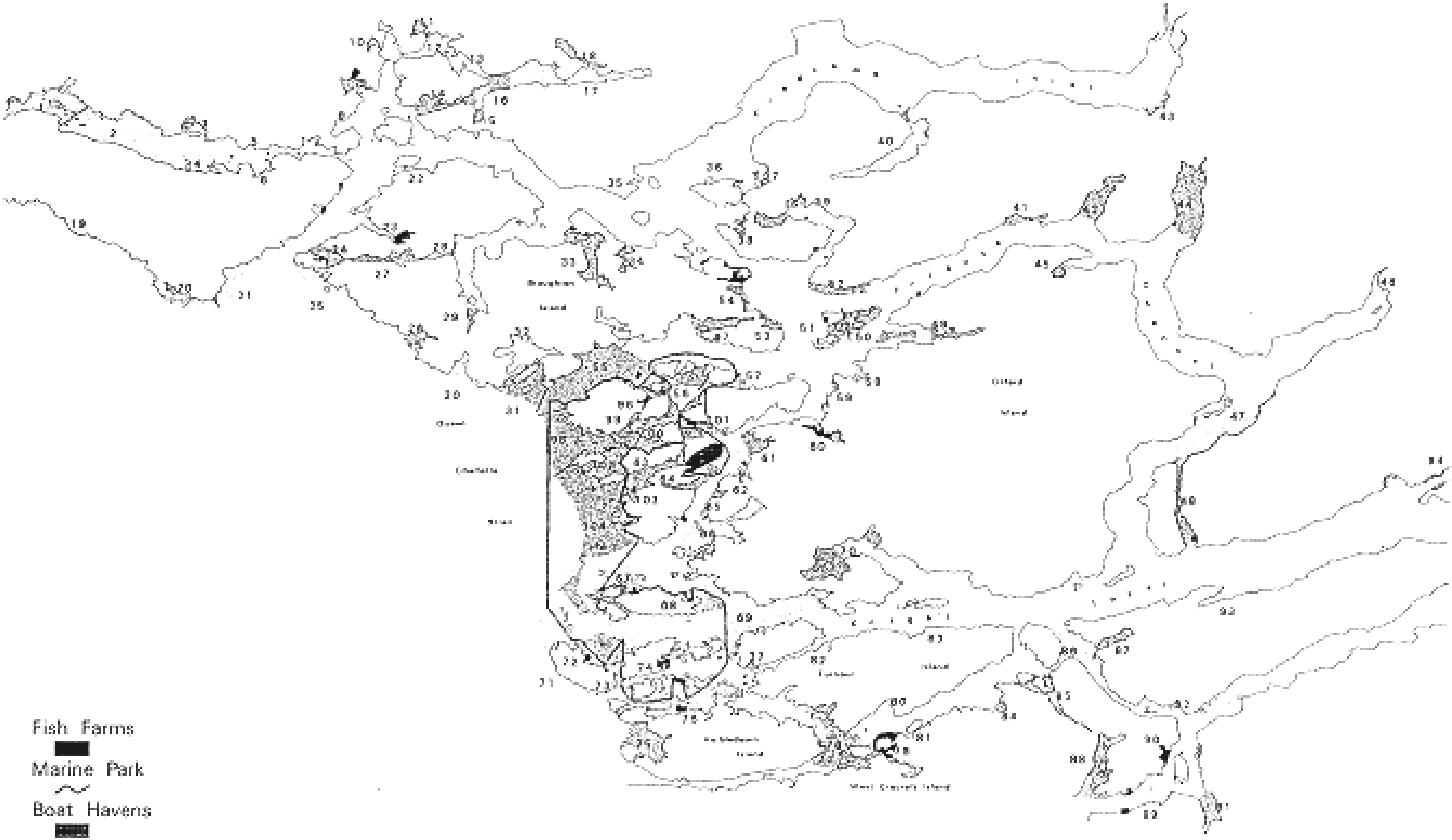
APPENDIX A — MAPS



Fish Farms

■

Marine Park

〜

Boat Havens

▨

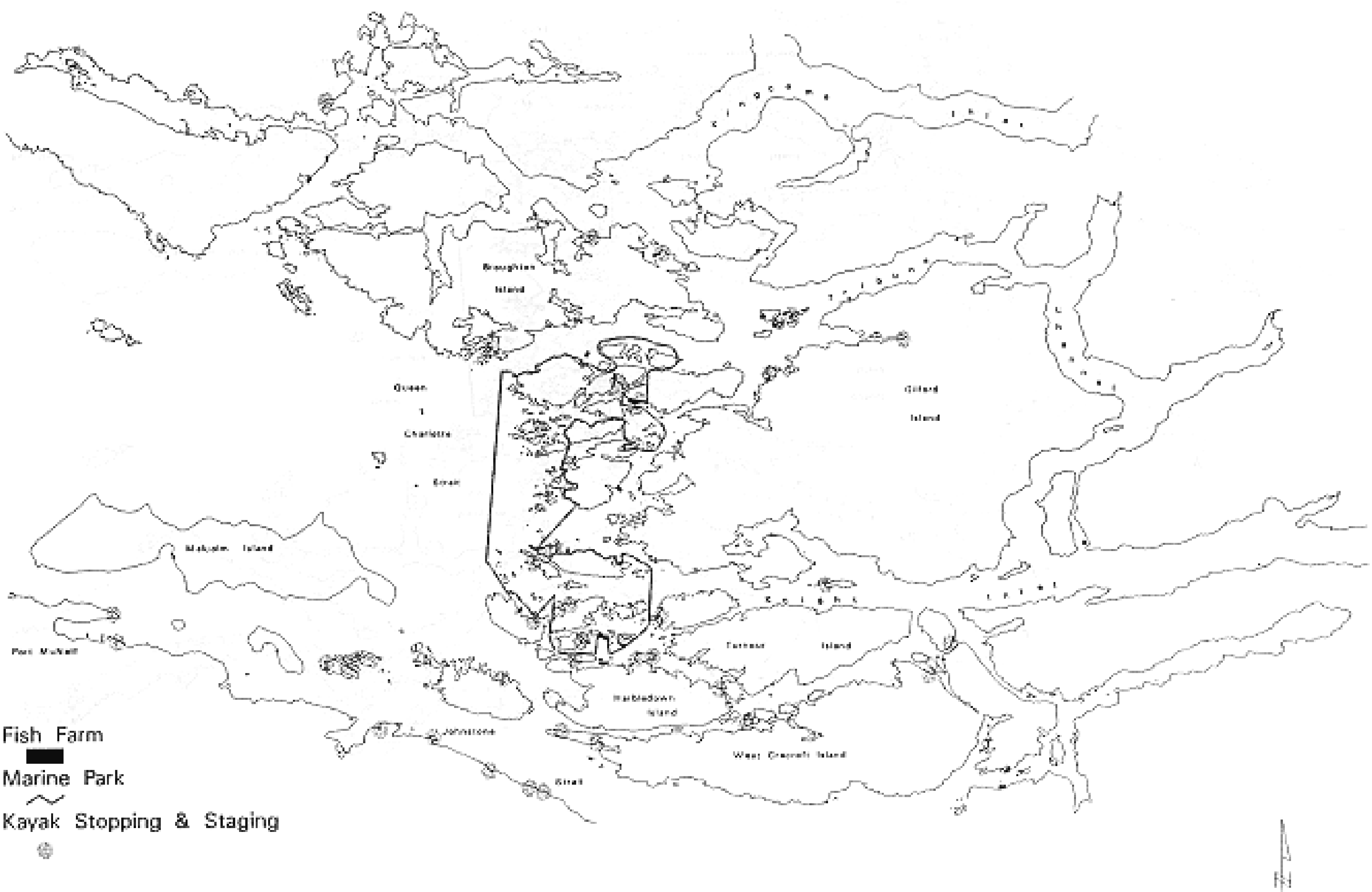
Recreation

▨ Critical Recreation Areas From CRIS

· Important Recreation Areas From CRIS


Kingcome Inlet
Broughton Island
Tribune Channel
Queen Charlotte Strait
Gilford Island
Malcolm Island
Port McNeill
Knight Inlet
Turnour Island
Harbledown Island
Johnstone Strait
West Cracroft Island
Fish Farm
Marine Park
Anchorage
N


Broughton Island
Queen Charlotte Strait
Gilford Island
Malcolm Island
Port McNeill
Turnour Island
Harbledown Island
Johnstone Strait
West Cracroft Island
Fish Farm
Marine Park
Kayaking Routes
N


Kingcome Inlet
Broughton Island
Tribune
Queen Charlotte Strait
Gilford Island
Malcolm Island
Port McNeill
Knight Inlet
Turnour Island
Harbledown Island
Johnstone Strait
West Cracroft Island
N
Fish Farm ■
Marine Park 〜
Kayak Stopping & Staging ⊛


Kingcome Inlet
Broughton Island
Tribune Channel
Queen Charlotte Strait
Gilford Island
Malcolm Island
Port McNeill
Knight Inlet
Turnour Island
Harbledown Island
Johnstone Strait
West Cracroft Island
Fish Farm
Marine Park
Scuba Diving Area

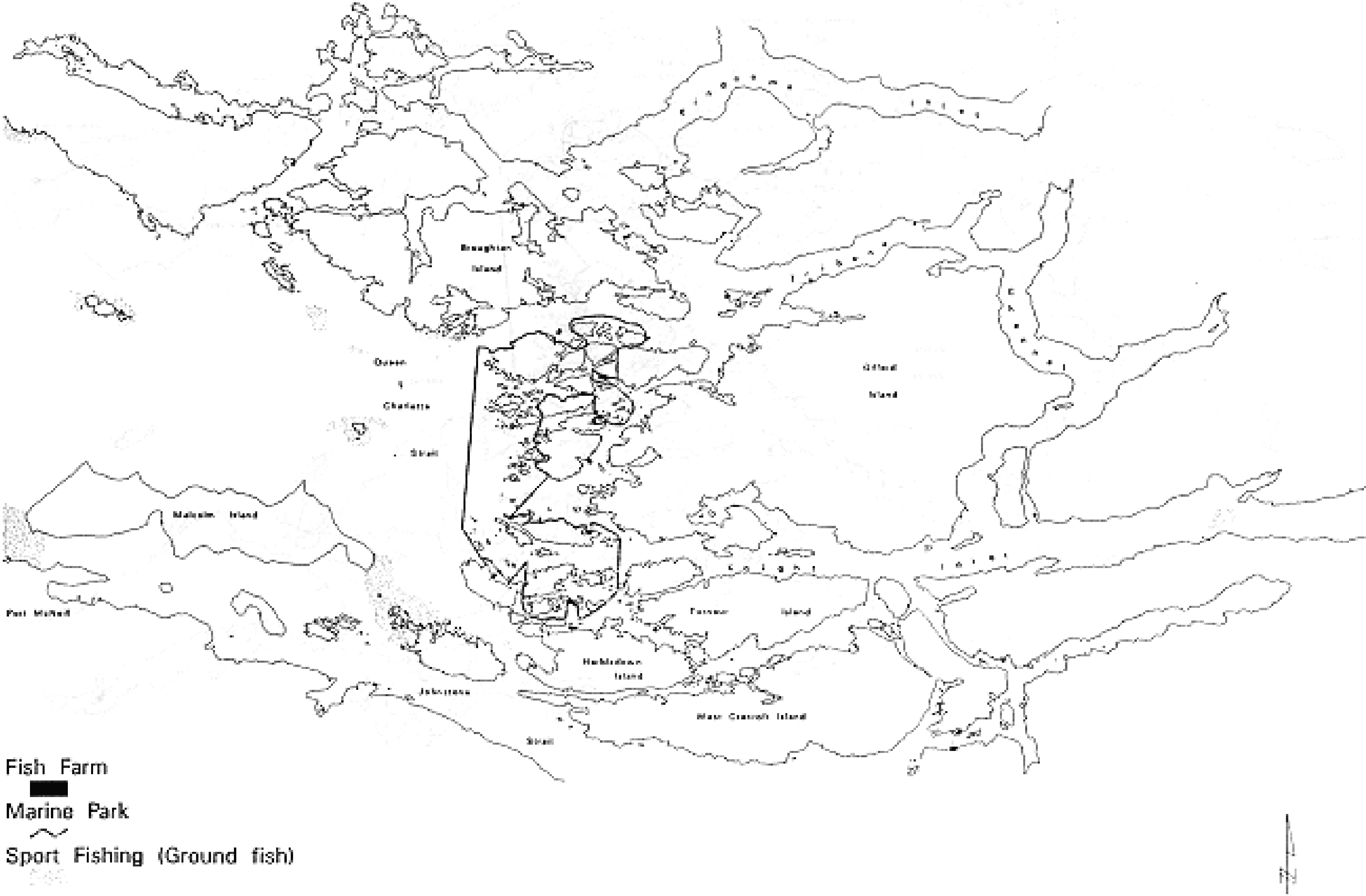

Broughton Island
Queen Charlotte Strait
Gilford Island
Malcolm Island
Port McNeill
Knight Inlet
Turnour Island
Harbledown Island
Johnstone Strait
West Cracroft Island
Fish Farm
Marine Park
Clam Area


Broughton
Island
Queen
Charlotte
Strait
Gilford
Island
Malcolm Island
Port McNeill
Turnour Island
Harbledown
Island
Johnstone
Strait
West Cracroft Island
Fish Farm
Marine Park
Prawn Area


Broughton
Island
Queen
Charlotte
Strait
Gilford
Island
Malcolm Island
Port McNeill
Knight
Inlet
Turnour
Island
Harbledown
Island
Johnstone
Strait
West Cracroft Island
Fish Farm
Marine Park
Crab Area

Kingcome Inlet
Broughton Island
Tribune Channel
Queen Charlotte Strait
Gilford Island
Malcolm Island
Knight Inlet
Port McNeill
Turnour Island
Harbledown Island
Johnstone Strait
West Cracroft Island
Fish Farm
Marine Park
Herring Area
N


Broughton Island
Queen Charlotte Strait
Gilford Island
Malcolm Island
Port McNeill
Turnour Island
Harbledown Island
Johnstone Strait
West Cracroft Island
Fish Farm
Marine Park
Sport Fishing (Salmon)


Kingcome Inlet
Broughton Island
Tribune Channel
Queen Charlotte Strait
Gilford Island
Malcolm Island
Knight Inlet
Port McNeill
Turnour Island
Harbledown Island
Johnstone Strait
West Cracroft Island
Fish Farm
Marine Park
Sport Fishing (Ground fish)
N

APPENDIX B — SALMON FARM CASE HISTORIES