Salmon Aquaculture Waste Management Review & Update

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Innovation & Excellence in Environmental Science

Salmon Aquaculture Waste Management Review & Update

Prepared for:

BC Ministry of Environment, Lands and Parks
Environment & Resource Management
Pollution Prevention & Remediation Branch

By:

G3 Consulting Ltd.
4508 Beedie Street
Burnaby, BC
V5J 5L2

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EXECUTIVE SUMMARY

G3 Consulting Ltd. (G3) prepared this report for BC MELP, Pollution Prevention and Remediation Branch (Victoria), with the following objectives:

- evaluate the costs, operations, waste management capability and examine the feasibility of “closed” circulating systems compared with “open” netcage systems in BC;
- review any new regulatory tools and mechanisms with respect to waste management that could be applicable to BC; and
- document emerging research with respect to plankton blooms and netcages.

In 1996, Hatfield Consultants Ltd. and EVS Environment Consultants prepared a review of literature for MELP pertaining to environmental effects of salmon netcage aquaculture in BC. The current report updates information on selected topics, augmented by current information on additional topics of concern identified in the terms of reference.

Major risks of open cage culture include attacks by predators; escapes of fish; toxic algal blooms; and diseases entering from external environment. Counterbalancing these risks is the cheaper operation of cage culture compared to other systems. Proponents of extra large open cages (e.g., 30 m^2) cite more swimming in the enlarged volume as a performance enhancer. Improved anti-predator systems would reduce the negative aspects of open netpen farming as would the adoption of stronger cages, better anchoring systems and avoidance of certain fish transfer procedures deemed of high risk. This trend identifies the need to improve protocols above and beyond actual hardware and tools used.

In response to growing concern regarding waste reduction limitations from open cage and netpen systems, closed systems have received much attention, given their potential for controlling waste reduction and removal. Enclosures may reduce some risks, although fish may still escape through damaged bags. Bags provide some control over depth of water for intake (thereby possibly reducing some algae entrainment) and enabling short-term isolation by using oxygen systems. Bags also shield fish from predators. They do not reduce disease risk.

On-land systems reduce all the above risks except that of algae blooms. Given sufficient oxygen they may isolate their systems from intake during a bloom. These systems have generally proven too expensive (very high capital and operating costs). Risks of equipment failure are countered by back-up systems (gen-sets, oxygen systems, extra pumps, etc.), which are also expensive.

Closed Systems

Closed recirculating systems have been used in BC to raise hatchery fish for many decades, and are advantageous as commercial operations. Closed systems have considerable potential for waste removal and treatment, and reduced escape and predation problems; however, these systems are complex and expensive to buy and operate. Many designs exist, particularly in Europe and the US. Advantages of such systems include: reduced land and water requirements; a high degree of environmental control, allowing year-round growth at optimum rates; the feasibility of locating in close proximity to prime markets; and improved waste control and removal. Such systems have often failed to become viable, however, due to poor design, inferior management, or flawed economics (this argument also holds for enclosed systems in certain cases). Closed systems remain perceived as expensive ventures that are as much an art as a science.

Enclosures (Ocean Bag Systems)

Enclosures, such as ocean bag systems (e.g., Future SEA), may provide the waste control of recirculating systems with the advantage of a lower operating cost. While capital costs appear 10 times those of open netpens and one-sixth those of recirculating systems (including capital investment of system and set up costs), cost of production appears only minimally higher than that of open netpens. The principal advantages of bag enclosures over open cages or nets include their potential to reduce escapes and predation, their higher stocking densities, and removal of greater than 80% of solid waste. Pilot studies have demonstrated some promise of a more efficient operation regarding escapes, densities and feed ratios. This result apparently relates, at least in part, to the stronger current of enclosed tanks, which promotes faster swimming. Recent research has demonstrated that fish perform better when swimming faster. Improvements include lower feed conversion rate (better conversion), higher growth rates, reduced aggression, possibly reduced stress, and higher survival. Much of this research has been conducted in Sweden in the early 90s but has since been repeated. With regard to waste treatment, there are no reliable data available (independent third party monitoring) that provide levels of efficiency of present waste traps and concentrators in enclosures over open netpens (which must rely on tidal and current action to disperse waste and do not remove it).

Siting of enclosures, as currently designed, appears to remain limited to more quiescent bays, as they run the danger of collapsing in higher-velocity waters (e.g., Bay of Fundy experience). It remains for the SEA System to be more thoroughly and further tested under commercial conditions to comprehend their actual limitations and advantages. Their potential limitation to more areas with less flushing action may underscore the need for waste treatment of such systems.

The prevalent waste removal system encountered for enclosed bag/tank systems is the use of waste traps and concentrators, such as that promoted by Future SEA Technologies, which focusses on particle load, and leaves the dissolved nutrient fraction untreated. Current research has demonstrated that over 70% of the N released by an aquaculture facility (closed or open) occurs in the dissolved fraction. Of this fraction, at least 80% is directly available to aquatic plants (plankton and macrophytes), potentially causing eutrophication and toxic algal blooms. Some innovative alternatives are currently under research and pilot operation, including the use of source-reduction and integrated culture.

Great potential exists for treating and using sludge once removed from an aquaculture facility. Irrigating salt-tolerant crops (halophytes) with saline effluent may be a useful strategy for preventing eutrophication of coastal waters by direct discharge. Halophytes have demonstrated a capacity to act as biofilters of nutrients (particularly nitrate) in aquaculture effluent and are currently being developed as biomass, forage and oilseed crops using saltwater irrigation.

Need for Innovative Alternatives

The present concern regarding continuing deterioration of coastal ecosystems and its subsequent impact on aquaculture and other uses calls for the application of a “precautionary principle” to any development activity that might not be sustainable. Researchers and proponents of the aquaculture industry are currently investigating new techniques, methods, options and tools to increase the cost efficiency and ecological sustainability of aquaculture. Innovative approaches include drawing on experiences of the agriculture industry through use of integrative culturing using polycultures. Other means include source-reduction (e.g., use feeds designed to protect the environment), or adoption of indigenous fish of lower trophic level.

Ecological Footprints & Sustainability

The area required to assimilate nutrients released from aquaculture indicates how densely farms can be placed in an area without risking self-pollution, formation of algal blooms, and other adverse impacts. The footprint for waste assimilation, as well as the strain on the environment, can be reduced by integrating seaweeds in intensive aquaculture. Suggestions for sustainable aquaculture (i.e., farming with low ecological footprint) include use of source reduction technology (e.g., increased feed efficiency) and a focus on intensive rather than extensive systems to reduce area use. Others promote use of enclosed systems in which water is filtered for particulate and dissolved nutrients before release to the environment. Such treatment may be accomplished through use of seaweeds as biofilters or high-technology cleaning solutions.

More research is required to determine ecological footprints of the various aquaculture types in temperate climates like BC. Small, intensive farming facilities with recirculating systems may incur many hidden costs and impose greater ecological footprints than larger, less intensive facilities.

Aquaculture may contribute to environmental degradation, but, paradoxically remains dependent on the supply of clean waters, seed larvae supply and other ecosystem services. Moreover, aquaculture production should not be viewed as an alternative to fishing unless farms exclusively use herbivorous fish. Many farms, particularly in BC, use carnivores (e.g., salmon, trout) that depend on diets of wild fish (in the form of high protein fishmeal). Such a practice is not sustainable.

Aquaculture Regulations

As in BC, regulation of salmon aquaculture in each jurisdiction investigated (with the exception of Alaska, where it is illegal) is in a state of flux. The aquaculture industry underwent rapid growth through the 1980s and early 1990s, with the support of governments eager to provide employment in depressed regions, to develop alternative food supplies, and to relieve pressure on wild fisheries. Governments were reluctant to impose heavy regulatory restrictions on the industry, and when issues of environmental concern began to arise more frequently (e.g., disease, waste accumulation, and escapes of exotic species), mechanisms for environmental evaluations and enforceable standards were often not in place. In addition, responsibility for salmon aquaculture has often exhibited considerable overlap between government departments, each with their own agenda.

The New Brunswick aquaculture industry is, at present, overseen by a single agency, the Department of Fisheries and Aquaculture (DFA). Aquacultural waste management in NB is not subject to a specific regulatory framework, but certain provisions of the NB *Aquaculture Act* and the federal *Fisheries Act* are applicable. The Sustainable Development Section (SDS) of the DFA and the NB Salmon Growers Association are co-operating closely on development of an industry Code of Practice. Protocols being developed will particularly address four waste management components: blood-water and mortalities, viscera and effluent from processing, accumulated waste under cages, and debris at sites, in water or on beaches. The Aquaculture Environmental Coordinating Committee has recently drafted a second Environmental Monitoring Program (EMP) for salmon aquaculture sites in southwest NB, and is developing an Environmental Remediation Guide. The EMP is intended to be a cost-effective management tool for obtaining and evaluating basic data and information pertaining to organic enrichment in sediments.

On April 7, 2000, the Government of Norway proposed changes in the *Act Relating to the Breeding of Fish, Shellfish, Etc.*, including ones strengthening environmental provisions. Such changes are seen as representing modernization in attitudes regarding industry co-operation with authorities on environmental issues. The changes detail the responsibility and authority of the Ministry of Fisheries with respect to the aquaculture industry and care of the surrounding environment. Environmental supervision is to be directed by a set of regulations established in co-operation with the Ministry of Environment. Following a public hearing, new regulations may be implemented in 2001. Norwegian fisheries and environment authorities have, in co-operation with relevant professional groups, financed development of the regulatory tool and methods for environmental supervision and monitoring. Elements of the procedure, known as MOM (Modelling-Ongrowing Fish Farms-Monitoring), include parameters that should be measured, methods that should be used, frequency of measurements and interpretation of results obtained.

Regulation and monitoring of Scottish aquaculture has adapted and grown with the industry, and political changes have brought new environmental regulations. Most notably, Scotland has been granted greater autonomy within the UK, and jurisdiction of the EU has become more established. *The Environment Act 1995* promotes cleanliness of tidal waters, conservation and enhancement of natural beauty and amenity of coastal waters, and conservation of aquatic flora and fauna. The Scottish Environment Protection Agency (SEPA) is the competent authority responsible for regulating pollution from cage fish farms. SEPA sets numeric or descriptive conditions on discharges from fish farms to control their impact in tidal waters, and also defines appropriate environmental monitoring to ensure that Discharge Consents are appropriate. SEPA recently issued a Guidance manual on Regulation and Monitoring of cage fish farms. Scotland has well-established monitoring programs to ensure compliance with the legislation. The complexity of regulatory and monitoring issues the aquaculture industry presents has required new techniques be developed, including mathematical modelling to set environmental targets for some medicines. A national approach has been needed that would benefit the industry and the regulators and allow focus to be brought to wider issues requiring research and development. SEPA routinely monitors cage fish farms to ensure compliance with Consents to Discharge, ensure EQSs and other standards are being met, measure effects on the environment, determine any action to be taken and audit results of self-monitoring. SEPA monitors for compliance with Consent conditions through monthly paper or electronic returns from the operator that detail the medicinal treatments undertaken and the biomass of stock held. Fish farm shore bases are also routinely inspected, including records of stock held, medicinal treatments, chemical storage facilities, disposal facilities for dead fish and other solid wastes and facilities for net washing and disposal of net-washings.

Growth of the Chilean industry has far outpaced the capabilities of the authorities to regulate production, technological developments and controls. This situation has given rise to considerable autonomy for the industry, with questionable results in environmental degradation of production sites, control of disease and incidence of transfer, and use of antibiotics and associated impact on the aquatic system. Though the aquaculture industry relies on a high degree of self-regulation, many companies struggle to undertake such regulation, given increasing competition. The evolution of Chilean salmonid production since the early 1980s has led to state regulations adapting to industrial change in a reactive rather than proactive manner, and lagging behind the development of the industry. The recently developed Chilean EIA System is applicable to both public and private sector projects and activities, and is intended to ensure environmentally sustainable implementation. The process identifies potential adverse environmental impacts in order to avoid, minimize, or counteract them, and contributes to the decision-making process regarding siting, design and technology. EIA regulations also prescribe abatement, restoration or compensation measures that must be incorporated into projects to prevent adverse impacts. Projects and activities likely to have an environmental impact must undergo an EIA. Control of diseases by regular treatment is largely unregulated in Chile compared with restrictions in other salmon farming countries. As the use of antibiotics remains the industry's most negative aspect environmentally, treatment regimes in Chile require closer scrutiny by regulatory authorities.

In 1985, the Washington State Legislature adopted a policy that "aquaculture is agriculture" and designated the Department of Agriculture (WDOA) the lead state agency for promoting and marketing cultured salmon. Responsibility of the Washington Department of Fish and Wildlife (WDFW) was limited to administering fish disease control and prevention regulations developed jointly with the WDOA. Washington State fisheries managers are particularly interested in the consequences of escapes of Atlantic salmon and effects on wild salmon should they co-mingle with other fish and wildlife in waters of the state, given that many Pacific salmon stocks in Washington have recently been listed as *endangered* or *threatened* under the Endangered Species Act. The WDFW hopes to re-establish its position of actively managing all fish and shellfish of the state, including private sector aquaculture products. While acknowledging that marketing, commodity boards, and promotion of agriculture products appropriately resides with the DOA, WDFW feels it should be reassigned all aspects of management of live commercial aquaculture fishery products, and be provided with the necessary resources. WDFW also believes that, while it is important to maintain a viable finfish and shellfish industry in the state, it is imperative that commercial aquaculture in no way jeopardizes natural resources of the state, and that only by joining the responsibility of managing both aquaculture and wild resources under one agency will such management goals be achieved.

Salmon aquaculture is highly restricted in Alaska. Section 16.40.100, "Aquatic farm and hatchery permits," under Alaska Statute Title 16, *Fish and Game Code*, states, "Notwithstanding other provisions of law, the commissioner may not issue a permit under this section for the farming of, or hatchery operations involving, Atlantic salmon."

In British Columbia, the development and adherence to a "performance based management" system would allow the industry to develop within clear guidelines and procedures.

Toxic Algal Blooms

During the past decade, there has been a worldwide increase in marine microalgae that are harmful to finfish, shellfish, and human consumers. Correlative field data, coupled with experimental evidence, suggest that some algal species not normally toxic may become so when exposed to altered nutrient regimes from overenrichment. Outbreaks of some species have also coincided with *El Niño* events, suggesting that global climate change and warming trends may also encourage their growth. Approximately 20 of the 5,000 known phytoplankton species along the west coast produce toxins or are directly lethal to fish, while an estimated 25 additional species are responsible for other problems, such as water discolouration or "red tides."

Paralytic shellfish poisoning (PSP) results from a number of saxitoxin derivatives produced by dinoflagellates of the genus *Alexandrium*. Domoic acid poisoning (DAP; also called amnesic shellfish poisoning, ASP) is caused by the pennate diatom, *Pseudo-nitzchia pungens* and related species. Though other toxic species associated with diarrhetic shellfish poisoning (DSP) are present in BC (e.g., *Dinophysis* spp.), DSP has not yet been reported. Along coastal BC, upwelling during spring and summer in response to strong and persistent northwest winds may bring cold, nutrient-rich waters that support rich phytoplankton blooms in the surface layer. Along the coast of BC, Washington and Oregon, surface nutrient concentrations are generally high everywhere during the winter, but are higher nearest the coast in summer when phytoplankton blooms may occur. The Columbia and Fraser Rivers are sources of high nitrate, phosphate and silicate in both winter and summer.

Effects of nuisance blooms on the aquaculture industry can be devastating, with economic losses in BC estimated at $20 million, attributable particularly to the chloromonad flagellate *Heterosigma*. One method of bloom avoidance by netpen fish farms is to skirt the perimeter of pens with polyester tarps, preventing advection of surface blooms of *Heterosigma* into the pens. Closed systems are generally recognized as being more protected from nuisance algal blooms than open cage systems, due to the optional positioning of water intakes in most enclosed and closed recirculating systems. A unique feature of the SEA System™ is its ability to draw water from varying depths using an adjustable intake. This feature apparently enables the aquaculture facility to consider and avoid algal blooms, which can be depth-dependent.

Aquaculture facilities may release dissolved and solid nutrients to the aquatic environment, causing hypernutrification and eutrophication. Besides the increase of phytoplankton production, eutrophication may cause additional effects that may be more sensitive and relevant indicators of receiving-environment impact, such as changes in energy and nutrient fluxes, pelagic and benthic biomass and community structure, fish stocks, sedimentation, nutrient cycling, oxygen depletion, and shifts between perennial and filamentous benthic algae. Excessive N and P discharge (hypernutrification) from aquaculture operations may stimulate algal blooms and create nuisance conditions. Salmon farms may contribute ammonium, phosphate and organic nutrients to the water column exploited by phytoplankton. The lack of direct evidence of hypernutrification and eutrophication may be due to the usually high water exchange rates. Phytoplankton populations in this enriched water may increase some distance from the farm area (away from where impact studies usually are performed). Moreover, since the structure of plankton communities often displays high natural variability, eutrophication effects cannot be proven without extensive monitoring programs designed specifically to detect such effects. Therefore, the lack of reported effect may be a function of inadequate study design, low sensitivity, and inappropriate end-point measurements.

1.0 INTRODUCTION

G3 Consulting Ltd. (G3) has prepared this report for the BC Ministry of Environment, Lands and Parks (MELP), Pollution Prevention and Remediation Branch. Objectives of this project, as defined by MELP, were to:

1. evaluate the costs, operations, waste management capability and examine the feasibility of "closed" circulating systems compared with "open" netcage systems in BC;
2. review any new regulatory tools and mechanisms with respect to waste management that could be applicable to BC; and
3. document emerging research with respect to plankton blooms and netcages.

Worldwide, salmon-farming operations provide about one-third of the total annual salmon harvest. In 1995, the harvest of farmed fish accounted for approximately 37% of salmon production in BC.

Salmon farming is most productive in cool waters well flushed by tidal action and protected from ocean storms. The southern BC coast, comprising a network of islands, peninsulas and quiet bays, is particularly well suited for salmon aquaculture, given its good marine water quality, accessible shoreline, ready supply of fresh water, safe moorage, and proximity to population centres.

When the salmon aquaculture industry was first introduced to the BC coast in the early 1970s, chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) were farmed almost exclusively. Atlantic salmon (*Salmo salar*), with their faster growth rate and greater tolerance for higher stocking densities, were later introduced. By 1988, 101 salmon-farming companies operated in BC. Economic and environmental factors have since resulted in ownership being consolidated into 16 companies.

Species diversification in BC finfish aquaculture has been the subject of research for several years, following the lead of Norway and Japan (more than 50 finfish species reared). Use of blackcod in BC aquaculture has been researched for several years, with this species now approaching commercialization (Pennell, pers. com.). With aquaculture of blackcod and halibut being developed in BC (Pennell, pers. com.), the future of the BC finfish aquaculture industry appears to be growing faster than projected by the recent Coopers & Lybrand report (1997; cited by Marvin Shaffer & Associates Ltd. *et al*., 1997; Pennell, pers. com.).

The rapid growth of the BC salmon-farming industry in the 1980s caused public concern about possible impacts on other coastal users and the marine environment. It was recognized that a co-ordinated regulatory system was required. Federal and provincial governments subsequently established roles in regulating the industry:

- Fisheries and Oceans Canada maintains regulatory authority for health of fish in aquaculture facilities, food and public health safety, conservation and protection of wild fish stocks and habitat, and protection of navigable waters;
- the BC Ministry of Agriculture, Food and Fisheries licenses aquaculture operations and controls most operational aspects of salmon aquaculture; and
- MELP regulates siting and waste discharge permits.

1.1 BC Salmon Aquaculture Review

In July 1995, as part of a moratorium on granting new salmon aquacultural tenures, the Minister of Environment, Lands and Parks (MELP) and the Minister of Agriculture, Fisheries and Food (MAFF) requested that the BC Environmental Assessment Office (BCEAO, 1997a through f) conduct a review of the adequacy of current methods and processes used by the two ministries to regulate and manage the industry in BC. The BCEAO had been established under the BC Environmental Assessment Act in 1994 to oversee environmental impact assessments of major projects.

Five issues were examined under the Salmon Aquaculture Review:

1. impacts of escaped farm salmon on wild stocks;
2. disease in wild and farmed fish;
3. environmental impacts of waste discharged from farms;
4. impacts of farms on coastal mammals and other species; and
5. siting of salmon farms.

The BCEAO established a Technical Advisory Team (TAT) of experts to work with a Review Committee in preparing comprehensive discussion papers making recommendations concerning each of the five issues. The TAT concluded that, “salmon farming in BC, as presently practiced and at current production levels, presents a low overall risk to the environment.” This general finding was tempered, however, by certain reservations (BCEAO, 1997c):

- continuing concern about localized impacts on benthic (seabed) organisms, shellfish populations and marine mammals suggested the need for additional measures to protect them; and
- significant gaps in the scientific knowledge on which BCEAO TAT conclusions were based pointed to the need for monitoring and research in such areas as,
  - potential impacts of interactions of escaped farmed salmon with wild populations;
  - identification and control of disease and disease pathogens;
  - potential for disease transfer and impacts from antibiotic residues; and
  - effects of waste discharges on water quality and seabed life.

1.2 Earlier Literature Review

In 1996, Hatfield Consultants Ltd. and EVS Environment Consultants prepared a review of literature pertaining to environmental effects of salmon netcage aquaculture in BC for MELP (Winsby *et al*., 1996). The current report updates information on selected topics covered in the previous report, augmented by current information on additional topics of concern.

2.0 CLOSED CIRCULATING MARINE SYSTEMS

With an annual increase estimated at 4% to 11%, aquaculture is the world's fastest growing food production sector (FAO, 1997). For example, more than 100 aquatic species are farmed in the United States. Approximately 10 types of finfish and shellfish in both freshwater and marine environments dominate the US industry, and are raised primarily in ponds, tanks, raceways, netpens and cages (Goldburg and Triplett, 1997). Catfish constitute close to half US production.

Aquaculture has been practiced in BC for nearly 100 years, and has included oyster culturing, salmonid enhancement and other forms of production (BC Salmon Farmer's Association, 1998). Sockeye hatcheries began operating in BC in the 1930s (Pennell, pers. com.). Open netpens, such as the Polar Circle, have dominated the BC aquaculture industry. Many aquaculturists, particularly larger companies (e.g., Omega Salmon Group), have been investigating and adopting larger, square, steel caged systems. The closed system is a relatively new sector in the BC aquaculture industry, with such companies as Future SEA Technologies (incorporated in 1994) providing bags and technology to local farmers (e.g., Totem Oysters Ltd.).

Aquaculture may have the potential to contribute to environmental degradation, but, paradoxically, it is dependent on a supply of clean waters, seed larvae, and other ecosystem services (Rönnbäck, in press). Moreover, aquaculture production should not be viewed as an alternative to fishing unless farms exclusively use herbivorous species (e.g., tilapia, catfish, carp, oysters and clams). Farms in many regions, including BC, raise carnivorous species (e.g., salmon and trout) that are dependent on diets of wild fish (as fishmeal; Goldburg and Triplet, 1997).

The present concern for continuing deterioration of coastal ecosystems and the subsequent impact on aquaculture and other marine uses suggests that a "precautionary principle" be applied to any development activity that might be unsustainable (Troell *et al*., 1999a). Researchers and aquaculture proponents are currently investigating new techniques, methods, options and tools for increasing cost efficiency and ecological sustainability of the industry. Innovative approaches include drawing on experience of the international agriculture industry, which includes integrated polycultures. Other means include source-reduction (e.g., using feeds designed to protect the environment), or culture of indigenous fish of lower trophic levels.

In response to a growing concern regarding limited capability to reduce waste from open cage and netpen systems, closed systems have recently received much attention due to their potential for regulating waste reduction and removal. "Closed" systems may be partially closed, such as *in situ* enclosures of Future SEA or Procean, land-based (seawater pumped) tanks or completely closed, such as recirculating (reuse) systems. The usual distinction made by those in the saltwater industry between "closed" and "open" is:

- between a floating bag and an open netcage or an open net; or
- between a land-based pumped seawater facility and an open netcage.

The major interest has been in reducing risks associated with open cage culture. These systems are all "open" in the sense that water returns to the external environment, and there are no issues of water conservation or heating. Recirculating systems that reuse or recycle water are more aptly termed "closed" systems, as these systems are designed to preserve water or heat. Nevertheless, they also discharge effluent to the external environment.

2.1 Existing Closed System Designs

Closed, recirculating systems have been used to raise fish in hatcheries for many decades, and are advantageous as commercial operations. Closed systems provide a high potential for waste removal and treatment and avoidance of escape and predation problems. These systems tend to be complex and expensive to build and operate. Many designs are in operation, particularly in Europe and the US (Section 2.6.1).

Such enclosures as ocean bag systems may combine the waste control advantage of recirculating systems with lower operating costs. Two examples of enclosed marine systems are described below.

2.1.1 Procean AS

Procean AS, a Norwegian engineering company established in 1992, developed an ocean bag system that contains an outlet to capture and analyze waste. Headquartered in Bergen, Norway, the company also operates an office in Seattle, Washington. In addition to ocean bags, Procean manufactures land-based systems such as the Aquahive system, consisting of a combination of modular concrete cells, which has been suggested as an alternative to raceways and separate circular tanks. The company uses its Biofish water recirculation system, which features a decentralized bioreactor in each tank. Procean AS suggests that Aquahive is ideal for cultivating large salmon smolt and other high-volume production where water supplies are limited. Solid waste is removed and collected in a separate sludge collector. Although repeated requests for information were made to Procean (www.sea-world.com/procean), none was forthcoming by the time of this writing.

2.1.2 Future SEA Technologies

Incorporated in 1994, Future SEA Technologies Inc., located in Nanaimo, BC, developed the *SEA* (Sustained Environmental Aquaculture) *System*™ technology, an enclosed floating fabric bag for fish rearing. Fish grown in the SEA System remain isolated from the surrounding external aquatic environment (Clarke, 1997; Brenton, pers. com.). Each bag is equipped with a pump that can draw water from a selected depth to control water quality, current speed and temperature. Pumps deliver approximately 20,000 gallons per minute (~91 m^3/min) of external water through the enclosure. The current from water circulation within each bag exercises the fish, and the vortex flow either directs faeces and other waste into the cone-shaped bottom for collection and further processing, or directly discharges it in a desired direction. Given it provides for oxygen injection and aeration, Future SEA indicated the system may enable higher stocking densities (Hatt, 1999).

Future SEA collaborated with the Canadian Department of Fisheries and Oceans (DFO) for biological and technical assessment of the SEA System™ at the Pacific Biological Station (PBS) in Nanaimo, BC.

Scale model testing at National Research Council (NRC) towing and wave tank facilities has demonstrated that the shape of the bag is unaffected in currents up to 2.7 knots and undergoes only minor distortion at 3.5 knots. The bag was subjected to wave heights of 3.0 m with no adverse impact (Future SEA Technologies, pers. com.). Failures have been reported, however, in exposed coastal waters of New Brunswick (Lafreniere, pers. com.).

A June 9, 2000 press release issued by Future SEA Technologies (Andrew, 2000) announced that approximately 28,000 Atlantic salmon had been removed from the SEA System™ in Lime Kiln Bay, NB due to concerns regarding the condition of the bags. Two bags had developed stress marks, indicated by delamination of the bag material, and there was a 60 cm separation of a bag seam caused by a material defect. Damage was attributed to a combination of strong Bay of Fundy tides and two severe winter storms. No fish were reported to have escaped. Design modifications are to be made for applications of the system in areas of strong currents, and trials are to resume in spring 2001.

Future SEA systems currently in use include:

- Scotia Rainbow, of St. Peter's Bay, Cape Breton Island, NS (Ehman, 1998), which has employed eight bag cages since December, 1998;
- Aquatas Pty. Ltd., Hobart, Tasmania, (Brenton, 1999), the second largest salmon farming operation in Australia, which had purchased six Future SEA bags as of October 1999 (four that included waste trap and concentrator systems);

- South Southeast Regional Aquaculture Association (SSRAA), Alaska (Brenton, 2000); and
- Totem Oysters Ltd., Saint Vincent Bay, off Hotham Sound, BC, which installed several bags in January 2000 to raise rainbow trout.

2.2 Comparison of Capital Costs of Enclosures & Netpen Systems

Though the aquaculture industry is growing rapidly and many proponents expect sustainable profits, it remains a young industry with a history of failed ventures. It is evident that many operations have failed, not because of equipment failure or an inability to comply with imposed regulations, but because of unsound business judgements.

With increasing technological options, greater requirements for effective waste removal and treatment, and adoption of larger, supposedly more efficient facilities, differences in capital costs among open netpens, enclosed and closed recirculating systems may be lessening.

2.2.1 Enclosures (Future SEA Technologies, Inc.)

Cost of the Future SEA System enclosed 12 bag system (12 m by 5 m bags, usually freshwater and without a waste trap or concentrator) is approximately $1.07 million (including a cage system, treated net and mooring costs; Dubreuil, pers. com.). Approximate additional costs include $10,000 per bag for waste traps and $10,000 for concentrators (usually one per bag).

To develop its technology and assist in market expansion, Future SEA Technologies Inc. relies on venture capital from the Working Opportunity Fund (EVCC) Ltd. and Aquahold Technologies (VCC) Ltd., and Crown Life Insurance Company, a private sector institutional investor (Hatt, 1999; Andrews, pers. com.).

Scotia Rainbow Inc., Nova Scotia

Scotia Rainbow purchased an eight-bag system from Future SEA Technologies Inc. for $1.7 million in late 1998 (Hatt, 1999). Installation costs and additional services were likely part of this capital expenditure. Mr. Serge Lafreniere, President of Scotia Rainbow, endorsed Future SEA's service guarantee following installation. The eight-bag system, installed in the brackish waters of Saint Peter's Bay (in the Bras d'Or system), Cape Breton Island, has supported three crops of cultured steelhead trout during two years of operation. Operational costs are approximately $1.65/lb (~$3.63/kg), and market value estimated at $3.00/lb to $3.50/lb (~$6.60/kg to $7.70/kg; Lafreniere, pers. com.).

Totem Oysters, Sechelt, BC

Totem Oysters Ltd. is located in Saint Vincent Bay, adjacent to Hotham Sound on the Sunshine Coast of BC. Proprietor Mr. Gus Angus provided round figures for purchase of two Future SEA bags (without waste traps and concentrators) of approximately $300,000. The 15 m diameter bags were installed in January 2000 to culture Rainbow trout and costs included the bags, floatation collar, hand rail, oxygen unit and two pump stations with 15 horsepower (~11 kW) electric motor. Totem employs electric water pumps powered by shore-based diesel generators via underwater cable to the barge adjacent to the bags. Totem estimated additional setup costs to be $100,000, making the total capital investment $400,000 for a two bag system (Angus, pers. com.). The site combines old and new technology by Future SEA. Angus further added that unit costs were lower with more bags purchased, and cited the round figure cost for a four-bag system of approximately $450,000, exclusive of additional setup costs.

Angus, who has been farming fish since the early 1980s, runs both open netpens and enclosures at his facility. Costs of Totem's open netpens (15 m diameter Polar circles) were one tenth those of enclosures. Angus believes that the added efficiency of enclosures (e.g., feeding ratio, higher density, and accountability for morts) justifies the capital costs. Totem cultures rainbow and steelhead trout at densities of approximately 4 kg/m^3, a level lower than that considered typical of this type of system (~40 kg/m^3; Andrews, pers. comm.).

Aquatas Pty. Ltd., Hobart, Tasmania

Aquatas Pty. Ltd., of Tasmania, Australia, installed two Future SEA bags in July 1999. Three Future SEA bags complete with water traps and concentrators, purchased in November 1999, are currently in operation. In March 2000, another two bags were installed along with five waste traps (Carington Smith, pers. com.).

The entire operation is sea-based, using a converted US Navy barge as service platform to run hydraulics, gensets, control and monitoring gear, and living quarters. The 8 bags and waste traps/concentrators cost approximately AUS$1.85 million. The US service barge cost an estimated AUS$400,000. Aquatas estimated the entire operation, including shipping and Australian Duty (3% to 4%), cost AUS$2.25 million (Carington Smith, pers. com.). No comparable capital costs were available for netpen systems.

2.2.2 Netpens

Most salmon farmers used small wooden pens until approximately 1983 (Pennell, pers. com.). Since then, many types and brands of netpens have been used in BC. Popular configurations have included flotillas of square 15 m/side steel pens and large square pens (30 m/side). Circular pens have also been popular (e.g., Polar circle), with typical sizes ranging from 15 m to 90 m circumference (70 m to 90 m appears most popular). Cost of a 90 m netpen (complete farm) is lower than $30,000, typically $20,000, depending on specifications for ropes and netting (e.g., grade, treatments, etc.). A 15 m circumference pen was purchased by Totem several years ago for approximately $16,000 (Angus, pers. com.). Unit prices vary, depending on specifications and number of netpens (Cards Aquaculture Products, pers. com.)

The open netpen sector is apparently moving from circle netpens to larger, square, steel cages, which entail higher capital investments of up to $1,000,000. Currently popular with the industry is an arrangement of six nets (24 m square and 13 m to 17 m deep). Several larger companies have invested in this kind of netpen (e.g., Omega Salmon Group).

According to Mulholland (1998), the main reason for adopting larger cage systems is cost effectiveness. Shifting from a 15 m steel square to a 30 m steel square reduces capital cost per growing area by 50%, and shifting to a plastic 40 m diameter circle (common worldwide) reduces cost per growing area by 73%. Mulholland's (1998) comparison of general costs of different cage sizes is presented in Table 2-1.

Comparison of Future SEA with Steel Caged Open Net

As part of its cost-benefit comparison, Future SEA provided the capital costs for its enclosed bags and steel caged systems, summarized in Table 2-2. (Dubreuil, pers. com.).

Future SEA (Dubeuil, pers. com.) also compared capital costs of their SEA System (twelve 12 m by 5 m bags) with a 6,000 m^3 land-based facility (at $1,000/m^3) for growing Atlantic salmon. The Future SEA bag was costed out at $1.4 million (different from capital costs given in Table 2-2), compared to $6,000,000 for a land-based facility. These estimates must be viewed judiciously as sources for costs of the land-based system were not provided, nor were details given of the specific land-based system used for comparison. Costs of $1,000/m^3 for a flow through hatchery and $1,200/m^3 are considered typical (Andrews, pers. com.).

**TABLE 2-1:
Comparison of Different Cage Sizes & General Costing**

Shape	Material	Dimensions (m)	Area (m^2)	Cost per Pen ($)	Cost per m^2 ($)
square	steel	12	144	14,000	97
		15	225	19,000	84
		30	900	36,000	40
circular	HDPE	30 (diameter)	706	22,000	31
		40 (diameter)	1,256	28,500	23
		50 (diameter)	1,963	33,000	17

Reference: Mulholland, 1998.

**TABLE 2-2:
Capital Costs of Open Netpen Steel Cage (15 m x 15 m x 15 m) &
Future SEA Enclosed Bags (15 m x 12.5 m)**

Capital Item	Caged System ($)	Future SEA Enclosure ($)
Main System	264,600	1,050,000[1]
Treated Net	60,000	NA
Mooring	42,000	21,000
Total	**366,600**	**1,071,000**
Replacement Net or Bag	60,000	286,321
walkway, feed system, feed boat, barge with building, building	cost not provided	cost not provided

1. includes treated bag

2.3 Comparison of Operational Systems & Costs of Enclosures & Netpen Systems

Enclosures and netpen systems were compared, using Future SEA System bags and standard (15 m x 15 m x 15 m) steel caged netpens as examples. Operational systems were compared by third party research (e.g., DFO). Cost comparisons provided by Future SEA staff were derived through modelling. Estimates of operational costs were sought from independent third parties. Some information was available, although most was not directly relevant to BC marine situations. A cost report of netpens compiled by Pacific National Group (with some comparison to enclosures) was intended to be available in July 2000.

2.3.1 Operational Systems Comparison

The DFO Mariculture Facility in Departure Bay conducted several comparative experiments between the enclosed SEA System™ and open netpens in the late 1990s, including coho growout tests (Clarke, 1997), harvest quality of the same coho (Clarke, 1998a), production of Atlantic salmon (Clarke, 1998b), and sea lice observations (Clarke, 1999). The results presented are prefaced by the following caveats regarding the validity of comparison between open and enclosed systems. First, the DFO open cage pen was very small. Second, Departure Bay has not been traditionally regarded as a good site for cage culture (Pennell, pers. com.). Scientific validity would be gained from siting SEA bags where open cages (big commercial sites under commercial conditions) are typically located.

Coho Growth Test

Coho salmon were stocked into a bag and adjacent netpen in March 1997 (Table 2-3).

**TABLE 2-3:
Bag & Netpen Starting Conditions**

Condition	Bag	Netpen
Volume	875 m^3	324 m^3
Stocking Number	9,554	1,043
Fish mean weight	627.7 g	621.0 g
Stocking density	6.8 kg/m^3	2 kg/m^3

During the 1997 coho growth test, fish in the bag were reported to grow more successfully, as evidenced by lower mortality, more efficient food conversion and higher specific growth rate. The growth coefficient was considerate of fish size and water temperature (Iwama and Tautz, 1981; Iwama, 1996). Performance traits are summarized in Table 2-4.

A greater growth coefficient for fish in the bag confirmed that growth was faster in the bag under comparable conditions. In addition, fish in the netpen endured the presence of toxic phytoplankton during the trial.

**TABLE 2-4:
Performance Traits for Coho Growth Tests
in SEA System™ Bags vs. Netpens**

Performance Criterion	Bag	Netpen
Feed Conversion Rate (simple economic)	1.22:1	1.75:1
Mortality (%)	1.58	4.10
Harvest Weight (grams)	2,292.5	1,725.6
Accumulated Thermal Units (ATU)	1237	1379
Mean Temperature (°C)	9.74	10.86
Specific Growth Rate (% body weight/day)	1.02	0.80
Growth Coefficient	3.74	2.51

Source: Clarke (DFO), 1997

Harvest Quality of Coho

Analyses of physiological conditions and flesh quality were performed on coho salmon raised in bags and adjacent netpens. Analyses included levels of several compounds in plasma, proximate composition, pigmentation, characteristics of carcass muscle development, and organoleptic properties.

Lactate levels in coho plasma in the bag were consistently higher than those in netpens. Data were not considered to represent typical values in the two culture technologies, given that they included the response of fish to sampling procedures. Fin erosion did not differ between bag and netpen fish. Bag coho had higher mucous cell counts, likely resulting from increased level of swimming. This finding was considered advantageous in defense against external fish pathogens. Abundance of visceral fat (assessed using a subjective visual rating) did not differ between bag and netpen fish. Drip loss differed significantly, with bag fish losing less weight in storage than netpen coho. No difference was observed in carotenoid content between bag and netpen coho.

Atlantic Salmon Growth

Atlantic salmon smolts from a commercial hatchery were stocked January 20, 1998 into a single bag and adjacent netpen (Table 2-5).

**TABLE 2-5:
Bag & Netpen Starting Conditions**

Condition	Bag	Netpen
Volume (m^3)	875	324
Stocking Number	9,819	1,203
Fish mean weight (g)	57.1	57.2
Condition Factor	1.15	1.14
Stocking density (kg/m^3)	0.64	0.21

Fish in the bag were reported to be significantly larger than netpen cohorts on first sampling (March 12), indistinguishable on second sampling (June 16) and notably larger again upon study termination July 30, 1998. Economic feed conversation rates (EFCR; amount fed divided by change in biomass, not adjusted for mortality) were initially poor in the netpen but improved as the spring progressed. EFCR in the bag was consistently lower (i.e., better) from the outset and throughout the study. Performance in the bag surpassed that recorded for netpen fish (Table 2-6).

**TABLE 2-6:
Performance Traits for Atlantic Salmon
in SEA System™ Bags vs. Netpens**

Performance Criterion	Bag	Netpen
Feed Conversion Rate (simple economic)	0.99:1	1.44:1
Mortality (%)	25.0	35.1
Fish mean weight (g)	510.0	414.5
Fish weight gain (g)	452.9	357.2
Condition Factor	1.44	1.33
Accumulated Thermal Units (ATU)	2,050	2,178
Specific Growth Rate (% body weight/day)	1.15	1.04
Growth Coefficient	2.02	1.65
Stock density (kg/m^3)	4.28	0.97

Source: Clarke (DFO), 1998b

Sea Lice Observations

Lower incidence of the sea louse *Lepeophtheirus salmonis* were recorded in bag Atlantic salmon than in netpen salmon during a 9-month growth trial from November 1998 to July

1999 (Table 2-7). DFO (Clarke,1999) suggested that possible causes of the difference in lice prevalence included the advantageous placement of the SEA System™ intake and the influence of greater swimming speed and exercise levels in the bag. BC currently does not experience the problem of sea lice to any great extent (Pennell, pers. com.). Application of pesticides is of concern in Scotland and Ireland, where the sea lice problem is marked.

**TABLE 2-7:
Confirmed Observations of Sea Lice in Bag
vs. Netpen Grown Atlantic Salmon**

Criterion	Sampling Period			
	May 19, 1999		July 19, 1999	
	Bag	Netpen	Bag	Netpen
Number of Fish sampled	25	25	25	25
Number of fish infected	8	16	2	15
Total number of lice	10	24	2	24
Prevalence	32%	64%	8%	60%

Source: Clarke (DFO), 1999

2.3.2 Comparison of Operational Costs

Successful operation of an aquacultural facility relies on sound accounting and economic planning, taking into consideration marketing, production, and financial feasibility. From the perspective of environmentally sound practices, prevention of waste (including fish escapes [this issue is further discussed in Section 3.5.2]) in the form of source reduction (e.g., high protein and nutrient feeds, drugs, other chemicals), or collection, recycling and reuse of wastes, must be accounted for as part of capital and operational costs. For instance, marketing feasibility assessment should consider not only the product-fish market, but a market for the facility's waste product. Strombom and Tweed (1992) provided a detailed breakdown of business plans for determining feasibility of an aquacultural operation (Appendix 1). The detailed worksheets (e.g., consisting of expectations, marketing, production and finance) provide a good framework for assessing criteria of a viable unit. Neither costs nor potential income, however, account for waste management.

Comparison of Net Cages to Enclosed Systems (Future SEA)

Future SEA Technologies provided cost of production (COP) estimates for coho salmon in enclosed bags and net cages (Dubreuil, pers. com.). COP was based on a bio-economic mathematical model that incorporated a biological component (growth curve, population dynamics, bio-energetic feed model, water temperature model, and metabolic rate model for expected oxygen consumption) and an economic component (costs only). Data for a full grow-out period were derived from DFO pilot research with Future SEA, and some client performance data (e.g., Totem and others).

Parameters considered in the model (see Appendix 2) included those of performance, set up, and production. Performance parameters consisted of:

- direct farm costs (smolt, feed, labour, oxygen, fuel for pumping, medication, etc.);
- depreciation (proportion of capital expenditure assigned to grow-out period; assumed the bag component [e.g., pump, floatation ring] depreciates over a 5-year period and remaining equipment over 10 years; and
- interest over capital investment (8% per annum).

Setup parameters (Appendix 2) comprised assumed levels of such physical, biological and economic factors as:

- stocking characteristics (timing, smolt weight, target harvest weight);
- system characteristics (SEA System, e.g., size, maximum density, number of units, and total rearing volume);
- environmental characteristics (e.g., water temperature, salinity and oxygen); and
- feeding efficiencies.

Average cost of production (COP) calculated for Future SEA enclosures compared to that of net cages was based on production parameters (e.g., growth, inventory, biomass, feed, density, performance, metabolism, labour and environmental considerations; Appendix 2).

Weekly production costs for coho reared in six SEA Systems 15 m diameter by 12.5 m deep assumed that the site had access to shore power ($0.065 per kWhr compared to $0.15 per kWhr for electricity generated by genset). Average reported COP per fish was $15.86 ($3.44/kg round weight) and assumed to include all costs in and all fish alive at harvest out (Appendix 2).

For 15 m square steel net cages, Future SEA assumed a higher monthly mortality rate (0.75% vs. 0.40%), a lower attainable rearing density (20 kg/m^3 vs. 40 kg/m^3), increased feeding inefficiencies, and cheaper labour costs. Average COP per fish for net cages, according to the Future SEA model, was $16.73 ($3.64/kg round weight; Appendix 2).

Future SEA also compared costs of producing Atlantic smolts in the SEA System with those of a land-based system (Appendix 2). Although Future Sea provided cost breakdown based on assumptions provided, as the company provided neither the basis nor source of the land-based numbers (e.g., how fixed capital costs were derived), the comparison must be viewed with caution. Cost per smolt for the SEA System was $0.74 compared with $1.00 for the land-based system (Dubreuil, pers. com.).

Enclosed Bags (Scotia Rainbow)

Scotia Rainbow provided an operational cost for culturing steelhead trout in their Future SEA closed bag system. Company President Mr. S. Lafreniere costed out the closed bag system, using only the Lift-UP waste removal system (see Section 2.4.1), at $1.65/lb (~$3.63/kg) of fish with a market value of $3.00/lb to $3.50/lb of fish (~$6.60/kg to $7.70/kg). Lafreniere estimated an additional annual operational cost of $25,000 to $30,000 for a filtration waste removal system anticipated to remove close to 100% of the solids. This cost did not include potential revenue from sale of sludge to local farmers for use as fertilizer, or cost of removal from the site.

Enclosed Bags (Aquatas Pty. Ltd.)

At its facilities south of Hobart, Tasmania, Aquatas uses 15 m by 10 m bags with holding capacity of 1,450 m^3. Stocking densities range from 15 kg/m^3 to 60 kg/m^3 (Carington Smith, pers. com.). By contrast, Aquatas operates net cages at approximately 8 kg/m^3 to 12 kg/m^3. Given that the Future SEA system had been in operation for less than one year before their communication with us, Aquatas did not provide operating costs, citing biomass produced, speed of growth, mortalities, and feed conversions as key issues to consider. Owen Carington Smith, revealed that their operational costs were approximately four times those of conventional cage systems on a kg/m^3 basis. Hence, the biomass yeild would need to be high to demonstrate cost effectivness of the system. Carington Smith suggested that reduced mortality and higher growth would be important.

Net Cages (Pacific National Group)

An assessment by Mr. Kevin Onchlin of the Pacific National Group, providing cost-of-production data and assessment for open net cages (and limited information on enclosed and, possibly, on land-based systems), will be available in July 2000. The report will summarize several years to current (2000) production. Data were not available to date.

Alberta Ministry of Agriculture, Food and Rural Development

Cost breakdowns provided by the Alberta Department of Agriculture, Food and Rural Development (1996) for a fresh water aquaculture grow-out operation and a commercial trout hatchery and fingerling operation have been included in Appendix 3.

2.4 Waste Discharge, Closed & Open Systems

The quality and quantity of wastes from aquaculture depend primarily on culture system characteristics and the choice of species, but also on feed quality and management (Iwama, 1991). Waste from an aquaculture facility is typically produced as either effluent or sludge. Effluent consists of exchanged water with dilute pollutant concentrations, while sludge contains particulate matter that is more concentrated. Environmental impacts depend on hydrodynamic conditions and sensitivity of the receiving ecosystem. Principal wastes produced by intensive mariculture systems include uneaten feed, faeces, dissolved nutrients, dissolved organic compounds, chemicals and therapeutics (NCC, 1990; Beveridge *et al*., 1994; Hargrave, 1994; Troell, 1996).

Significant waste discharges from fish farms may cause:

- decay of excessive organic compounds, which will reduce dissolved oxygen concentrations in water;
- excessive nitrogen and phosphorus levels, which may stimulate algal blooms and create nuisance conditions; and
- elevated particulate matter, which can deposit on the bottom substrate of the receiving water, either physically altering habitat conditions of the water body or chemically causing local depletion of dissolved oxygen.

Oxygen depletion may result in production of ammonium (Kupka-Hansen *et al*., 1991) and hydrogen sulfide (Gowen *et al*., 1991), and increased phosphorus release (Holby and Hall, 1991; Kupka-Hansen *et al*., 1991).

Approximately 72% N and 70% P in feed is not retained by fish (Ackefors and Enell, 1990). Ackefors and Enell (1994) estimated annual releases into the water column to be 9.5 kg P and 78 kg N per tonne of fish, with a feed conversion coefficient of 1.5 and feed contents of 0.9% P and 7.2% N. Improvements in feed composition, digestivity and feed conversion efficiency in recent years have reduced annual discharge to 7.0 kg P and 49.3 kg N per tonne of fish (Ackefors and Enell, 1994). Figure 1 (after Rosenthal, 1994) provides estimates of the distribution of N from salmonid cage cultures.

Elevated nutrients have been linked to increased bacterial populations and a likelihood of disease in the farm fish (e.g., opportunistic pathogens such as vibrios in fish; Arulampalam *et al*., 1998).

Waste reduction may include:

1. reducing P and N through low P/N feed and improving P digestion efficiency;
2. effluent minimization by adopting recirculating systems; and
3. effluent treatment (reduce P and N input to receiving system) by separating and disposal of solids.

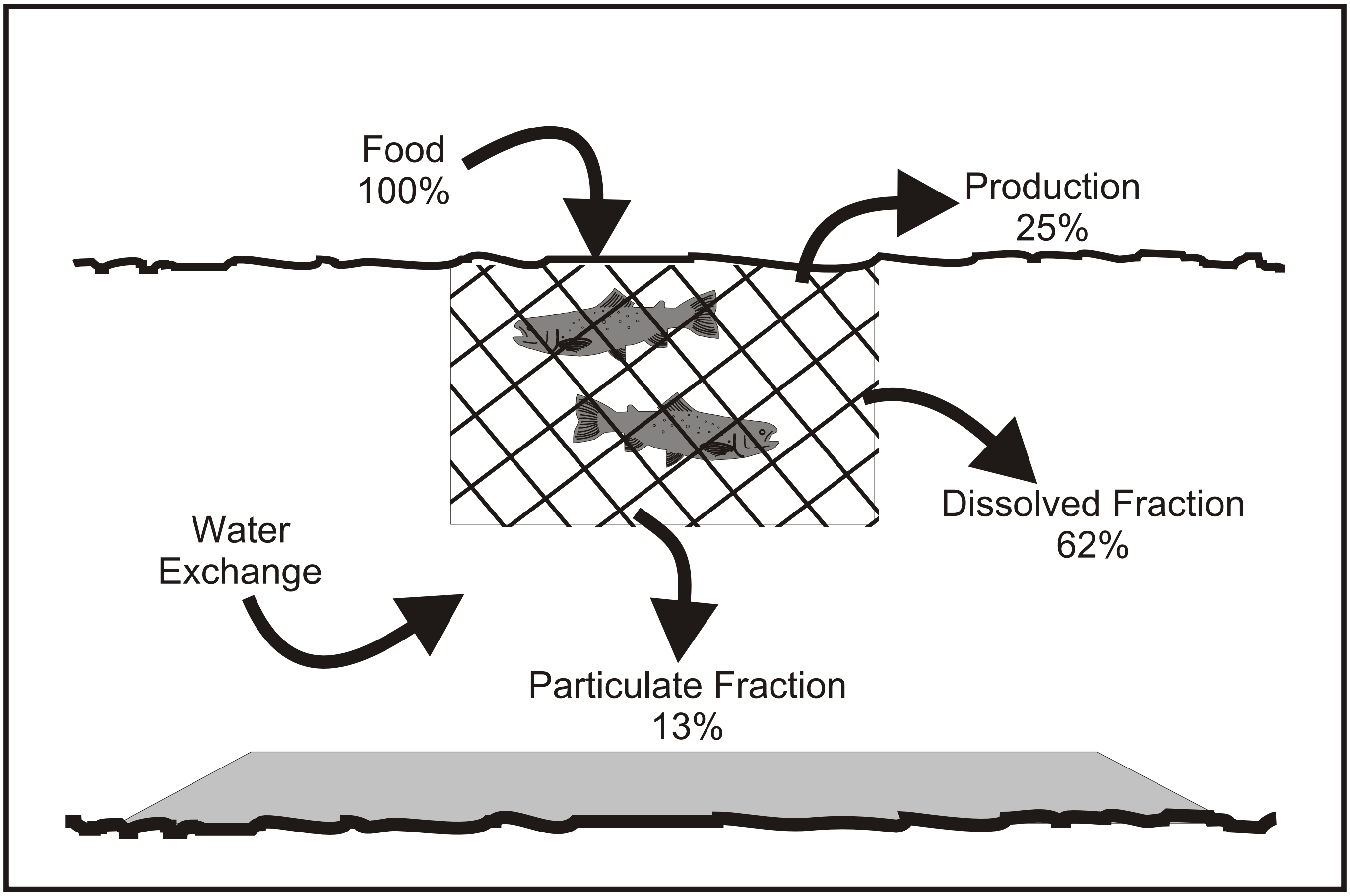

Figure 1 Distribution of Nitrogen in Salmonid Cage Culture
(Adapted from Rosenthal, 1994)

Settling characteristics of aquacultural solids vary from facility to facility. Many types of particle removal systems have been designed and developed for use in the market, including screens, vortices, and settling basins (the latter being the least effective; Pennell, pers. com.). Wong and Piedrahita (2000) advocate use of settling-velocity curves to design efficient settling basins and other primary treatment structures. The dimensions and rate of flow into a settling basin can be used to compute the basin overflow rate (OFR).

Comparison of OFR with the settling curve establishes the theoretical removal efficiency of the basin, given the characteristics of the water to be treated. Based on their study of a commercial rainbow trout facility, Wong and Piedrahita (2000) suggested that a sedimentation basin should be designed with an OFR of approximately 0.5 cm/s or lower in order to capture about 80% of the settleable material.

Bacterial pathogens and farmed species escapees are also considered waste components (Troell *et al*., 1999b). One of the main issues in closed versus open systems and on-land systems, escapes and colonization (e.g., of foreign species) remains a complicated and vast issue, outside the scope of this report. Many approaches to reducing either escapes or colonization remain, however, and are currently being researched. Pennell (pers. com.), promotes the investigation of using non-reproductive fish (used extensively by Chile) as one of the many potential solutions to this environmental issue.

Aquaculture Sludge

Aquacultural sludge has lower solid and BOD_5 concentrations than those typical of municipal sludge. Of solids in aquacultural sludge, more than 80% are volatile, 20% higher than those in municipal sludge. Aquacultural sludge also contains higher N and P. In a comparative study of municipal and aquacultural sludge, Chen (1998) found that the average TKN content of aquacultural sludge was 4.0% of the dry solid mass, whereas the typical value for municipal sludge was only 2.6%. The average TP value was 1.3% of the dry solid mass, while that typical of municipal sludge was only 0.7%. Olson (1991) found that fish wastes contained a higher percentage of N than cattle, pig or sheep wastes. The high TP and TKN contents in the fish sludge originate from the feed, most fish feeds contain 7.2% to 7.7% of N by weight. Of the N in these feeds, 67% to 75% will be lost to the aquatic environment, either directly to the water column or to sediments and biota (Iwama, 1991).

Sludge Waste Disposal

The aquacultural sludge disposal process most often used in other parts of the world is direct land application. Application methods include sprinklers and tank trucks. Given that high-rate land application of animal manure as a fertilizer has been proven to cause adverse environmental impacts (Overcash *et al*., 1983), a better approach to aquacultural sludge management is to use this waste only according to its fertilizer value for crops. The high N content of aquacultural waste (4% to 6%) makes it beneficial to crops (Chen *et al*., 1999), but limitations for such application have also been identified (Olson, 1991), including:

- odour;
- propensity for the applied sludge to form a crust;
- expense of hauling and spreading; and
- slow N release rate.

In addition, it should be noted that sludge traps do not affect the dissolved portion of nutrients, such as nitrogen (see below). Nitrogen is the nutrient of major concern in marine environments. A general consensus has developed among most scientists that at least 80% of total losses (dissolved and organically bound) from fish farms are available to plants and have a potential to cause eutrophication (Persson, 1988; 1991; Troell *et al*., 1999b). In BC waters, many researchers do not consider dissolved waste from salt water salmon farming a problem as most farms are located in high-energy, tidal current areas, in water already high in dissolved nutrients (Taylor, pers. com.; Pennell, pers. com.). It is equally apparent, however, that long-term studies in BC (e.g., long-term phytoplankton observations) regarding extended operations of salmon farms are nonexistant (Pennell, pers. com.). This translates into an inability to discern signals of change in the environment that may be too subtle or incremental for current research to observe. In addition, diversification and changes in siting of farms may alter the claimed scenario.

Research results presented below address the effect of high salt content of mariculture sludge on land plants.

Aquaculture Effluent

Solutions for aquaculture waste treatment have mainly focussed on reducing particle load through sludge removal, leaving the dissolved nutrient fraction largely untreated (Wong and Pierdrahita, 2000). Wong and Pierdrahita (2000) further acknowledged the importance of a rapid and efficient solids removal system to minimize further breakdown of the particulate material into the dissolved fraction.

Integrated Cultivation

With the recognized economic and ecological limitations of mono-specific operations (both in agriculture and aquaculture), integration of algal cultivation with fish and shrimp farming, particularly in open sea systems, is gaining much interest and support (Haines, 1975; Vandermeulen and Gordin, 1990; He *et al*., 1990; Neori *et al*., 1991; Lin *et al*., 1992; Primavera, 1993; Flores-Nava, 1995; Phang *et al*., 1996; Haglund and Pedersén, 1993; Neori *et al*., 1996; Troell *et al*., 1999a,b; Chopin *et al*., 1999). The synergistic integration of seaweed/plant culture with fish/shellfish culture may effectively serve the dual purposes of waste treatment (recycling) and additional income. An important consideration of such waste treatment is removal and assimilation of dissolved nutrients (both N and P), which tend to be transported over much greater distances than particulate nutrients (Troell *et al*., 1999a) and are not removed by many current waste systems aimed at removing solids.

A notable portion of the world aquaculture industry comprises edible seaweeds, with *Laminaria* spp., *Porphyra* spp., and *Gracilaria* spp. being the majority of organisms cultured. Researchers have shown that proximity to finfish aquaculture facilities provides nutrients to seaweed at a time when *in situ* nutrients may otherwise be limiting (Chopin *et al*., 1999). While commercial food production remains a priority, these seaweeds have been successfully used onshore as filtration beds and as nutrient stripping bands in integrated offshore facilities.

Many pilot projects and systems currently operating are using polycultures to capitalize on release of fish farm nutrients, to treat wastes, and to increase revenue. Troell *et al*. (1999a) and Chopin *et al*. (1999) provide viable case studies, using red algae *Porphyra* and *Gracilaria* alongside salmon farms, demonstrating high efficiencies of nutrient removal, concomitant with increased profit for both open net cages and enclosed and land-based recirculating systems. Kautsky *et al*. (1996) integrated the agarophyte *Gracilaria* into salmon mariculture in Chile and reduced the release of N and P by 56% and 94%, respectively.

Despite promotion, research and developed technology, BC does not at present support a seaweed harvest or culture industry. This issue requires further investigation. Pennell (pers. com.) suggests that culturing of bivalves, which grow well in cool waters of BC and take in N and P, may provide a practical approach for integrative culturing.

Land Application of Mariculture Sludge

Irrigating salt-tolerant crops (halophytes) with saline effluent from aquacultural facilities may be a useful strategy for reducing eutrophication of coastal waters by direct discharge in areas where this is practical. In BC, where estuarine land is highly protected, direct application of sludge may not be feasible (Pennell, pers. com.). Halophytes have exhibited a capacity to act as biofilters of nutrients in aquaculture effluent (Brown and Glenn, 1999). Wild halophytes are being developed as biomass, forage and oilseed crops using saltwater irrigation (Glenn *et al*.; 1991; 1994; 1996; 1997; Miyamoto *et al*., 1996; Swingle *et al*., 1996).

Brown and Glenn (1999) developed a consumptive approach to the disposal of saline aquaculture effluent. These researchers successfully used aquaculture effluent salinized to 31 ppt NaCl to form a saltwater recirculating system containing hybrid *Tilapia* to irrigate halophytic crop plants under normal soil conditions. They selected the succulent salt marsh shrub *Suaeda esteroa*, a potential forage crop, and grew it in sandy loam soil in drainage lysimeters to determine forage yield. High yields were achieved. Biomass from this species was able to replace conventional grass hay in fattening diets for sheep in previous studies (Swingle *et al*., 1996). Production of *Suaeda esteroa* was greater than that of Sudan grass, a conventional forage crop of the same area (Tucson, AZ).

Brown and Glenn (1999) determined that agricultural crops acted as efficient biofilters, effectively reducing nitrate (and volume of discharge). This capability is partly a function of the plant's tissue accumulation of nitrogen in order to synthesize osmo-compatible solutes that it needs to osmoregulate in highly saline environments (Storey *et al*., 1977).

Suaeda esteroa was less effective in removing P, taking up one-fifth the amount of P as that of N. P removal was largely attributed to the physical soil processes (e.g., sorption-desorption reactions, immobilization and decomposition). Given that N, not P, is considered the limiting nutrient for phytoplankton growth in coastal and estuarine areas (Ryther and Dunstan, 1971; Goldman *et al*., 1973), phosphorus removal was not considered critical.

Brown and Glenn (1999) stated that the area of halophytes needed to treat aquacultural effluent depends on the facility's water exchange rate, its volume, and potential evapo-transpiration. For example, for a shrimp farm that only discharged water at harvest, the harvest water from a 1 ha pond, 1.5 m deep could be used to irrigate 18 ha of halophytes for one week. For a low-end estimate for systems that exchange water, a pond 1 m deep, discharging an average of 20% of its water per week, would require approximately 2.5 ha of halophytes to continuously treat water from each hectare of shrimp pond.

Neori *et al*. (1996) used a seaweed biofilter to maintain quality of effluent water from a fish recirculating system. These researchers determined that a 3:1 ratio of seaweed area to fish production was required. Brown and Glenn (1999) suggest that use of halophyte fields would, in general, be far less expensive than constructing seaweed biofilter ponds. They argue, however, that monetary yields from a seaweed biofilter may compensate for increased construction costs. The market for edible seaweeds accounts for a sizable percentage of world aquaculture production.

Fallowing

Fallowing (periodic shutdown) is mentioned here briefly in that it provides an option for sediment impact control. In Ireland, regional fallowing programs are being introduced to control sea lice that build up in farm regions. Fallowing provides sea lice control and an effective tool against local disease (Pennel, pers. com.).

Management of Feeding (Source Reduction Technology)

Recent use of underwater video and other techniques have allowed farmers to observe fish feeding and link feeding rate and duration to actual fish behaviour, so that fish are fed equally and sufficiently without overfeeding. Earlier practices, which based feeding rate and duration on surface activity, were unsuccessful. Case studies exist where FCR was greatly reduced through use of video reconnaissance (Pennell, pers. com.). Two implications of this practice are that getting food to fish in amounts they require enables better growth, and that less food falls through the open pen than under the old regime. Increased efficiency in feeding translates to less waste in cost of food not eaten and input to the environment. Use of feeds that are more easily digested (lower faeces production) would reduce waste production. Fishmeal with better, low temperature reduction processing will result in less solid waste and possibly less N released if amino acid balance remains optimal (Pennell, pers. com.). In addition, as salmon burn protein they produce high quantities of dissolved nitrogen (Pennell, pers. com.). Use of alternative fish species (e.g., herbivorous fish) may provide an alternative, at least in freshwater systems.

In addition, work with rapeseed and soy protein has demonstrated promising results with trout and salmon (e.g., D. Higgs at DFO West Vancouver Lab; Pennell, pers. com.). Pennell envisions land-based protein "grain fed salmon" production that closely reflects how US catfish producers market their catfish crop. At present, costs and GMO issues limit potential for implementation. Large feed companies and seed producers (e.g., Canola Council), however, are investigating this potential market.

Related is use of hydrosolates, highly digestible products from fish processing waste and by-catch liquefied by enzymatic processes. These products are excellent feed components and beneficially use by-catch and processing waste otherwise discarded. In summer 2000 Ocean Biosource Inc. (OBI), in partnership with the Washington Marine Group and Cossack Caviar, launched an innovative project in Northern BC and Alaska that would fully use fisheries by-products previously dumped or left to deteriorate. The consortium predicted it would process 400 tonnes of fresh fishery by-products per day into value added specialty ingredients for aquafeeds, animal feeds, and organic fertilizers. Fish hydroysate products are used as "flavourants" and specialty protein supplements with wide applications as safe natural ingredients in animal feeds (Northern Aquaculture, 2000).

Above practices are in strong contrast with the immense herring and capelin catch in Newfoundland that is simply ocean-dumped following roe extraction. Feeds and feeding remains an important subject that requires research and development, and is related to the important consideration of source reduction and ecological footprint.

2.4.1 Ecological Footprints

Rees (1996) defined the aquatic ecological footprint as, "the corresponding area of productive aquatic ecosystems required to produce the resources used and to assimilate the wastes produced by a defined population at a specified material standard of living." Kautsky *et al*. (1996) conceived a narrower definition for "ecological footprint" applied to the aquaculture industry as, "the area of open coastal waters required to cancel the eutrophication effects of each square metre of aquaculture activity."

By calculating a farm's ecological footprint as defined by Kautsky *et al*. (1996), the spatial ecosystem area required to handle released waste may be illustrated (Robertson and Philips, 1995; Berg *et al*., 1996; Kautsky *et al*., 1997b; Folke *et al*., 1997). The area required to assimilate nutrients released from aquaculture indicates how densely farms can be placed in an area without risking self-pollution, formation of algal blooms, and other deleterious effects.

Using the ecological footprint definition of Kautsky *et al*. (1996), Berg *et al*. (1996) demonstrated that intensive tilapia cage farming required a pelagic system with an area 115 times the area of the cages. In a semi-intensive tilapia pond, nutrients were assimilated within the pond itself. Robertson and Philips (1995) calculated that N and P released from a semi-intensive farm could be entirely assimilated by a mangrove forest 2.4 to 2.8 times larger in area than the pond itself. For intensive shrimp farming, required size increased to 7.4 to 21.6 times the pond area.

Integration of seaweeds in intensive aquaculture can reduce the footprint for waste assimilation and overall environmental stress. Troell *et al*. (1999a) calculated such a reduction of the footprint for an open cage salmon-*Gracilaria* culture in Chile. The salmon cage potentially released 5.52 kg N/m^2/a and 0.924 kg P/m^2/a. These researchers assumed an average pelagic primary production of 200 mg C/m^2/d for the area and an atomic ratio of 80 C:15 N: 1 P. Troell *et al*. (1999b) calculated footprints for N and P waste as 340 and 400 times larger than the cage area, respectively. When integrated with the seaweed *Gracilaria* the corresponding footprint was reduced to 150 and 25 times the cage area for N and P, respectively. This reduction translated to an increased carrying capacity of the area to absorb nutrients and associated potential for higher stocking densities.

Rees's (1996) broader and more accurate definition of "ecological footprint" factors "resource" into the equation, including more than simply the area of the facility used in the Kautsky *et al*. (1996) definition. When including such resources as consumption of energy, and goods and services associated with facility operation, calculations of ecological footprints may be radically different from those cited above. Wackernagel and Rees (1995) produced at least 23 categories of consumer goods and services, each associated with an appropriated area, to be included in the ecological footprint calculation.

Suggestions for sustainable aquaculture (i.e., farming with low ecological footprint) have included using source reduction technology (e.g., increased feed efficiency; Heinen *et al*., 1996) and focussing on intensive rather than extensive systems to reduce area used (Flores-Nava, 1995; Menasveta, 1997). Others promote use of enclosed systems, where water is filtered for particulate and dissolved nutrients before being released to the environment. Such treatment may be accomplished by using seaweeds as biofilters (Enander and Hasselstöm, 1994; Flores-Nava, 1995) or high-technology cleaning solutions. More research is required to determine ecological footprints (Rees's definition) of the various aquaculture types in temperate climates like that of BC. Small, intensive-farming facilities with recirculating systems may incur many hidden costs and impose greater ecological footprints than larger, less intensive facilities.

Pennell (pers. com.) suggests that there may be limitations to the application of "nutrient footprints" to phytoplankton in areas of high flushing and exchange with water below the euphotic zone. Given that much of the nutrient production of any point source becomes mixed with the water column, it may not be available for phytoplankton unless the water is stratified. Pennell suggests, however, that effects of solid waste on bottom fauna is another matter.

2.4.2 NGO Reports (United States)

Goldburg and Triplett (1997) provided further perspective to issues surrounding comparison of closed to open systems, concerning waste production, prevention and ecological footprints.

Goldburg and Triplett (1997) recognized that wastes from open aquaculture systems, such as netpens and cages, could not be readily collected for treatment. Their report identified netpens as the type of system most likely to cause environmental problems, in that few practical methods exist for collecting fish wastes and that they are highly vulnerable to fish escapes. According to the report, siting netpens in areas with strong currents or tides that flush wastes remains a limited solution. The study recommended source reduction technology be used, applicable to both open and closed systems (e.g., feeds with low fishmeal content and fish that require less fishmeal, i.e., partially or entirely herbivorous fish). The report further recommended such incentives as "eco-certification" programs.

2.4.3 Enclosed Systems

The prevalent waste removal system encountered for enclosed bag-tank systems is employment of waste traps and concentrators, such as that used by Future SEA Technologies, which focusses on particle load (Cripps, 1994) and leaves the dissolved nutrient fraction untreated.

Troell *et al*. (1999a) provided an alternative form of waste removal by using seaweeds in enclosed tanks as a biofilter to remove dissolved nutrients often associated with eutrophication and toxic algal blooms. In this study, the macro-alga *Gracilaria*, co-cultivated with salmon in eight circular 8 m^2 tanks established in Chile, reached production rates as high as 48.9 $kg/m^2/a$, and removed 50% of dissolved ammonium released by fish in winter and 90% to 95% in spring. Fish production reached 30 kg/m^3 during a 13-month production period. Ammonium concentrations in fish effluent measured as high as 500 µg/L. Production of *Gracilaria* increased total income by 18% (not including production costs).

Future SEA Technologies

The SEA System™ creates a vortex flow that directs fish faeces and other production waste into the bag's cone shaped bottom. Solids may be removed in two ways:

- untreated via a movable deep water discharge pipe that can broadcast in several directions to minimize concentrated waste impact in any one area; or,
- exiting water and waste may be passed through a Future SEA engineered waste recovery trap to concentrate solids for further processing.

Third party freshwater tests determined that 90% of solid waste was captured using the recovery trap (Dubreuil, pers. com.).

Although salt-water third party tests were not available, Future SEA's design criteria called for at least 80% of solid waste to be filtered out before discharge (based on Ontario government guideline for removal of settleable solids; Schmidt, 1999; van Rensburg, pers. com.). Together with Aquatas Pty. Ltd., in Tasmania, Future SEA is currently conducting pilot saltwater testing of the trap/concentration system (described below). This aquaculture waste treatment solution is mainly focussed on reducing particle load (Cripps, 1994), leaving the dissolved nutrient fraction untreated.

In bags with and without the waste-removal system installed, Future SEA retrieves fish carcasses using what they refer to as a mort retrieval line, which returns dead fish to the surface for removal. This system acts much like the Norwegian Akva Lift-UP system used by some facilities.

<u>Freshwater Waste Trap Efficiency Study (Ontario)</u>

Future SEA undertook a 24-hour sampling program at one of their facilities in Ontario to determine the efficacy of the Future SEA waste trap and solid-waste concentrator in a freshwater environment (year not provided; Dubreuil, pers. com.). The study consisted of collecting five-gallon composite samples every two hours over the sampling period, from which one-litre aliquots were taken for analysis of settleable and total suspended solids. Flow through the sludge line was continuous and the "mort" line was not operated during the sampling period. Flow rates measured were somewhat lower than desired.

Sludge recovery was derived from mass balance calculations of sludge concentrations in the trap. Total loading of sludge collected in the trap over the sampling period was calculated using total sludge line suspended solids concentrations (mg/L) based on average flow and time weighted actual flow. Sludge recovery ranged from 3.6 kg to 3.7 kg, with a theoretical efficacy reported at 95% to 97%. Supporting data, however, appeared incomplete, arguments contradictory, and interpretations unclear. For this reason, efficacy estimates should be viewed with caution.

Saltwater Waste Traps (Aquatas Pty Ltd.)

The Aquatas site in North West Bay, south of Hobart, Tasmania, is somewhat exposed and subject to one metre waves, winds up to 100 km/hr, but low tidal impact. Water temperatures range from 9ºC to 24ºC, and depths are approximately 20 m.

Future SEA and Aquatas are currently co-ordinating a pilot waste-removal project. Sludge and water are collected in the waste trap at the bottom of the bag and dilute sludge (0.1%) is transported in a 6 inch line to a waste concentrator moored next to the bag. The concentrated sludge (~10%) is then pumped to a tank on land for subsequent disposal by truck to farmland by a removal contractor. As of fall 2000, Aquatas had not acquired mass balance evidence for the environmental efficiency of the waste traps, except to offer an anecdotal comment, "the traps work well with a lot of material being removed on a weekly basis. The bottom has noticeably improved in the short time we have been using the traps" (Carington Smith, pers. com.). Carington Smith suggested that use of waste traps may permit the aquaculture farmer to avoid fallowing of sites, necessary under their relatively shallow farming conditions.

At present, the waste trap material is not being used to generate revenue. Aquatas has not investigated the feasibility of removing salt from the waste product for potential use as fertilizer. Carington Smith suggested that another year of experience would likely enable evaluation of the economic feasibility of the waste trap system. Capital costs constitute the major drawback to their use (Carington Smith, pers. com.).

Scotia Rainbow Inc.

Scotia Rainbow plans to employ a waste management system in their Future SEA enclosed bag systems in Nova Scotia (Ehman, 1998). The company has installed an *Akva Lift-UP* system, which removes dead fish and waste, including residual feed. The Akva Lift-UP system was developed by Lift-UP-Akva Ltd., located near Bergen, Norway. The module permits waste particles to be retrieved to the surface for examination and subsequent filtration or disposal. The system employs a specially designed container mounted at the exit end of the Lift-UP waste removal unit, which may be manually or automatically operated (Lift-UP-Akva Ltd., undated).

During summer 2000 Scotia Rainbow plans to install a filtration system expected to remove close to 100% of solids. They anticipate that operation costs of the waste removal system (design unspecified) would add approximately $25,000 to $30,000 to current operation costs (Lafreniere, pers. com.). Scotia Rainbow has been researching and developing markets for the waste.

Totem Oysters Ltd.

Gus Angus, proprieter of Totem, operates both open netpens and Future SEA enclosed bags. While neither system is equipped with waste treatment, his observations, through several diving excursions under and around the two types of cages, included:

- buildup of faecal material under netpens;
- fairly high velocity outflow from effluent pipe of enclosed bags with no visible deposition of fish waste;
- presence of increased numbers of ratfish under the enclosures.

Angus (pers. com.) claims that the solids portion entrained into the funnel and eventually out the effluent pipe of the enclosed bag, is broken down into highly flocculent smaller particles upon hitting the screen of the enclosure. The flocculent material is subsequently distributed effectively through the high velocity effluent pipe.

2.4.4 Net Cage Systems

Waste removal in net cage systems has relied primarily on the ability of the receiving environment to flush and dilute waste products. Pollution prevention and abatement have therefore been highly dependent on judicious siting of farms in locations where tidal and current actions will actively remove and redistribute nutrients and contaminants associated with salmon farm wastes. It is widely accepted that the ability to predict the consequences of various loadings is required for the optimum siting of new cages or to limit the impact of expansion of existing cages (NCC, 1990).

Several innovative techniques for removing and treating fish farm wastes have been put forward and are in use, including integrated culturing and use of "cone-diapers" to capture settleable waste.

Integrated Seaweed Culture

Troell *et al*. (1999a) discuss use of seaweeds to remove dissolved nutrients often associated with eutrophication and toxic algal blooms. In their study, the macro-alga *Gracilaria* cultivated on ropes near a 22 tonne fish cage farm demonstrated a 40% higher growth rate than those of controls. These researchers determined that *Gracilaria* assimilated 6.5% of the released dissolved N (significantly less than within a tank system). The high rates of water exchange that often characterizes coastal fish farming is an important consideration, given that the proportion of integrated seaweeds that benefit from the surplus of dissolved nurtients increases with the time that nutrient levels remain high in the water passing the cages (Løland, 1993). Two factors that further determine the potential for seaweeds to remove nutrients are their capacity to respond to increased nutrient concentration (i.e., assimilation rate), and the level of precision to which the current pattern can be predicted (i.e., how exposure to nutrient-rich water can be maximized; Troell and Norberg, 1998).

NorAm Aquaculture

NorAm Aquaculture makes use of an experimental waste-recovery system in a protected abandoned fresh-water quarry. This system collects fish waste and uneaten food in a plastic inverted cone-diaper attached to the bottom of the pen. Uneaten food and faeces collect in a septic tank-like container at the bottom of the cone and this material is then pumped periodically through two-inch plastic pipes to holding tanks on shore. The sludge is collected weekly by local farmers to spread on their hayfields. The diaper functions efficiently in the protected, non-tidal waters of the quarry, but is not anticipated to be as successful in less quiescent environments such as most marine situations (Northern Aquaculture, 1999).

2.5 History of MariCulture Corporation's SARGO System

Washington-based MariCulture Corporation developed a hard-walled floating tank system called SARGO, and operated a prototype for approximately one year (1996-1997) near Clam Bay, Puget Sound (PCHB, 1998a). The prototype consisted of a single tank with a volume of 875 m^3, whereas the full-sized system of 2,000 m^3 has never been constructed. MariCulture raised Atlantic salmon in the prototype at densities of 29.6 kg/m^3.

MariCulture projections indicated that the SARGO system was more profitable than netpens, predicated on the assumption that the SARGO system can produce 600 tonnes per year, a volume that would require a density of at least 45 kg/m^3 (PCHB, 1998a). Mariculture, however, never grew fish at densities required for SARGO production levels to compare favourably with those of netpens. Furthermore, projections for the SARGO system did not reflect the higher interest costs that would be incurred for purchasing the more expensive system.

Hard-walled, floating tank technology may potentially solve problems associated with aquacultural waste and fish escapement, but remains prototypical and not economically feasible until it produces fish at volumes and costs comparable to those of netpens (PCHB, 1998a).

2.6 Land-Based Recirculating Systems

As previously mentioned, “closed” systems, as defined by the industry, refer more to systems other than “open” as defined by *in situ* net cages or pens, and include *in situ* enclosures (bags) and land-based seawater pumped facilities. Recirculating land-based systems tend to more aptly reflect the term “closed” in that water is reused and heated. Recirculating systems are reviewed briefly here along with other land-based systems generally. Land-based operations are also briefly compared with open netpens.

Fisheries researchers have used recirculating systems for holding and growing fish for more than thirty years. Efforts to advance these systems to commercial scale food fish production have increased dramatically in the last decade in several countries, including New Zealand (e.g., Aquaculture Technologies New Zealand Ltd., 1999). Water reuse systems are designed to preserve water or heat (where water is expensive or scarse; heat always being expensive due to the high heat capacity of water). Advantages of such systems include:

- reduced land and water requirements (Masser *et al*., 1999);
- a high degree of environmental control, allowing year-round growth at optimum rates (Ebeling, 1998; Masser *et al*., 1999; Singh and Wheaton, 1999);
- isolation from external pathogens (small amounts of incoming water treated; Pennell, pers. com.);
- the feasibility of locating in close proximity to prime markets (e.g., geographical independence in site selection; Singh and Wheaton, 1999); and
- improved waste control and removal (Pennell, pers. com).

Such systems have often failed to become viable, however, due to poor design, inferior management, or flawed economics (this argument also holds for enclosed systems in certain cases). Closed systems are still generally perceived as expensive ventures that are as much an art as science (Losordo *et al*., 1998; 1999). While these systems work well, the “art” as well as the problems usually begin at the very high re-use levels and the very high stocking levels often required for economic feasibility (Pennell, pers. com.).

The history of water reuse systems has taken place largely in fresh water, though many salt water reuse systems exist, the principles being nearly identical in fresh and salt water. An extensive and detailed body of literature pertains to this topic, including dedicated journals and trade papers.

Ebeling *et al*. (1995) and the Minnesota Department of Agriculture (with University of Minnesota; 1997) provided a thorough review of recirculation systems, including design and costs. The latter study, in particular, breaks down costs in detail (Appendix 4).

Goldburg and Triplett (1997) provided an example of a commercial recirculating system in the US. Integrated Food Technologies (IFT) in Emmaus, Pennsylvania, annually raises 500,000 pounds of hybrid striped bass, tilapia, steelhead, and yellow perch in tanks in a former factory. IFT recirculates 98% of its water and treats its effluent by several methods. Some of the wastewater is used to grow hydroponic crops, such as lettuce.

Oxygen enrichment using pure (usually liquid) oxygen reduces water flow, or increases residence time of water in fish containers. Simple aeration also does this. Such simple re-use systems are called water extenders.

Of main concern with recirculating systems is effective and economical removal of solid and dissolved waste from culture water and aeration without harming the cultured fish (Singh and Wheaton, 1999). Pennell (pers. com.) states that particulates from the total output of fish (which varies with feed) varies from 16% to 30% for nitrogen and 54% to 59% for phosphorus. Pennell further asserts that uneaten feed pellets, which are heavy and will sink relatively fast, provide an important part of the particulate fraction. Solid waste removal, by physical separation and nitrification of ammonia and nitrites into nitrates by a biofilter, is normally practiced in most recirculating aquacultural systems. Such removal is considered slow, requiring significant filter retention times, with up to 50% of the system water in the treatment unit at any given time. The reduced amount of effluent water (supernatent – sludge having been created separately and removed) is usually very high in NO_3 and other dissolved minerals such as phosphorus. While some P may be sequestered on minerals in the system, on the particulate fraction, the majority exits with the effluent (Pennell, pers. com.).

Use of ozone (Singh and Wheaton, 1999) is under investigation as a more rapid alternative to the slow process of physical separation and nitrification of ammonia and nitrite into nitrates by a biofilter. Most techniques in use do not affect the amount of nutrients released into the aquatic environment, with the exception of nutrients locked up in sludge. Some research is presently being undertaken that will convert NO_3 to N_2. In freshwater systems, liquid effluent is usually released into the environment. Plants (algae, rooted macrophytes, crops) may be used to remove nutrients. In urban environments, effluent and sludge are discharged through the domestic treatment facility.

Troell *et al*. (1999a) discussed the efficient and cost-effective use of seaweeds, as part of integrated cultures, to remove dissolved nutrients in land-based systems. These authors provided case studies of land-based systems where the agarophyte, *Gracilaria chilensis*, effectively removed 50% of the dissolved ammonium in the winter, increasing to 90-95% in spring, and providing an increased total income (due to production of *Gracilaria*) of 18%.

Effluent from most BC salmon and trout hatcheries (including DFO) is directly discharged to the aquatic environment. In some cases, large settling ponds with considerable water residence time are used to sequester P and settleable solids.

MELP has been a pioneer in recirculating production hatcheries (e.g., Vancouver Island Hatchery and Abbotsford Hatchery). PRA Ltd. (Nanaimo) sells recirculating systems for FW hatcheries (one installed in Sechelt).

In their overview of critical production considerations (e.g., waste solids constraints) and design of recirculating aquaculture tank production systems, Losordo *et al*. (1998) discussed removal of aquaculture waste in the form of settleable, suspended, floatable and dissolved solids. They considered the first two to be of primary concern and that dissolved organic solids can become a problem in systems with very little water exchange.

Figure 2 provides an overview of the principal unit processes and removal in recirculating systems of the four major types of waste generated by aquaculture production (e.g., settleable, suspended, floatable and dissolved solids).

Losordo *et al*. (1999) further reviewed component options of recirculating aquaculture tank production systems that include those involved in waste solids removal. Among many examples, these researchers described traps used in tanks with circular flow patterns, such as the ECO-TRAP™ (developed by the Centre for Scientific and Industrial Research [SINTEF] for AquaOptima AS, Pir Senteret, 7005 Trondheim, Norway, US Patent No. 5,636,595.). Shown in Figure 3, this double drain effectively collects sludge with an average dry weight solids content of 6%.

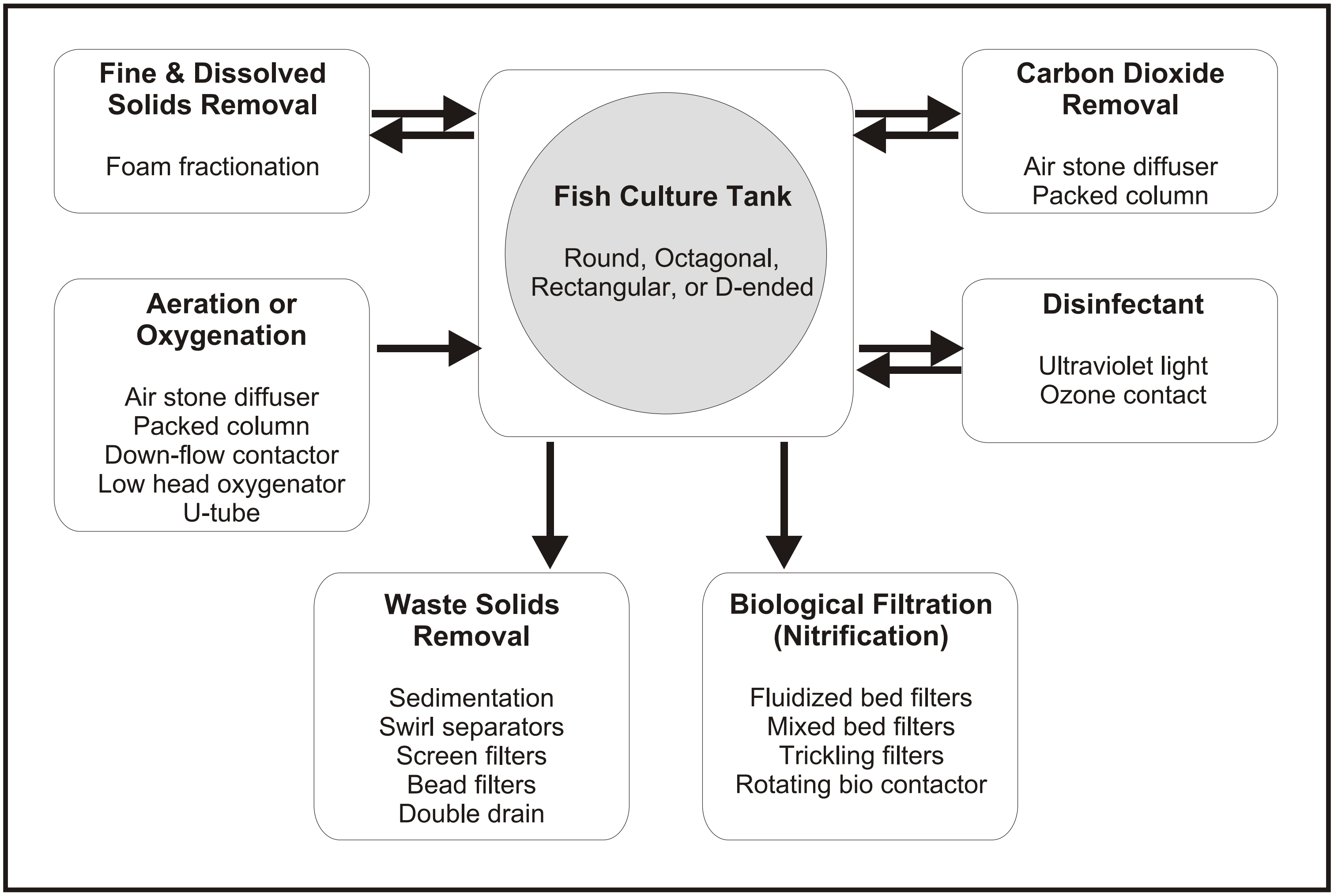

Figure 2 Required unit processes and some typical components used in recirculating aquaculture production systems (Adapted from Losordo *et al*., 1998)

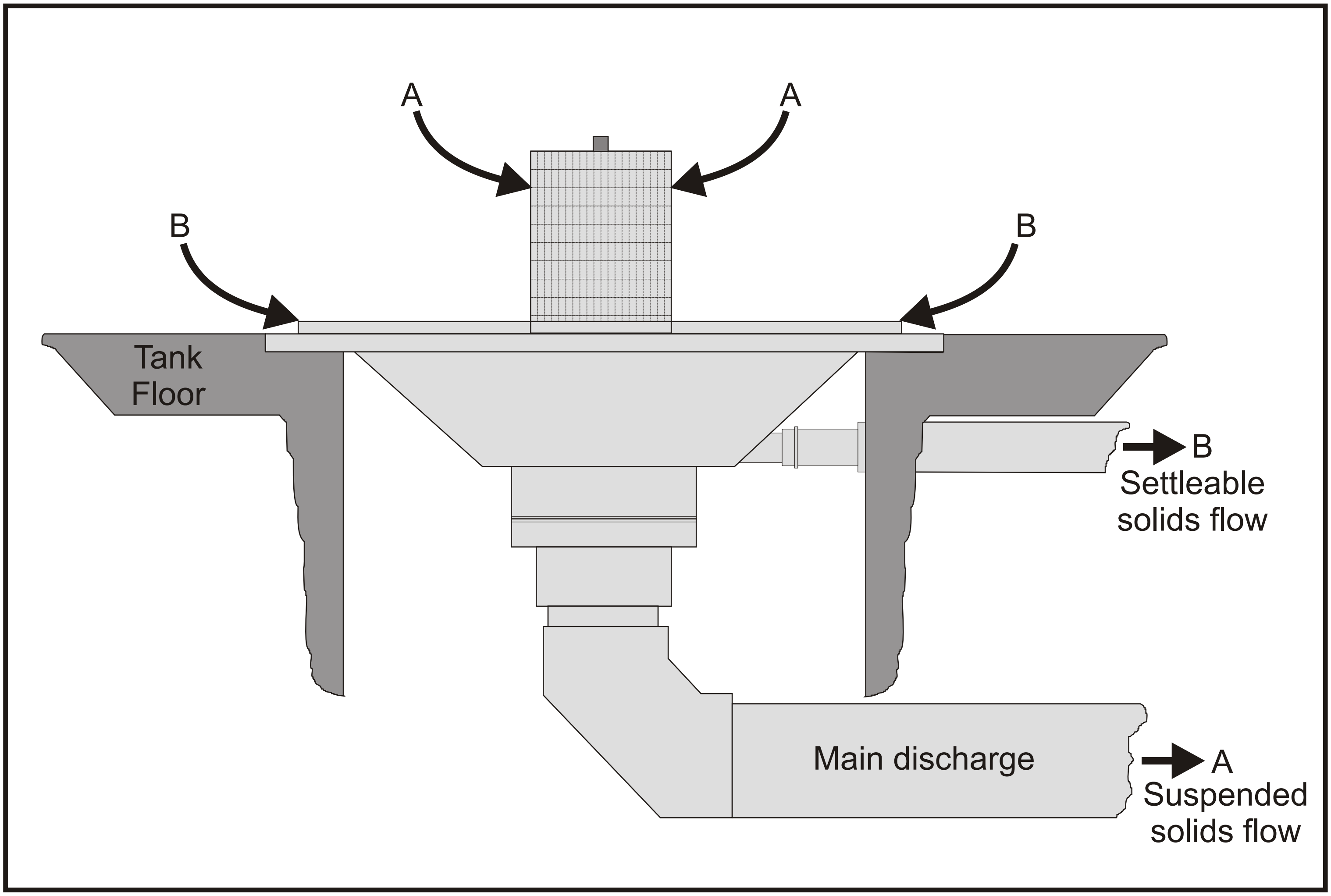

Figure 3 The ECO-TRAP™ particle trap
(Adapted from Losordo *et al*., 1999)

The eco-trap is only one of many different methods for the collection of particulate material in recirculating systems. Gentle treatment of fish faeces is essential to avoid break-up for collection, unless (like with the enclosed SEA-System [see comments by Angus at Totem Oysters], the intention is to disperse them). Sludge from smolt hatcheries may comprise about 10% to 20% of the N and P produced (government and private) in BC, which should be easily dealt with as applied fertilizer (Pennell, pers. com.).

Aqua Tech, a New Zealand company specializing in bio-filtration systems for onshore farms, charges NZ$4,267 for its standard active aerated biological recirculating filtration unit.

Table 2-8 provides a comparison of land-based and open water sea-based systems conducted by the BC Environmental Assessment Office (1997f). The comparison applies to offshore open cages rather than to enclosed bag systems, which have not proven sufficiently durable for exposed marine areas.

Advantages of offshore open cages do not necessarily apply to near-coast netpens. While coastal netpens have proven commercially viable, their effects on receiving environments have been noted.

TABLE 2-8:
Comparison of Land-Based & Sea-Based Systems

System Type	Advantages	Disadvantages
Exposed Offshore Open Marine Systems	• Proven commercial viability; • Avoids/reduces environmental issues associated with near-shore coast (e.g., benthic smothering; nutrient loading of inshore waters, predator interactions); • Less conflict with competing coastal resource users; • Higher quality rearing environment, leading to a potentially healthier, higher quality product.	• Changes required in farming methodologies; • Investment in new engineering and new capital; • Changes required in industry corporate focus; • Potential for navigational conflict; • Uncertain government policy and regulatory environment; • Possible redirection of economic benefits associated with processing and services.
Land-Based Saltwater Systems	• Highly controlled, more optimal rearing environment for culture fish; • With treatment technology, avoidance of potential deleterious impacts on the marine environment associated with waste discharges; • Easier, safer working environment; • Limits or eliminates escapes and interactions with predators.	• Poor record of economic success – commercial viability doubtful at this time; • High capital and energy costs; • Treatment of solid wastes and waste water difficult, although technology is emerging; • Environmental issues associated with water intake and effluent still evident without recirculation/treatment; • Highly restrictive siting requirements; • Conflict with upland property users expected.

Reference: Environmental Assessment Office of British Columbia, 1997

BC's on-land system has twice gone into bankruptcy (Pennell, pers. com.). Norway, which has such systems, appears not to be building new systems. Iceland has several large on-land systems, most of which have undergone bankruptcy or been otherwise amortized. Iceland takes advantage of geothermally heated water or heat sources (e.g., rearing Red Sea bream) and does not make use of waste controls (e.g., effluent discharged to the seashore; Pennell, pers. com.).

3.0 REGULATORY FRAMEWORK - OTHER JURISDICTIONS

This section provides an update of regulatory frameworks in New Brunswick, Norway, Scotland, Chile, Washington State, and Alaska. An effort has been made to provide information on the most recent developments in each jurisdiction, reiterating information provided by Winsby *et al*. (1996) only when required for context. The level and scope of information presented varies for each jurisdiction according to availability and state of development of regulatory mechanisms.

As in BC, regulation of salmon aquaculture in each jurisdiction investigated (with the exception of Alaska) is in a state of flux. The aquaculture industry underwent rapid growth through the 1980s and early 1990s, with the support of governments eager to provide employment in depressed regions, to develop alternative food supplies, and to relieve pressure on wild fisheries. Governments were reluctant to impose heavy regulatory restrictions on the industry, and when issues of environmental concern began to arise more frequently (e.g., disease, waste accumulation, and escapes of exotic species), mechanisms for environmental evaluations and enforceable standards were often not in place. In addition, responsibility for salmon aquaculture has often exhibited considerable overlap between government departments, each with their own agenda.

3.1 New Brunswick

The aquaculture industry in New Brunswick (NB) has been growing rapidly, with Atlantic salmon (*Salmo salar*) representing approximately 95% of production. Salmon farming generated C$106 million in 1998 (DFA, 2000).

The New Brunswick *Aquaculture Act* (Government of NB, 1988) and associated Regulation 91-158 (Government of NB, 1991) consolidate legislation pertaining to the NB aquaculture industry. The industry is, at present, overseen by a single agency, the Department of Fisheries and Aquaculture (DFA; changes in ministerial responsibilities are forthcoming). As described by Winsby *et al*. (1996), the *Act* and Regulation pertain mainly to licensing and tenure of commercial aquacultural operations. With regard to environmental protection, Section 11 of the *Act* gives the Registrar authority to make licences subject to several terms and conditions, including ones related to measures to be taken to:

- minimize the risk of environmental degradation;
- prevent escape of aquacultural products;
- minimize risk of disease, parasites, toxins or contaminants spreading to other aquaculture sites; and
- ensure the maintenance of applicable health, grade and genetic standards.

The Regulation stipulates (Section 11) that the Registrar of Aquaculture may refuse to issue, renew or amend an aquaculture license where it would cause undue conflict with other fishery activities or with ecologically and environmentally sensitive areas, or create unacceptable environmental risks.

On March 23, 2000, the NB government announced a substantial restructuring of its departmental structure (Communications New Brunswick, 2000). Eight new departments were formed by consolidation and merging of existing structures. Among nine departments with responsibilities shifted to new departments was the Department of Fisheries and Aquaculture, now to be divided among the departments of Investment and Exports, Business New Brunswick, Food Production, and Environment and Local Government.

The new Department of Environment and Local Government (ELG) was created to foster a more integrated approach to environmental management, conservation and compliance, and land use zoning and planning (Communications New Brunswick, 2000). The administration of environmental regulations related to the NB aquaculture industry will be transferred to ELG.

At present, the Department of Environment regulates only freshwater operations and not marine aquaculture, though it has the potential authority under the *Clean Water Act*. DOE has been underfunded and understaffed to the extent that it has relinquished this responsibility (G. Shanks, pers. comm.).

3.1.1 Recent Changes to Waste Management Regulations

Aquacultural waste management in NB is not subject to a specific regulatory framework, as such, but certain provisions of the NB *Aquaculture Act* and the federal *Fisheries Act* are applicable (Janowicz, pers. comm.). The Sustainable Development Section (SDS) of the NB DFA co-chairs the Aquaculture Environmental Coordinating Committee (AECC), composed of federal and provincial agencies and aquaculture industry representatives. The AECC has the responsibility of addressing all issues of aquacultural-environmental interaction, providing recommendations to the Minister of Fisheries and Aquaculture and the Canada-NB MOU Steering Committee on Aquaculture, including research priorities (DFA, 1999a).

During the 1998-1999 fiscal year DFA funded a report sponsored by the New Brunswick Salmon Growers Association (NBSGA) to identify the wastewater treatment systems for salmon processing facilities that would best contain the Infectious Salmon Anaemia (ISA) virus. The SDS participated in the industry-led ISA Containment Committee to develop a strategy for implementation of the report, and has worked closely with the Department of Environment to implement strategies for containment of salmon waste (DFA, 1999a).

The SDS and the NBSGA are co-operating closely on development of an industry Code of Practice, similar to that of the BC Salmon Farmers' Association (Sweeney, pers. comm.). Protocols being developed will particularly address four waste management components: blood-water and mortalities, viscera and effluent from processing, accumulated waste under cages, and debris at sites, in water or on beaches (DFA, 1999a).

During the 1998-1999 fiscal year the ISA virus continued to influence parts of the Bay of Fundy, and infected sites were fallowed and disinfected to ensure the virus was controlled. No new marine lease or license applications or amendments were accepted for consideration pending the approval and implementation of a Marine Site Allocation Policy for the Bay of Fundy area, expected to be implemented during the 1999-2000 fiscal year. The policy would guide government decisions on allocation of marine lands for aquaculture and outline the establishment of a management regime for the current aquaculture sector (DFA, 1999a).

3.1.2 Update of Waste Discharge Regulations

The waste management Code of Practice being developed jointly by the SDS and NBSGA is to include a series of protocols pertaining to discharge of various types of waste and to site disinfection. Of particular concern has been the need to control the spread of the ISA virus (Sweeney, pers. comm.). In particular, direct discharge of blood-water and stun water (super-cooled solution used to stun fish before slaughter) to the marine environment would be prohibited. Both would be sent on-shore for proper treatment and disposal.

The NBSGA desires that the industry be self-regulating and that government enforce regulations only after all efforts to convince non-compliant licensees to improve their operations have failed (Sweeney, pers. comm.).

3.1.3 Recent Changes to Monitoring, Reporting & Enforcement Mechanisms

The AECC has recently drafted a second Environmental Monitoring Program (EMP) for salmon aquaculture sites in southwest NB (DFA, 1999b), and is also developing an Environmental Remediation Guide (ERG; DFA, 1999c).

The EMP is intended to be a cost-effective management tool for obtaining and evaluating basic data and information pertaining to organic enrichment in sediments at individual salmon aquacultural sites annually. Criteria for rating sites would be based on indications of bacterial mats, visible gas bubbles, anoxia, as defined by redox potential (E_h) and sulphide limits, and presence and density of macrofauna. Sites would be rated in categories A, B, B- or C; ratings B- or C would trigger a management response under the ERG.

Rating criteria, appended to the draft EMP (DFA, 1999b), are provided in Table 3-1. Criteria were adapted from those of Washburn and Gillis (1995) and Wildish *et al*. (1999).

**TABLE 3-1:
Rating Criteria,
Draft New Brunswick Environmental Monitoring Program**

Rating	Degree of Effect	Observed & Measured Conditions
A	low	• oxic • Redox Potential (E_h) > +100 mV_{NHE} • sulphide < 300 uM
B	moderate	• oxic • Redox Potential (E_h) = 0 to 100 mV_{NHE} • Sulphide = 300 to 1,300 µM
B-	impacted upon	• hypoxic • Redox Potential (E_h) = 0 to -100 mV_{NHE} • Sulphide = 1,300 to 6,000 µM
C	high	• anoxic • Redox Potential (E_h) = < -100 • mV_{NHE}Sulphide > 6,000 µM

The NBSGA has been assigned the responsibility of hiring contractors to conduct the monitoring program, under terms and conditions agreed to with DFA. The contractor would undertake the EMP sampling program, submitting chemical analyses for E_h/sulphides and observed conditions to the DFA Registrar of Aquaculture within one week of completion. A copy would simultaneously go to the licencee. The contractor would also submit to DFA an annual public report identifying composite E_h/sulphide readings and the number of sites in each rating category, but not identifying individual sites. All sites are to be monitored annually, even if fallow. Annual audits would be conducted on a representative portion (20%) of the total monitoring program to ensure availability of accurate and reliable information.

The EMP is to be conducted during the period of peak growth and feeding, mid-August to mid-October. Core samples for E_h/sulphide analysis would be taken along a minimum of two transects per site, or one transect per 100,000 fish. A diver would fill out a checklist of conditions observed at each transect at each site (e.g., presence and extent of *Beggiatoa* bacterial mats; presence and relative abundance of macroinvertebrates; presence of gas bubbles; depth of organic matter; estimated current speed and direction; and depth), and also make a videotape record. The EMP methodology would be similar to that developed by Wildish *et al*. (1999).

Protocols for regional monitoring, not yet developed, are eventually to be incorporated into the EMP. It is anticipated that regional monitoring would provide information on far field impacts and cumulative influences of aquaculture.

Aquaculture sites rated B- or C during the EMP would be subject to the ERG. Operators of sites rated C would be required to develop a Remediation Management Plan that identified a schedule of site-specific actions for mitigating adverse impacts on the receiving environment. Operators of sites rated B would be required to meet with the DFA Site Remediation Committee to discuss measures that could be implemented to reduce the risk of the site declining to a C rating.

Site-specific Remediation Management Plans may include some or all of the following:

- improvements or changes in husbandry practices (e.g., feeding regime, feed type, feed usage record keeping, stocking density, net cleaning practices, adjusting feed usage, employing new methods for determining when fish are satiated;
- re-orientation of site, or use of a different cage design or configuration;
- application of new technology, e.g., a type of pen that might reduce waste loss or accumulation;
- site fallowing or fallowing of cage rafts;
- year-class separation;
- licence production decreases;
- assessing cumulative influence of other cage sites in the area;
- abandonment of site;
- bacterial remediation of undercage sediments;
- physical remediation of undercage sediments, could including harrowing or other physical disturbance of the sediments; or,
- physical removal of waste materials from under the cages for disposal on land or sea with appropriate permits.

A pilot site remediation trial is planned for summer 2000, with an emphasis on addressing accumulated pesticide, metal and therapeutant residues (G. Shanks, pers. comm.).

3.2 Norway

Norway is, by far, the world's largest producer of farmed salmon, accounting for approximately 53% of total world production in 1999 (Norwegian Seafood Export Council, 2000). Seafood is Norway's second largest export product (after crude oil), and the aquaculture industry represents approximately 40% of fish export value. An estimated 95% of farmed salmon are destined for export (ODIN, 1996). Atlantic salmon (*Salmo salar*) is the dominant species, farmed production levels rising from approximately 20,000 tonnes in 1983 to over 400,000 tonnes in 1999.

As described by Winsby *et al*. (1996) regulation of the salmon aquaculture industry in Norway is shared by the ministries of Fisheries, Environment, Agriculture, and Local Government and Labour. In regards to regulation of waste management and monitoring, two statutes are of particular importance: the *Act Relating to the Breeding of Fish, Shellfish, Etc.*, and the *Pollution Act*.

The Ministry of Fisheries has within it the Department for Aquaculture, Industry and Export. The Aquaculture Section of the department oversees all Aquaculture Act regulations pertaining to management of the aquaculture industry and sea farming (ODIN, 1996), including policy formulation, environmental issues, enforcement, and handling of complaints on licences, and is responsible for the Program on Development and Stimulation of Sea Ranching (PUSH). Since the Aquaculture Act was first implemented in 1973, all finfish and shellfish aquaculture in Norway has been regulated by a system of licences aimed at balanced, sustainable development of a profitable and viable regional industry.

3.2.1 Recent Changes to Waste Management Regulations

On April 7, 2000, the Government of Norway proposed changes in the *Act Relating to the Breeding of Fish, Shellfish, Etc.*, including ones strengthening environmental provisions. Such changes are seen as representing modernization in attitudes regarding industry co-operation with authorities on environmental issues (Johansen, pers. comm.). The changes, detailing the responsibility and authority of the Ministry of Fisheries with respect to the aquaculture industry and care of the surrounding environment, include:

- authority to introduce requests for environmental supervision;
- authority to introduce internal control;
- authority to introduce arrangements for approval of sites and equipment, including proposals concerning the authority to expand the sphere of the *Act*;
- more definite authority to forbid aquaculture activity in certain areas;
- authority to introduce fees; and
- expansion of the scope of penalties.

Environmental supervision is to be directed by a set of regulations established in co-operation with the Ministry of Environment. The detailed outline of the regulations on environmental inspections at aquaculture sites will be developed in close co-operation with the industry. Following a public hearing, new regulations may be implemented in 2001 (Johansen, pers. comm.).

3.2.2 Update of Waste Discharge Regulations

Treatment of waste from salmon farming is regulated by the *Pollution Act* and a relatively new regulation (18 December 1998) related to Establishment, Operation and Disease-Prevention Measures at Fish Farms. The Regulation is based on both the *Act Relating to the Breeding of Fish, Shellfish, Etc.* and the *Act relating to Measures to Counteract Diseases in Fish and other Aquatic Animals* (the Fish Disease Act).

Under the Regulation a licence holder must ensure that a 2-year management plan is in place for fish farming operations, that, at minimum, must state:

- which sites are to be stocked and when; and
- which sites are to be left fallow, and for how long.

Comprehensive record-keeping is required of licence holders, and records are to be kept at the farm a minimum of five years and produced for inspection upon request. For each licence, site and unit/sea cage, the following information is required for each calendar month:

- stocking and stocks of aquatic animals;
- fish density;
- net depth;
- consumption of feed, type of feed, type of fish meal, feed manufacturer and brand;
- number of escaped fish, reason, time, average weight and state of heath, and date of notification of Fisheries' regional office; and
- slaughter quantity and mortality level.

The following information is required monthly at the licence and site level:

- state of health of aquatic animals, records of any disease diagnoses, who made them, diagnostic tests, treatments, etc.;
- number of lice on salmonids during months when lice counting is required, in accordance with the method recommended by the Norwegian Animal Health Authority;
- consumption of medical products (type, name, quantity and period); and
- catches made for monitoring purposes and during recover fishing (number of fish, distribution of size, total weight, distribution of species).

Required monthly at the licence level is:

- handling and delivery of dead fish (method, quantity delivered, date, recipient);
- purchases of ready-made feed and fish meal (type of feed, type of fish meal, manufacturers, brands); and
- consumption of net impregnating agents (type of chemical, product name, quantity, consumption period).

A provision called "Controlling the fish farm's environmental impact on the site" simply states, "It is the responsibility of the licence holder to see that all sites in use are being operated in an environmentally acceptable way."

3.2.3 Recent Changes to Monitoring, Reporting & Enforcement Mechanisms

Norwegian fisheries and environment authorities have, in co-operation with relevant professional groups, financed development of the tool and methods for environmental supervision and monitoring. Elements of the procedure, known as MOM (Modelling-Ongrowing Fish Farms-Monitoring), include parameters that should be measured, methods that should be used, frequency of measurements and interpretation of results obtained.

Winsby *et al*. (1996) described the MOM framework as it existed when they conducted their review. Since that time, trials have been conducted and MOM has undergone periodic revisions, the latest available version being Hansen *et al*. (1997). MOM has not yet been fully implemented in Norway (Johansen, pers. comm.). A Norwegian Standard for

Environmental Supervision of Fish Farming Plants has been developed, based on MOM examinations.

Motivated by self-interest, many fish farm operators have already started using the environmental monitoring program (Johansen, pers. comm). Introduction of such a program will better document environmental impacts of fish farming, and provide a better basis for considering the carrying capacity and production limits of a site. It will enable authorities to monitor an individual site over time and implement remedial actions before environmental conditions become unacceptable. Furthermore, the simulation tool can, on stated terms, predict environmental trends at a site.

Once established, a system for environment supervision will secure an equal procedure for assessing environmental impacts of siting of a fish farming plant, as a single standard will be used when considering an application. It will provide data from environmental examinations and facilitate evaluations and processing of discharge permit applications.

MOM consists of a prognosis tool for calculating environment effects of an aquaculture operation (simulation model), a control tool for examining the actual influence on the environment (monitoring program) and marginal values for acceptable influence on the environment (environmental quality standards [EQSs]). Level of monitoring effort is based on the degree of exploitation or environmental impact (Hansen *et al*., 1997).

MOM is based on the premise that fish farm sites should not deteriorate over time and that the impact must not lead to extinction of benthic infauna beneath a farm. The system recognizes three degrees of site exploitation, each linked to a level of monitoring. A site is considered first degree if impact is small compared to the holding capacity, whereby simple monitoring is sufficient as pollution risk is low. A second-degree site is one where a moderate impact is known that requires more comprehensive monitoring. The third degree of exploitation occurs where an impact approaches threshold EQS values, necessitating thorough monitoring. A site is considered to have undergone unacceptable impact and to be overexploited if EQS values have been exceeded. In this way, the environmental impact is itself regulated (performance based), rather than the quantity of emissions (Hansen *et al*., 1997).

The monitoring program consists of three types of investigation: “A”, a simple measurement of the rate of sedimentation below the plant, “B”, characterization of sediment conditions below a fish farm, and “C”, an examination of benthic fauna along a gradient from the plant and outwards in the receiving environment.

Table 3-2 summarizes the relationship between degree of exploitation (DEX), level of monitoring (LOM) and frequency of A-, B- and C-investigations.

TABLE 3-2:
Frequency of Investigations Under MOM, Norway

Degree of Exploitation	Level of Monitoring	Type of Investigation		
		A	B	C
DEX 1	LOM 1	every 3 months	every 2 years	every 8 years
DEX 2	LOM 2	every 2 months	every year	every 5 years
DEX 3	LOM 3	every month	twice a year (spring & autumn)	every 2 years

Reference: Hansen *et al*., 1997

A-investigations consist of measuring the rate of sedimentation on the seabed under a fish farm, and no EQS values are applicable. Though easy to carry out, their usefulness is limited by a degree of uncertainty. Measurements repeated over time can provide information about the extent of sedimentation and overfeeding.

B-investigations provide simple descriptions of sediment condition, using the following three groups of parameters and applicable EQS levels:

- Group 1 – presence or absence of macro-benthos (>1 mm size) in sieved sediment samples;
- Group 2 – quantitative chemical parameters, pH and redox potential, that change as a function of decomposition processes; and
- Group 3 – qualitative variables that change as loadings of organic matter in sediments increase (presence of gas bubbles, colour, odour, thickness of sludge, and consistency).

C-investigations are studies of faunal structure in sediments. Sensitive to organic loadings, benthic infauna provide good indications of levels of pollutants. Such studies are intended to reveal long-term changes to receiving waters around fish farms, and tend to be most sensitive with low to medium organic loadings. General EQSs developed by the Norwegian Pollution Control Body are employed, though specific MOM standards are used close to farms (local and intermediate impact zones).

An MS-DOS-based simulation model developed for MOM has two main applications: estimating the environmental impact of a given fish farm on the receiving environment, and estimating how a farm can be operated without overexploiting the site and receiving environment. The model calculates sediment carbon-holding capacity as a function of current and oxygen content above the sediment. One sub-model calculates dispersal of organic matter as a function of depth, current, sinking velocity of organic matter and farm design. Simulations are expected to be useful in such determinations as setting optimal distances between rows of net cages, and calculating relative changes in holding capacity when sites are being compared, either when evaluating specific applications or in coastal zone planning.

3.3 Scotland

Production of Atlantic salmon dominates marine fish farming in Scotland, with output having increased steadily from 10,337 tonnes in 1985 to an estimated 111,918 tonnes in 1999 (Henderson and Davies, 2000). Operations are becoming concentrated on large sites with high levels of automation. Small tonnages of rainbow trout and turbot are also produced in sea cages (504 tonnes in 1998), and there is currently an increasing interest in halibut farming, although production has not yet reached fully commercial scale.

Scottish finfish aquaculture is concentrated in the more remote and rural areas of west and northwest mainland Scotland, the Western isles, Orkney and Shetland islands, where between 400 and 500 cage farms are located. Geographical and hydrographic conditions of these regions suit the species cultured.

A draft report has recently been prepared by Ms. Anne Henderson of the Scottish Environment Protection Agency West (Glasgow) and Dr. Ian M. Davies of the Fisheries Research Services Marine Laboratory (Aberdeen) that reviews regulation and monitoring of aquaculture in Scotland. Much of the information in this section has been derived from that report.

3.3.1 Recent Changes to Waste Management Regulations

Regulation and monitoring of aquaculture has adapted and grown with the industry, and political changes have brought new environmental regulations. Most notably, Scotland has been granted greater autonomy within the United Kingdom, and jurisdiction of the European Union has become more established.

Environmental Impact Assessment (EIA) is the subject of a European Union Directive implemented under *The Environmental Impact Assessment (Fish Farming in Marine Waters) Regulations 1999*. This Statutory Instrument came into force for all finfish species March 14, 1999, replacing the previous Environmental Assessment (Salmon Farming in Marine waters) Regulations 1988 and previous advice on thresholds for triggering an Environmental Assessment (Henderson and Davies, 2000).

In Scotland, cage fish farming came under pollution regulation in 1989 by virtue of *Schedule 23 of the Water Act 1989*, primarily functioning as part of *The Control of Pollution Act 1974, Part II.*

Medicinal substances administered to fish are regulated under the *Medicines Act 1968* and marketed under Marketing Authorizations for Veterinary Medicinal Products Regulations 1994. Several European Directives and Regulations also pertain to marketing of veterinary medicinal products. A pharmaceutical company seeking to sell a product in the UK must first obtain a Maximum Residue Limit (MRL) from the European Medicines Evaluation Agency, then a Marketing Authorisation (MA) from the Secretaries of State for Agriculture and Health. Advice is provided by an independent advisory body, the Veterinary Products Committee (VPC) that assesses applications according to three main criteria: pharmaceutical quality, efficacy and safety to consumers, fish farm operators, and the environment.

Antifouling net treatments are classed as pesticides and must be approved under the Control of Pesticides Regulations 1986 or the Plant Protection Products Regulations 1995 before being sold, supplied, stored, used or advertised in the UK. Non-agricultural pesticides (e.g., wood preservatives, surface biocides, public hygiene insecticides and antifouling products) are the responsibility of the Health and Safety Executive (HSE), which administers the registration process together with. The Ministry of Agriculture, Fisheries and Food (MAFF).

Some aquacultural chemicals with potential deleterious effects on the aquatic environment fall within the EC Directive on Dangerous Substances, administered by the Scottish Environment Protection Agency (SEPA). Member states are required to introduce programs to reduce pollution listed substances on the basis of emission standards calculated from water quality objectives; programs may involve substituting a less hazardous chemical and take into account the “latest economically feasible technical developments” (i.e., best environmental practice, BEP).

Protection and conservation of natural habitats and species in the EC are regulated by The Habitats Directive (92/43/EEC) and the Wild Birds Directive (79/409/ECC). European marine sites designated for conservation purposes of are Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) that extend below mean low water mark of spring tides. In fulfilling their statutory functions, all competent authorities must ensure they protect conservation interests for which any SAC or SPA was designated, and participate with other relevant authorities in developing a single management scheme.

3.3.2 Update of Waste Discharge Regulations

The Environment Act 1995 promotes cleanliness of tidal waters, conservation and enhancement of natural beauty and amenity of coastal waters, and conservation of aquatic flora and fauna. The Scottish Environment Protection Agency (SEPA), established under the Act, is the competent authority concerning all areas designated under Birds and Habitats Directives, and responsible for regulating pollution from cage fish farms. SEPA has a statutory duty to promote the cleanliness of Scotland's tidal waters and to conserve, where practical, its water resources and the flora and fauna of the marine environment. SEPA sets numeric or descriptive conditions on discharges from fish farms to control their impact in tidal waters. SEPA also defines appropriate environmental monitoring to ensure that Discharge Consents are appropriate. SEPA recently issued a Guidance manual on Regulation and Monitoring of cage fish farms (SEPA, 1998).

The *Environment Act* specifically defines fish farming effluent as "trade effluent," and it is an offence to cause or knowingly permit any trade effluent to be discharged into controlled waters. Fish farmers applying to construct new operations must obtain a Consent to Discharge (licence) under Section 34. This approach has been supplemented by considerations of BATNEEC (best available techniques not entailing excessive cost) steps needed to minimize the polluting effects of the discharge. Consent to Discharge documents set out numeric or descriptive operational conditions and restrictions under which discharges or damage to the aquatic environment are to be controlled and monitored, and encourage BEP to further minimize discharges. To date, consents have strictly addressed water and sediment quality issues rather than husbandry or management techniques.

The Crown Estate Commission (CEC) has jurisdiction over management of the territorial sea bed and the foreshore between mean high and low water marks. Statutory consultees of the CEC, including SEPA, Scottish Executive Rural Affairs Division (SERAD) and Scottish National Heritage (SNH), provide comment on a wide range of relevant issues before the applicant applies for consent to discharge (e.g., the dispersive character of each site, water quality issues, proximity of farms to each other and risk of chemical and medicine use, fisheries and fish disease issues, proximity to wild fish runs, conservation issues, fish processing operations and site servicing).

SEPA is responsible for applying relevant EC and UK environmental legislation and must publicly advertise all applications for Consents to Discharge, except cases where the discharge will have no appreciable effect. Interested parties may then make objection representations. In practice, almost all applications for new marine cage fish farms, increasing biomass at existing sites more than 10%, and use of medicines are advertised and copied to statutory consultees, costs borne by the applicant.

SEPA evaluation of Consent applications considers existing water, sediment and biological quality, and available environmental data. The hydrographic character must also be assessed. Such data, required as part of the application, are used to assess any preexisting environmental stress and the dispersive character of the receiving water.

It is not common for SEPA to judge a site completely inappropriate for fish farming, rather maximum acceptable biomass and level of chemical release are assessed. Evidence of environmental stress influences decisions and Consent conditions. SEPA encourages site fallowing and rotation, requiring such management practices at certain locations. Factors that may make a site unacceptable, leading to denial of the application, include:

- priority nature conservation designations where an unacceptable risk of adverse effects exists;
- poor site characteristics (e.g., quiescent conditions, pre-existing indications of anoxic sediments or low dissolved oxygen levels in the water above the sea bed); and
- close proximity to other conflicting water interests.

Site-specific Consent conditions are based on scientific assessment and enforced through compliance with Environmental Quality Standards. Operational standards can also be set, based on risk assessment procedures. The integrated approach considers effects on biodiversity, sustainability, socioeconomic factors, aesthetics, other users (e.g., other aquaculture sites, wild and sport fisheries, and water sports), and valuable habitats identified during consultations.

Required to be enforceable, clear, unambiguous and necessary, Consent conditions are site-specific, detailed, and include cage number and position, species cultured, and environmental impact management. The maximum allowable biomass of fish is limited, and thereby the accumulation of organic wastes on the seabed, preventing development of anoxic and polluted sediments and associated deleterious benthic effects. Bathymetry, location, flushing capability and seabed characteristics are used to assess the appropriate biomass, and mathematical models of solid waste deposition will soon be introduced to assist decision-making.

If Consent conditions are breached, a variety of actions can result, including:

- establishing a monitoring program for ongoing consent compliance;
- remedial action to reduce pollution or impact; or
- prosecution.

SEPA will recommend an operator reduce biomass or improve its management strategy if data indicate severe environmental deterioration over time, or that environmental criteria and standards were breached.

SEPA has adopted a mathematical modelling approach for consenting and controlling discharge of chemicals and medicines. Environmental risk assessments are carried out for each compound and environmental quality standards or environmental targets are set, according to approved dosage and method of administration. Short- and long-term dispersion models are applied, case-by-case, for bath treatments, and depositional models for infeed treatments.

The 1974 Paris Convention for Protection of the North Sea and North East Atlantic is directly applicable to marine aquaculture. One requirement has been to reduce discharge of various toxic and persistent chemicals, including dichlorvos, a sea lice treatment used in marine cage fish farms, by at least 50% by 1995. The Paris Commission (PARCOM) recommended national bodies develop BEP codes pertaining to output of toxic or potentially hazardous chemicals, regulation and licensing of drugs and chemicals, and impacts on water and environmental quality. Though recommendations are not legally binding, signatory countries are obliged to consider them when preparing and administering national policy and legislation.

3.3.3 Recent Changes to Monitoring, Reporting & Enforcement Mechanisms

Scotland has well-established monitoring programs to ensure compliance with the legislation (e.g., SEPA, 1998). The complexity of regulatory and monitoring issues the aquaculture industry presents has required new techniques be developed, including mathematical modelling to set environmental targets for some medicines. A national approach has been needed that would benefit the industry and the regulators and allow focus to be brought to wider issues requiring research and development.

As in British Columbia, Scottish aquaculture sites are located in some of the most remote and inaccessible areas, and consequently there are considerable logistical and resource difficulties in monitoring and inspecting. SEPA may undertake monitoring directly or approve self-monitoring by the operator or a suitable contractor appointed by the operator.

Neither the CEC nor the Planning Authorities have any formal monitoring role under revised planning and siting arrangements now in place. As landlord, the CEC has a voluntary monitoring strategy in place for shellfish and salmon growing sites. Site inspections are carried out in geographic areas in a cyclical manner, and cage type, numbers per area, and position within the lease site are recorded.

Monitoring programmes are in place to ensure effective regulation. Shellfish farms are not monitored for environmental impact under the existing legislation. SEPA routinely monitors cage fish farms to ensure compliance with Consents to Discharge, ensure EQSs and other standards are being met, measure effects on the environment, determine any action to be taken, and audit results of self-monitoring. SEPA monitors for compliance with Consent conditions through monthly paper or electronic returns from the operator that detail the medicinal treatments undertaken and the biomass of stock held. Fish farm shore bases are also routinely inspected, including records of stock held, medicinal treatments, chemical storage facilities, disposal facilities for dead fish and other solid wastes and facilities for net washing and disposal of net-washings.

There may be a need to monitor concentrations of medicines and chemicals in the environment, including occasional sampling sediments and water within treated cages. Sampling sediment to measure levels of in-feed medicines requires accurate position fixing and specialized sampling and analytical techniques. Videography is also appropriate for monitoring levels of waste feed below cages. Spot sampling of representative samples of feed and fish tissues can strengthen monitoring for illegal use of medicines and other substances, and requires careful planning, particularly in case analytical data may be used subsequently as legal evidence.

Data collection programs are designed for:

- pre-licence baseline studies (e.g., determining site sensitivity) and for post operational comparisons typically consists of hydrographic and bathymetric data, and biological and sediment data collected to specific protocols from a new site and reference locations;
- post-licence operational monitoring (e.g., effects assessment and consent compliance, during production, pre-stocking, fallowing or medicines application), often including transect-based benthic surveys or video transect work (strategies are under review); and
- assessing site recovery after removal of fish from cages or reduction of biomass.

Monitoring data are reviewed regularly to ensure their applicability and reasonableness, that resources are optimized, and to allow feedback into action programmes.

The regulatory framework for cage fish farming includes the concept of an Allowable Zone of Effects (AZE), the area of seabed or volume of a receiving water body in which some breach of a relevant EQS may be allowed. It is analogous to the “mixing zone” approach applied where effluent treatment technology is either unavailable or prohibitively expensive, and dilution or natural breakdown in the receiving environment is necessary before environmental standards are met.

Nutrients

The issue of carrying or holding capacity is currently under review but there are difficulties distinguishing inputs of nutrients from cage farming from those originating from forestry and agriculture (Henderson and Davies, 2000). There is little evidence that cage farms have caused significant widespread problems in Scotland but some risk may exist of elevated concentrations causing enhanced phytoplankton growth. The system flushing time is important in relation to primary productivity (plankton production) and it is recognized that periods over approximately three days would justify assessment of a region.

Dissolved Oxygen

Monitoring of dissolved oxygen (DO) concentration will only be required where the cultured biomass exceeds 1,000 tonnes and system flushing time exceeds three days (Henderson and Davies, 2000). Deoxygenation has not been a serious problem in most Scottish Waters. SEPA intends to monitor some deep basins that may be vulnerable. Some regions deoxygenate naturally at certain times of year, a process that may be exacerbated by fish farms.

Medicines & Chemicals

Scotland will introduce programs for monitoring medicines that may accumulate in sediments, appropriate to properties of the substance and the most sensitive environmental compartments (Henderson and Davies, 2000). As monitoring of medicines in water is constrained by difficulties relating a water sample to a particular time and distance from the treatment, and as medicines may be toxic at concentrations below analytical detection limits, routine sampling of medicines in water is not considered an effective use of resources. Water sampled soon after treatment and close to cages may occasionally be analyzed to ensure the veracity of modelling predictions. Sampling within treated cages is valuable, however, to ensure concentrations do not exceed recommended levels. SEPA does not regard antimicrobial agents as a priority target for monitoring as development of vaccines has decreased their use and their loading to the coastal environment.

Antifouling Treatments

The HSE is reviewing the 24 copper-based antifouling treatments licensed for use in aquaculture, and application of the EQS approach is still under development (Henderson and Davies, 2000). Copper is a List II substance under EC Dangerous Substances regulations and its concentration outside the AZE must comply with national EQS. SEPA investigations of the seabed around cage farms have identified some greatly elevated levels of copper and zinc. Though it is not known whether these findings are biologically significant, limits set in a number of countries may be adopted in Scotland. Interim target levels have been proposed.

Organic Waste Deposition

Effects of organic pollution on the seabed are usually localized and monitoring focuses on the immediate vicinity of the farm (Henderson and Davies, 2000). Monitoring is scaled to the size of farm, level of risk, and site sensitivity. Farms with relatively small biomass in dispersive areas would be unlikely to cause problems compared to ones with large biomass in sensitive sites. Sensitivity of a site may be based on its dispersive character and could also take into account important local conservation issues. SEPA's aim is to obtain seabed monitoring data that demonstrate fauna and sediment condition beyond the AZE complies with appropriate quality standards. Less stringent standards may also be applied below the cages to ensure sediment there does not become totally anoxic. SEPA is evaluating the cost effectiveness of a near cage rapid impact assessment strategy for organic wastes, as a guide for priority action. The strategy would likely be based on a combination of video, benthic infaunal samples, and sediment chemistry criteria (e.g. sulphide, redox potential, organic carbon, copper). Expensive transect work now undertaken at many farms may be phased out.

Self-Monitoring & Audit

Given the large number of marine cage fish farms in Scotland, the policy that has been adopted is one of self-monitoring by the site operator (or a consultant), with periodic audit by the regulator (Henderson and Davies, 2000). Self-monitoring includes fieldwork and provision of paper records of biomass held and use of medicines and other chemicals, and relies on the operator carrying out a defined and agreed work program. Though data are provided to SEPA specifications, they may not be open for public scrutiny without operator permission (in contrast to all data collected by SEPA). The self-monitoring plan is reviewed periodically, at a frequency determined by agreement between SEPA and the operator, enabling the plan to be reviewed in the light of recent results, rather than waiting for the opportunity for SEPA to review the consent unilaterally, 4 years after the date of issue.

Monitoring data are evaluated by SEPA, which considers aspects of data quality including position fixing, sampling methods and analytical techniques. Audits of field techniques, analysis, data records or processes may be conducted.

Consumer Protection

The UK Ministry of Agriculture, Fisheries and Food (MAFF) sampled farmed salmon for a range of analytes, including residues of veterinary medicines, from 1987 to 1994, after which responsibility was passed to the VMD (Henderson and Davies, 2000). Surveillance has been statutory since 1998, under Directive 96/23/EC. The VMD's veterinary residues surveillance program plays a central role in ensuring consumer protection, supplemented and expanded by additional non-statutory monitoring.

Quality Standards

Protection of food quality for human consumption and regulation of pollution impacts depend on defined quality standards and comparison with monitoring results. Quality standards, used to assess acceptability of any residue concentration or environmental impact, determine any need for action by regulator, operator or other competent authority.

SEPA is required to identify existing and potential uses for the water body in order to establish Environmental Quality Objectives (EQOs) to protect those uses. EQOs may include, for example, protecting consumers, aquatic life (including plants and animals of commercial or conservation importance), aesthetic quality and recreational values, and safeguarding water quality for industrial use.

Statutory or non-statutory Environmental Quality Standards EQSs are set (nationally or locally) to meet defined EQOs. Standards are often given as concentration limits for specific chemicals of concern, though various biological and sediment standards have also been derived. EQSs are set for receiving waters rather than discharges. Where a number of uses (and EQOs) have been identified for a given water body, and where various standards (EQSs) have therefore been set to protect these uses (i.e., concentration limits for a given substance may vary according to water use), the most stringent of these standards is applied. Similarly, where several areas of legislation may apply, the most stringent EQSs must apply. For example, as EQSs to protect migratory fish are more stringent than those for waters for industrial use, EQSs for the former use will automatically protect the latter.

There are two main types of discharge from fish cages to the water column: those arising from use of medicines and those from the release of nutrients and antifouling chemicals. EQSs for such substances are often expressed as chemical concentration limits and control often involves site-specific mathematical modelling of dispersion over time and comparison of predicted environmental concentrations with an appropriate EQS. There is no theoretical reason why biological water quality standards could not be developed and there is considerable interest in development of bioassay and biomarker techniques.

Antifouling chemicals and nutrients can be considered in the same way as discharges from a conventional marine outfall. SEPA policy for marine outfalls specifies that EQSs should not be exceeded more than 100 m from the outfall and applies this principle to continuous discharges from marine cage fish farms. Acute toxicity should not occur outside the zone of initial dilution and chronic toxicity should not occur outside the zone of secondary mixing (SEPA, 1998).

Though some deterioration in physicochemical properties of sediment or resident flora and fauna are accepted within the AZE, complete deterioration within the AZE is not permitted. Targets and criteria have been set to ensure there are sufficient invertebrate animals to remineralize the additional organic matter, and to turn over and aerate the sediment.

An AZE is normally applied to a portion of seabed extending outward 25 m in all directions from the edge of the cage. Where there is sufficient information on local currents, mathematical models can be used to delineate an elliptical zone of effects covering an equivalent area. For example, the AZE might extend to 50 m or 75 m in the direction of current, with no detectable impact allowed in other directions.

It is much more complicated to derive quality standards for sediments than for water. After initially being deposited in the surface layer a pollutant can migrate and mix vertically through sediment layers, and may also be re-suspended. Though detectable, a substance identified as a pollutant may be non-toxic after binding to fine particles or organic matter and becoming biologically unavailable. Nationally accepted sediment quality standards do not yet exist in Scotland, and the term “criterion“ is applied to sediments rather than standard. Results of sediment sample chemical analyses are often compared with those of samples from uncontaminated reference sites.

For pollutants discharged intermittently (e.g., some medicines or treatments), a shorter term standard or maximum acceptable concentration (MAC) may be applicable to a single sample. For some, SEPA (1998) has derived an EQS for some sea lice treatments that should not be exceeded for more than 3 hours after release. Compliance with standards for sea lice treatments are usually assessed by mathematical modelling rather than by sampling and analysis. An additional EQS was derived for dichlorvos below which the concentration should fall before the next treatment.

3.4 Chile

Chile has a large and diverse shellfish and finfish aquacultural sector, second in size in the Americas only to that of the USA. Its salmon production, at 232,000 tonnes in 1998, ranked second to Norway worldwide (Fundación Chile, 2000). More than 40 companies in Chile are dedicated to farming salmon, and these companies operate approximately 1,400 fish farms in more than 180 authorized farming centres.

Commercial salmonid farming began in Chile in the late 1970s, and the major species produced through the mid-1980s were coho salmon (*Oncorhychus kisutch*) and rainbow trout (*O. mykiss*). Though chinook salmon (*O. tschawytscha*) and massou salmon (*O. massou*) were farmed in the beginning, production of these species is now insignificant. The main species farmed at present are Atlantic salmon (*Salmo salar*), coho salmon and rainbow trout (Fundación Chile, 2000).

As described by Barton (1997), the Chilean industry has been growing at a rate that has far outpaced the capabilities of the authorities to regulate production, technological developments and controls. This situation has given rise to considerable autonomy for the industry, with questionable results in environmental degradation of production sites, control of disease and incidence of transfer, and use of antibiotics and associated impact on the aquatic system. Though the aquaculture industry relies on a high degree of self-regulation, many companies struggle to undertake such regulation, given increasing competition. The evolution of Chilean salmonid production since the early 1980s has led to state regulations adapting to industrial change in a reactive rather than proactive manner, and lagging behind the development of the industry.

Regulation falls under two state departments. Aquaculture concessions fall under the jurisdiction of the Maritime authority and are dependent on a Ministry of Defence resolution, while Aquaculture Authorizations fall under the jurisdiction of the Water Authority, dependent on a resolution of the Undersecretariat of Fisheries. The Department of Aquaculture, a branch of the Undersecretariat for Fisheries, was established in 1992 with the aim of regulating the aquaculture industry. The division of responsibility ensures that regulation of monitoring and enforcement are not fully integrated, a situation exposing problems in the heart of the regulatory system.

3.4.1 Recent Changes to Waste Management Regulations

Winsby *et al.* (1996) cited the *General Law of Fisheries and Aquaculture*, promulgated in 1989, as the main Chilean regulatory instrument directing policies for development and management of aquaculture. Environmental regulations contained in this law appear to have been superseded since the early 1990s, when the Chilean government began developing an ambitious legal framework of environmental regulations.

The latest wave of aquaculture regulations began with intensive examination of the industry by the Technical Advisory Committees established by the Undersecretariat for fisheries during 1992 and 1993: Aquaculture Concessions and Authorizations; the National Aquaculture Register; the Import of Hydrobiological Species; Disease Control and Prevention; the First Introduction of Exotic Species; the Maximum Size of Farming Centres; and Environmental Protection for Aquaculture Projects (Barton, 1997).

Chile enacted the *General Environmental Law* (Law Number 19,300) in 1994, which contained several provisions aimed at strengthening institutional and regulatory capacity over environmental matters (CONAMA, 2000a). One such provision was creation of the National Environmental Commission (CONAMA), responsible for developing, implementing and co-ordinating environmental programs and policies. CONAMA began implementation of the Environmental Impact Assessment (EIA) System in 1997 (CONAMA, 2000b). The English translation of Article 72 states, “Regarding permits to grow and produce hydrobiological resources, described in Title VI of Law No. 18,892, General Fishing and Aquiculture (sic) Law and its amendments…the requirements for granting them and the technical and formal contents necessary to guarantee their compliance, shall be those set forth in this Article….In the Environmental Impact Study or Statement, as the case may be, the proper environmental measures for their execution must be specified.”

The drive for economic growth via export-led development has characterized the Chilean economy since the mid-1980s; however, the sustainability of this economic policy, with 80% of exports being resource-based, has not been fully addressed and CONAMA remains an organization with few sanctions and little authority. This situation explains many of the weaknesses inherent within the regulatory framework (Barton, 1997).

3.4.2 Update of Waste Discharge Regulations

The EIA System is applicable to both public and private sector projects and activities, and is intended to ensure environmentally sustainable implementation. The process identifies potential adverse environmental impacts in order to avoid, minimize, or counteract them, and contributes to the decision-making process regarding siting, design and technology. The EIA regulations also prescribe abatement, restoration or compensation measures that must be incorporated into projects to prevent adverse impacts. Projects and activities likely to have an environmental impact (defined by Article 10 of the *Law*) must undergo a mandatory EIA, and, according to effects, characteristics and circumstances of the project, proponents must submit an Environmental Impact Statement or an Environmental Impact Study (CONAMA, 2000b).

Owing to criticism from Chile’s private sector and non-governmental organizations (NGOs), the Environmental Impact regulation is under review. CONAMA is streamlining and revising norms and regulations in order to enable authorities to adequately administer and enforce the General Environmental Law. Effective in 1999, this legislation became liable under the Canada-Chile Co-operation Agreement for the Environment (Article 44.2; DFAIT 2000).

Control of diseases by regular treatment is largely unregulated in Chile compared with restrictions in other salmon farming countries. As the use of antibiotics remains the industry's most negative aspect environmentally, due to the impact on marine flora and fauna beyond the production cages, treatment regimes in Chile require closer scrutiny by regulatory authorities (Barton, 1997).

3.4.3 Recent Changes to Monitoring, Reporting & Enforcement Mechanisms

As in other jurisdictions, Chilean salmon producers have been proactive in developing self-regulatory frameworks. The industry is actively involved in the international Aquatoxsal project (Aquaculture Management, Ecological Interactions and Algae Blooms in the South of Latin America), financed by the Development and Technology Commission of the European Union (Fundación Chile, 2000).

The industry has also been working with the government research and development agency, Fundación Chile, and with Scientific Certification Systems of the US, in developing a program aimed at obtaining environmental certification for Chilean salmon farming. The goal is to develop environmental codes of practice for all phases of salmon farming, and eventually to create a Chilean Environmental Seal that is validated by international standards within ISO 14000.

3.5 Washington

The salmon netpen industry in Washington State produces over ten million pounds of salmon each year (~4,535 tonnes) with a total annual economic value exceeding US$40 million, approximately one-tenth the output of BC (Amos and Appleby, 1999). During the last thirty years, Atlantic salmon (*Salmo salar*) have become the mainstay of commercial netpen aquaculture in Washington, as they have throughout Europe, South America, Australia and the rest of North America. Qualities that favour Atlantic salmon for aquaculture in cold marine waters include consistent growth performance, resistance to disease, and appeal to consumers. Intensive Atlantic salmon breeding programs have selected for additional traits that make them highly domesticated and more amenable to culture than Pacific salmon, leading to their use in virtually the entire commercial marine netpen industry in Washington (Amos and Appleby, 1999).

Environmental regulation of the salmon aquaculture industry in the State of Washington involves numerous federal, state and local agencies. Roles of various agencies and entities are summarized in Table 3-3.

3.5.1 US Federal Regulatory Roles

Aquaculture arose quickly in the US during the last 30 years, though the total industry remains relatively small compared to that of other countries. Regulators have had to contend with complex issues related to ecosystem disruption and maintaining human health, clean water and clean air, and have often responded by adjusting the existing industrial permit structure to fit aquacultural operations. As a result, the regulatory framework varies significantly among US states, and conflicts have arisen among environmental and resource management agencies as aquaculture crosses lines of authority. For example, some states consider aquacultural effluent to be industrial waste, while others regard it as agricultural manure. (Maryland Department of Agriculture and National Association of State Aquaculture Coordinators, 1995).

TABLE 3-3:
Aquaculture Regulatory Framework in Washington State

	Agency or Entity	Responsibility
Federal	Environmental Protection Agency (EPA)	overall responsibility for water quality and wastewater discharge
	Department of Agriculture (USDA)	co-ordinates and disseminates aquaculture information; encourages aquacultural activities and programs
	Department of Interior (DOI) Fish and Wildlife Service	encourages and supports private aquaculture that is compatible with responsible stewardship of public resources; promotes understanding and consistent application of Federal permitting process; encourages fish health programs; provides technical assistance/advice/ information; conducts training, research and technology development
	Department of Commerce (DOC) National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS)	determines whether an activity constitutes a "taking" of a species listed as endangered or threatened under the Endangered Species Act (ESA); as escaped Atlantic salmon co-mingle in Puget Sound with populations of salmon species listed under ESA, if it were determined that co-mingling constituted a "taking" of the listed species, it would then be within NMFS authority to require netpen operators obtain a "take" permit to continue operation
	US Army Corps of Engineers	issues "404" permits that are required for any structure it is determined would affect navigation in waterways; aquacultural operators are required to obtain this permit prior to installing netpen structures.
State	Department of Agriculture (WDOA)	develops markets and delivers marketing support services; provinces disease inspection and control services (jointly with WDFW).
	Department of Ecology (DOE)	writes and issues EPA NPDES permits for marine netpens
	Department of Fish and Wildlife (WDFW)	administers fish disease control and prevention regulations
	Pollution Control Hearings Board	adjudicates appeals to actions taken by the Washington Department of Ecology
	Department of Natural Resources (WDNR)	issues leases covering aquatic lands netpens occupy
Local	Counties of Washington State	issues Substantial Development Shoreline Permits that all net operations must secure before constructing or operating an aquaculture netpen facility
	Treaty Tribes of Washington State	co-manages the fishery resource; co-manages fish stocks, including escaped Atlantic salmon; participates in development of disease control regulations and policies administered by WDFW

References: NOAA, 1998; EPA, 1999; US Fish & Wildlife Service, 1995; Washington Department of Ecology, 1998; Amos and Appleby, 1999.

At the federal level, the US Environmental Protection Agency (EPA) is responsible for water quality and regulating wastewater discharge, under the *Clean Water Act* and *Pollution Prevention Act* (EPA, 2000). Through the National Pollutant Discharge Elimination System (NPDES), the EPA has delegated authority for issuing discharge permits to states, including Washington, that adhere to these guidelines or add further restrictions. While serving this regulatory role, the US EPA carries out the clear policy of Congress, under the *National Aquaculture Act* of 1980, to “promote the development of environmentally safe and sustainable aquaculture to meet the growing national and global needs for protein from seafood and to relieve pressure on wild fish stocks” (EPA, 2000).

The National Aquaculture Act established the US Department of Agriculture (USDA) as the lead federal agency responsible for co-ordinating and disseminating national aquaculture information and encouraging aquacultural activities and programs in the public and private sectors (US Fish and Wildlife Service, 1995). A 1980 Memorandum of Understanding between the USDA, the Department of Commerce (DOC) and Department of the Interior (DOI), and the Joint Subcommittee on Aquaculture, chaired by USDA, were responsible for developing the National Aquaculture Development Plan, which identified the relative roles of these agencies and established a strategy for development of the aquaculture industry. DOI, through the Fish and Wildlife Service, and USDA, through the Forest Service, have roles in implementing the Federal environmental permitting process, and in co-ordinating research and training. The role of DOC, through the National Marine Fisheries Service (NMFS), National Ocean Service (NOS) and National Sea Grant College Program, under the umbrella of the National Oceanic and Atmospheric Administration (NOAA), includes comprehensive planning, conservation and management of aquaculture facilities within the coastal zone (NOAA internet site).

3.5.2 State Regulatory Roles

In 1985, the Washington State Legislature adopted a policy that "aquaculture is agriculture" and passed legislation designating the Department of Agriculture (WDOA) the lead state agency for promoting and marketing cultured salmon (Amos and Appleby, 1999). WDFW responsibility was limited to administering fish disease control and prevention regulations that were to be developed jointly with the WDOA. The WDFW recently released a report by Amos and Appleby (1999) advocating expansion of its regulatory role with regard to salmon aquaculture. Kevin Amos is the Washington State Director for Fisheries Health, and Andy Appleby is WDFW Aquaculture Specialist.

In the 1980s, the state legislature directed WDFW to compile existing knowledge regarding significant potential environmental impacts of fish farms in Puget Sound into a programmatic environmental impact statement (PEIS), to assist state, county, and local decision makers in evaluating proposals for fish farm sites. Issues considered in the PEIS (WDFW, 1990; cited by Amos and Appleby, 1999) included the import of new fish species, genetic issues, disease issues, and other factors potentially affecting the environment.

Washington State fishery managers have in the past imported, cultured, and stocked Atlantic salmon with the hope of establishing wild populations that would provide additional and unique fishing opportunities in the state. Smolts were released by the Department of Fish and Wildlife in 1951, 1980, and 1981 for the purpose of establishing runs. Additional releases have been made in lakes in an attempt to establish resident populations. No releases have resulted in the return of adult Atlantic salmon, and other attempts throughout the United States and world to introduce and establish Atlantic salmon outside the Atlantic Ocean have also failed (Amos and Appleby, 1999).

Among potential environmental impacts of netpen operations on the marine environment, Washington State fisheries managers are particularly interested in the consequences of escapes of Atlantic salmon and effects on wild salmon should they co-mingle with other fish and wildlife in waters of the state, given that many Pacific salmon stocks in Washington have recently been listed as *endangered* or *threatened* under the Endangered Species Act (ESA). No records were made of annual escapes of Atlantic salmon in Washington prior to 1996. Large numbers escaped in 1996 (107,000), 1997 (369,000) and 1999 (115,000; Amos and Appleby, 1999).

From the early 1970s when marine aquaculture began in the Puget Sound region of Washington, fishery managers have been aware of potential impacts of netpen fish on native fish stocks, though the best available early knowledge indicated that the impacts were insignificant and could be managed. To manage the potential impacts of disease, rules were developed in a collaborative process with state, federal, tribal and industry representatives, and implemented by WDFW in 1987. Legal authority over commercial aquaculture granted WDFW by the legislature in 1985 was restricted to fish disease prevention and control. As no example was known of Atlantic salmon being successfully established in a new area, escaped fish did not appear to present significant risk (Amos and Appleby, 1999).

The authority of the WDFW to regulate Atlantic salmon covers two areas. First, the Fish and Wildlife Commission and the Director of WDFW have extensive authority over Atlantic salmon when they are considered "food fish," consistent with their responsibility to manage all fish and wildlife in the state. The other authority WDFW has over Atlantic salmon is when they are classified as "private sector cultured aquatic products", the designation Atlantic salmon have when in captivity, being reared by an "aquatic farmer" in a commercial fish farm. The Legislature in 1985 limited WDFW authority over Atlantic salmon in the status of private cultured products (Revised Code of Washington 75.58.010): (1) “The director of agriculture and the director (WDFW) shall jointly develop a program of disease inspection and control for aquatic farmers….”, and (2) “.....The authorities granted the department (WDFW) by these rules…constitute the only authorities of the department to regulate private sector culture aquatic products and aquatic farmers….”

WDFW is also responsible for issuing hydraulic permits (HPA) for work conducted in state waters. It is unclear whether the limited authority granted WDFW to regulate aquaculture excuses commercial aquatic farmers from obtaining an HPA when conducting work within their operations.

In summary, when Atlantic salmon are in captivity and classified as commercial products, WDFW authority is restricted to developing and administering disease control regulations specified under RCW Chapter 75.58. Though any Atlantic salmon that escapes captivity immediately becomes classified as food fish, over which WDFW has full regulatory authority, the agency has the ability to take action against the party releasing the fish only when Atlantic salmon are stocked or released <u>purposely</u> without a permit. Accidental release of fish does not constitute a violation of the fish and wildlife code.

3.5.3 Ongoing Pollution Control Hearings

WDFW has other legally mandated roles in managing Atlantic salmon that lie outside the scope of legislative directives, and operates a number of marine netpens in Puget Sound. These pens culture Pacific salmon for a variety of management purposes. WDFW secured *National Pollution Discharge Elimination System* (NPDES) permits from the Department of Ecology (DOE) to operate these pens.

Under Revised Code of Washington 90.48, the Washington State Department of Ecology (DOE) is responsible for writing and issuing EPA NPDES permits for marine netpens (Amos and Appleby, 1999). It is within DOE purview to make these permits conditional on the operating procedures for pens that minimize or eliminate discharge of pollutants.

Issuance of the NPDES permits to WDFW was appealed to the Pollution Control Hearings Board (PCHB), the administrative body established to adjudicate appeals to actions taken by the Department of Ecology (Amos and Appleby, 1999), and DOE and WDFW became respondents in a legal action. The appellants were the *Marine Environmental Consortium, Washington Environmental Council, Protect Our Waters and Environmental Resources* and *Washington Trout*. An agreement negotiated in 1998 between WDFW and the appellants removed WDFW as a party in the litigation. WDFW agreed, as part of regular activities, to monitor weirs, traps and streams for Atlantic salmon, kill any intercepted, sample them for biological information. Fish data collected, collated, and provided to the appellants annually includes general health, stomach contents, and gonad development.

Extensive testimony was given at the board hearings on potential impacts of escaped Atlantic salmon on native stocks (PCHB, 1998a; 1998b; 1999). One issue determined by the board was the definition of Atlantic salmon, in the context of the appeal. The PCHB assigned Atlantic salmon to an additional legal classification (beside "food fish" and "private sector cultured aquatic products"), that of "pollutant", a designation that places Atlantic salmon under DOE jurisdiction. The basis this classification was that Atlantic salmon 1) escaped from a "point source", i.e., the netpen; 2) constitute biological material, as defined by *Webster's New World Dictionary*; 3) are "agricultural or industrial waste"; in that escapement of Atlantic salmon is a commercial loss, escaping salmon are a “waste” and that they become fewer by gradual loss (also Webster’s); and 4) are a species not native to Puget Sound.

3.5.4 Recent Legislative Changes Pertaining to Waste Management

As a result of the PCHB decision, escaped Atlantic salmon are regulated as "pollutants" under both the state *Water Pollution Control Act* and the federal *Clean Water Act* (Amos and Appleby, 1999). In response to a release of approximately 369,000 Atlantic salmon in July 1997, DOE issued an Administrative Order to Global Aqua Inc., the owner and operator of the failed net, requiring the company to develop a "fish release prevention plan" and an "accidental fish release response plan". An accidental fish release plan requires the grower to notify WDFW and DOE within two hours of a significant accidental release. DOE has issued a Notice of Violation to Northwest Sea Farms (Global Aqua's successor), for the June 1999 accidental release of an estimated 115,000 Atlantic salmon.

3.5.5 Anticipated Legislative Changes

At the US federal level, the EPA has begun a study of aquaculture in response to comments it received while preparing the 1998 Effluent Guidelines Plan. According to the US Federal Register, March 30, 1999, the EPA intends to summarize available information on aquaculture wastewater characterization, management practices, and wastewater collection, storage and treatment (EPA, 1999). The Agency will also examine environmental impacts associated with wastewater from aquaculture operations and existing case studies of costs and benefits of controls to mitigate adverse impacts. Along with industry demographics, trends and economic considerations, such information may be used to inform future decisions on the need for the EPA to regulate wastewater discharges from aquaculture.

Winsby *et al.* (1996) described potential changes to Washington salmon aquaculture regulations regarding waste management, waste discharge, and monitoring. The PCHB hearings described above have delayed implementation of regulatory changes, though proposed wording has been developed (Greg Cloud, DOE, pers. comm.)

In developing NPDES permits for netpens, DOE relies on WDFW for input in areas related to fish management. It is anticipated that DOE will work closely with WDFW in renewal of the current marine netpen permits when they expire in September 2001.

The WDFW hopes to re-establish its position of actively managing all fish and shellfish of the state, including private sector aquaculture products (Amos and Appleby, 1999). While acknowledging that marketing, commodity boards, and promotion of agriculture products appropriately resides with the DOA, WDFW feels it should be reassigned all aspects of management of live commercial aquaculture fishery products, and be provided with the necessary resources. WDFW also believes that, while it is important to maintain a viable finfish and shellfish industry in the state, it is imperative that commercial aquaculture in no way jeopardizes natural resources of the state, and that only by joining the responsibility of managing both aquaculture and wild resources under one agency will such management goals be achieved.

To better manage Atlantic salmon aquaculture and protect fish and wildlife resources Washington, Amos and Appleby (1999) made several recommendations:

1. re-establish the authority of WDFW or another appropriate state agency to regulate most aspects of commercial aquaculture, excluding marketing and commodity boards, which should remain with the DOA; such new authority would include abilities to a) determine species or stocks appropriate for culture in a specific geographic area; b) inspect farms and ensure appropriate practices and procedures are being followed to prevent escapes; c) provide educational opportunities to fish culturists throughout the state that would improve farm performance and protection of natural resources; and the establishment of an Atlantic Salmon Watch program similar to that of BC to be a focal point for gathering data on Atlantic salmon in Washington;
2. provide adequate resources to WDFW to evaluate the impact of escaped Atlantic salmon on fish stocks in Washington and provide resources necessary to manage the enhanced aquaculture regulatory authority requested by the department;
3. actively work with both federal and provincial fish management agencies in BC and the commercial industry to ensure aquaculture regulations and management policies are consistent throughout the region;
4. actively pursue implementation of an Atlantic salmon breeding program that requires use of non-reproductive populations (either mono-sex or triploid fish); and
5. institute a comprehensive code of salmon aquaculture practices, to be administered by WDFW, that promote environmentally sound fish culture.

3.6 Alaska

Salmon aquaculture is highly restricted in Alaska. Section 16.40.100, "Aquatic farm and hatchery permits," under Alaska Statute Title 16, *Fish and Game Code*, states, "Notwithstanding other provisions of law, the commissioner may not issue a permit under this section for the farming of, or hatchery operations involving, Atlantic salmon." Furthermore, Section 16.40.210, entitled "Finfish farming prohibited," states, "a person may not grow or cultivate finfish in captivity or under positive control for commercial purposes." This section does not restrict:

(1) fishery rehabilitation, enhancement, or development activities of the department;

(2) the ability of a nonprofit corporation that holds a salmon hatchery permit to sell salmon returning from natural water of the state, or surplus salmon eggs; or,

(3) rearing and sale of ornamental finfish for aquariums or ornamental ponds provided that the fish are not reared in or released into water of the state.

This law remains in effect as of April 2000 (Soares, pers. com.).

4.0 TOXIC PLANKTON BLOOMS & AQUACULTURE

The 1990s were witness to a worldwide increase in reports of marine microalgae harmful to shell-fish finfish, , and human consumers (Smayda, 1990; Hallegraeff, 1993; Anderson, 1995; Turner and Tester, 1997; Burkholder, 1998). The known number of species of toxic dinoflagellates, for example, increased from 22 in 1984 (Steidinger and Baden, 1984) to 59 little more than a decade later (Burkholder, 1998). Correlative field data, coupled with experimental evidence, suggest that some algal species not normally toxic may become so when exposed to altered nutrient regimes from overenrichment (Evardsen *et al*.; 1990, Bates *et al.*, 1991; Hallegraeff, 1993). Outbreaks of some species have also coincided with *El Niño* events, suggesting that global climate change and warming trends may also encourage their growth (Epstein *et al*., 1994).

An increase in harmful algal blooms (HABs) has been reported on the west coast of North America (Garrison *et al*., 1992; Taylor and Horner, 1994; Horner *et al*., 1997). Approximately 20 of the 5,000 known phytoplankton species along the west coast produce toxins (e.g., saxitoxins, domoic acid, etc.) or are directly lethal to fish through mechanical damage (e.g., some diatoms and raphidophytes; Taylor, 1990), while an estimated 25 additional species are responsible for other problems, such as water discolouration or “red tides” which may kill fish by depleting oxygen and possible noxious compounds (Table 4-1)

Table 4-1:
Toxic & Nontoxic Algal Species from the West Coast of North America

Algal Group/Species	Toxin Produced	Phenomenon Caused
1. Dinoflagellates • *Alexandrium* spp.	saxitoxins	• Paralytic shellfish poisoning (PSP)
2. Dinoflagelletes • *Dinophysis* spp.	Okadaic acid	• Diarrhetic shellfish poisoning (DSP), not currently known from the west coast
3. Planktonic diatoms • *Pseudo-nitzschia* spp.	Domoic acid	• Domoic acid poisoning (DAP) also known as amnesic shellfish poisoning (ASP)
4. Species associated with fish kills (diatoms & raphidophytes) • *Chaetoceros* spp. • *Heterosigma akashiwo*	Possibly ichthyotoxin	• Fish suffocation from setae ingestion; • Possible role of superoxides and hydroxyl radicals
5. Red Tide Species (dinoflagellates; diatoms; prymesiophyte flagellates, ciliates) • *Ceratium* spp. • *Gymnodinium* spp. • *Lingulodinium polyedrum* • *Noctiluca scintilans* • *Procentrum micans* • *Protoperidinium* sp. • *Rhizosolenia setigera* • *Phaeocystis* sp. • *Mesodinium rubrum*	Not documented	• Water discoloration (i.e., red tides); • Killing fish & invertebrates due to oxygen depletion; • Disruption of food-web dynamics; • Possible noxious compounds (e.g., *Phaeocystis*)
6. Parasitic dinoflagellates • *Hematodinium* sp.	NA	

Reference: Horner *et al*., 1997

Paralytic shellfish poisoning (PSP), the HAB of greatest concern in BC, results from a number of saxitoxin derivatives produced by dinoflagellates of the genus *Alexandrium*. Domoic acid poisoning (DAP; also called amnesic shellfish poisoning, ASP) is caused by the pennate diatom, *Pseudo-nitzchia pungens* and related species.

Though other toxic species associated with diarrhetic shellfish poisoning (DSP) are present in BC (e.g., *Dinophysis* spp.), DSP has not yet been reported (Horner *et al*., 1997; Burkholder, 1998).

The raphidophyte flagellate *Heterosigma akashiwo (carteraie)*, and the spiny diatoms *Chaetoceros concavicornis*, *C. convolutus* (and possibly *C. danicus*), have caused extensive fish kills along the west coast (Horner *et al*., 1997). Red tides produced by abundant dinoflagellates also occur throughout the west coast. According to Horner *et al*. (1997), none of the red tide-forming species is known to be toxic, decay of their dense blooms may kill shellfish and other invertebrates due to oxygen depletion, and they may also influence the behaviour and feeding of zooplankton. Raphidophycean flagellates, however, are known to produce haemolytic, neurotoxic, and haemagglutinating compounds, and superoxide and hydroxyl radicals that cause fish mortality (Khan *et al*., 1997; Whyte *et al*., 1998).

4.1 HAB Sources & Movements

Horner *et al*. (1997) reviewed the physical and chemical characteristics of Pacific coastal waters and potential mechanisms of HAB dispersal. In summary, coastal upwelling during spring and summer in response to strong and persistent northwest winds may bring cold, nutrient-rich waters that support rich phytoplankton blooms in the surface layer. Though the physical mechanism responsible for nutrient enrichment of the euphotic zone is not completely understood, the consequences include high rates of production and seasonal development of large algal blooms along the west coast. Along the coast of BC, Washington and Oregon, surface nutrient concentrations are generally high everywhere during the winter, but are higher nearest the coast in summer when phytoplankton blooms may occur. The Columbia and Fraser Rivers are sources of high nitrate (>5 micromoles), phosphate (>1 µM), and silicate (>20 µM) in both winter and summer (Horner *et al*., 1997).

In a study of HABs in the Philippines, Babaran *et al*. (1998) concluded that onshore wind-generated waves played a significant role in formation of "seed beds" and resuspension of resting cysts from the sea bottom, which initiate the onset of algal blooms.

4.1.1 PSP

Although there are no confirming data, observations along the open Pacific coast suggest that blooms are advected into estuaries and embayments from adjacent coastal waters (Horner *et al*., 1997).

In some areas, the onset of early summer blooms of *Alexandrium catenella* and resultant mussel toxicity is dependent on development of a warm (14ºC) surface water layer several metres thick (Nishitani and Chew, 1984). Other factors that may control onset and duration of *Alexandrium* blooms in inland waters include nutrients (N and P), reduced turbulence, and parasitism by the dinoflagellate *Amoebophyra ceratii* (Taylor, 1968; Nishitani and Chew, 1984).

4.1.2 DAP (ASP)

The relationship between environmental conditions and the production of domoic acid by the diatom *Pseudo-nitzschia* spp. (confirmed for *P. australis*, *P. multiseris* and *P. pungens*) is not clear (Horner *et al*., 1997). Garrison *et al*. (1992) speculated that toxic events may be limited to seasons when stratification and nutrient depletion occur in nearshore regions where developing blooms deplete the dissolved nutrients.

DAP was first reported on the west coast of North America in 1991, at Monterey Bay, California, (Work *et al*., 1993). Blooms of *P. australis* persisted during late summer and autumn from 1991 to 1994, when hydrographic conditions ended the upwelling season (Walz *et al*., 1994). Blooms also occurred during spring upwelling, but were less developed and generally shorter in duration. Domoic acid was reported in razor clams along the Oregon and Washington coasts in late 1991, and implicated in a few cases of illness. In autumn 1994, a bloom of the three known toxic producing *Pseudo-nitzschia* diatoms persisted in Hood Canal (Horner *et al.*, 1996). Mussels were shown to more rapidly take up and depurate domoic acid than other bivalves (Drum *et al*., 1993).

Experiments using domoic acid-toxic anchovies as feed for juvenile rainbow trout suggested that domoic acid in fish food may not constitute a health hazard to either the fish or to the consumer (Hardy *et al*., 1995). The fish remained apparently healthy, sequestering the domoic acid to their viscera and feces, not blood or muscle.

Blooms of *Pseudo-nitzschia* appear to originate offshore Vancouver Island in the Barkley Sound area (Taylor and Haigh, 1993).

4.2 Relationships of Blooms to Aquaculture

This section discusses both the effects of aquaculture on plankton communities of the marine environment and the effects of toxic plankton blooms on the industry. Discussion serves largely to update, augment and (in some cases) provide rebuttal to information compiled and conclusions drawn for MELP in a report by Hatfield and EVS (Winsby *et al*., 1996). Where possible, using information currently available, algal issues between open netpens and enclosed bags are compared.

4.2.1 Effects of Nuisance Blooms on Aquaculture

Effects of nuisance blooms on the aquaculture industry can be devastating, with economic losses in BC estimated at $20 million (Taylor, 1993), attributable particularly to the chloromonad flagellate *Heterosigma* (Whyte *et al*., 1998). Of major concern to aquaculturists is the protection of cultured fish populations from toxic effects of species regularly occurring in the coastal waters, such as *Heterosigma* that may not become noticeable until fish die (the so-called “hidden flora”).

One method of bloom avoidance by netpen fish farms is to skirt the perimeter of pens with polyester tarps, preventing advection of surface blooms of *Heterosigma* into pens. This technique also allows for upwelling of deeper colder water, either by aeration or use of air-lift or hydraulic pumps, inhibiting *Heterosigma* growth by lowering water temperature (Whyte *et al*., 1998). De-stratification of the water column by vertical convection also inhibits growth of *Heterosigma*, which during the day generally concentrates within the top 4 m of the water column (Whyte, 1997). In 1997, however, Whyte *et al*. (1998) measured vertical algal distribution to a depth of 25 m on the west coast of Vancouver Island at Clayoquot Sound.

Closed systems are generally recognized as being more protected from nuisance algal blooms than open cage systems, due to the optional positioning of water intakes in most enclosed and closed recirculating systems.

Future SEA Technologies Example

A unique feature of the SEA System™ is its ability to draw water from varying depths using an adjustable intake (Brenton, 2000). This feature apparently enables the aquaculture facility to consider and avoid algal blooms, which can be depth-dependent.

Future Sea Technologies conducted experiments using open netpens and the enclosed SEA System™ in Departure Bay, near Nanaimo, BC, during an observed *Heterosigma carteraie* bloom in June (year not given; Brenton, 2000). Counts of *H. carteraie* were up to 4,500 cells/mL in the top 5 m of the water column outside the bags and in the netpens adjacent to the bag farm. Fish losses may occur at 1,000 cells/mL. The intake of the SEA

System™ was situated at a depth of 15 m. Cell counts inside the bag did not exceed 400 cells/mL. Future Sea Technologies reported 50% fish kills in the netpens. No fish died in the enclosed systems.

The precise causes of intense and sudden blooms of the chloromonad flagellate *Heterosigma* and its association with fish kills has yet to be determined (Hershberger *et al*., 1997). Blooms of *Heterosigma* appear to be related to its ability to vertically migrate through the water column on a diurnal cycle (Watanabe *et al*., 1988). Relating vertical migration of *Heterosigma* to salinity gradients, Hershberger *et al*. (1997) postulated that Hetersigma blooms may arise when sudden rainstorms or heavy runoff from rivers, followed by clement weather with little or no wind (enabling the water column to stratify long enough), permitted *Heterosigma* cells to concentrate at the surface. This scenario is consistent with research by Taylor and Haigh (1993), who reported that the annual appearance of *Hetersigma* blooms in the Straight of Georgia coincided with stratification of the water column. Stratification was initiated by maximum runoff from the Fraser River. The bloom disappeared when the salinity gradient was destroyed by strong winds or upwellings. Placement and monitoring of variable intakes must be considerate of the diurnal vertical movements of *Heterosigma* with respect to salinity. It would be prudent to link the variable intake movements to factors such as salinity that can be measured.

4.2.2 Aquaculture Effects on Plankton

Aquaculture facilities may release dissolved and solid nutrients to the aquatic environment, causing hypernutrification and eutrophication. Alongside the increase of phytoplankton production, eutrophication may cause additional effects that may be more sensitive and relevant indicators of receiving-environment impact, such as changes in energy and nutrient fluxes, pelagic and benthic biomass and community structure, fish stocks, sedimentation, nutrient cycling, oxygen depletion, and shifts between perennial and filamentous benthic algae (Folke *et al*., 1997).

Although most BC waters provide highly flushed conditions least likely to observe these effects, the potential exists for excessive nitrogen and phosphorus to be discharged from aquaculture operations (hypernutrification) that may stimulate algal blooms and create nuisance conditions (Chen *et al*., 1999). Salmon farms may contribute the following nutrients to the water column exploited by phytoplankton:

- ammonium excreted by fish;
- phosphate through remineralization; and
- organic nutrients (e.g., biotin from uneaten food; Gowen and Bradbury, 1987).

Surface renewal of phosphate liberated in bottom sediments may occur in fjords during spring overturn before onset of diatom blooms. While phosphate enters the water column primarily through processes of remineralization from sediments below open netpens, ammoniacal nitrogen is generally released into the upper strata of the water column and is, therefore, more readily available to growing phytoplankton. Hall *et al*. (1992) estimated that between 95 and 102 kg nitrogen is released per tonne of produced fish (based on trout in a marine environment). Troell *et al.* (1999a) supported other researchers in stating that at least 80% of total nitrogen losses (dissolved and organically bound) from fish farms are plant available. Nitrogen remains the major limiting nutrient in coastal marine waters.

Due to the content of fish food and the nature of fish waste, effluents from fish farming generally contain very high N/P ratios (Folke *et al*., 1997), considered a likely cause of toxic and nontoxic algal blooms (Carlsson *et al*., 1990; Kaartvedt *et al*., 1991). Kaartvedt *et al*. (1991) linked blooms of the toxic planktonic alga *Prymnesium parvum*, which killed 750 tonnes of salmon and rainbow trout in fish farms in a Norwegian fjord, to nutrient loading from fish farms.

Haigh *et al*. (1992) and Taylor *et al*. (1994) investigated N/P ratios in relation to fish farms in Sechelt Inlet and found no evident hypernutrification or change in N/P ratio at the open net-cage farms. In studies of open net-cage salmon farms in BC, Gormican (1989) and Korman (1989) determined that ammonium concentrations in water returned to background by a point 10 m downstream. These researchers did not investigate whether the reduction was due to uptake, dilution, or nitrification to nitrites and nitrates. Korman (1989) determined, however, that chlorophyll *a* (live biomass of phytoplankton) was not significantly higher near fish farms studied. Bacterial oxidation of ammonia to nitrate via nitrite (nitrification) is one step in the cycling of nitrogen in the environment (Blackburn and Blackburn, 1992). Subsequent reduction of nitrate by bacterial denitrifiction can alleviate effects of eutrophication through removal of nitrogen to the atmosphere as nitrous oxide or nitrogen gas. This cycle is interupted, however, when nitrification is suppressed by low oxygen tension and presence of sulphur compounds and a broad range of organic compounds (Kasper *et al*., 1988), all prevalent in intensive cage cultivation waste effluent.

Few publications have directly linked releases of dissolved fish farm waste with hypernutrification or eutrophication in marine waters (Troell *et al*., 1999a). It has, therefore, been argued that nutrient release from fish farming is of minor importance (e.g., Gowen, 1990). Gowen *et al*. (1988) investigated the enclosed sea lochs of Scotland and discerned no change in phytoplankton composition near farms. Enhanced productivity and localized biomass increase were not established. During investigations of Norwegian fjords, Aure and Stigebrandt (1990) concluded that fish farming caused minimal eutrophication in the upper layers of fjord waters. Ruokolahti (1988) and Rönnberg *et al*. (1992), however, found increased growth of attached algae near fish cage farms in Baltic archipelagos. Kautsky *et al*. (1997a) also provide evidence for significant inorganic nutrient loading from finfish monoculture activities. Moreover, the industry of integrated culture (e.g., culturing seaweeds within or near fish farms) is based on nutrient release from farm effluent (Troell *et al*., 1999a; Chopin *et al*., 1999).

After investigating nitrogen hypernutrification as a potential cause for *Heterosigma* fish kills, Pridmore and Rutherford (1992) concluded that mean nitrogen was increased by 30% due to salmon farms in Great Glory Bay on the South Island of New Zealand. Winsby *et al*. (1996) provided little evidence for nitrogen hypernutrification in BC, although they documented extensive *Heterosigma* blooms during 1988 and 1989.

In their 1995 review, Winsby *et al*. (1996) concluded that no significant links could be established between marine open netpen fish farming and harmful phytoplankton blooms or general phytoplankton composition, biomass or productivity (Black, 1993;Taylor and Horner, 1994). Taylor (2000, pers. comm.) further generalized that small, shallow and nearly enclosed environments (such as aquaculture sites used in New Zealand, Scotland and Ireland) are more likely to exhibit adverse effects than deep, well-flushed systems (corresponding to most sites in BC, Chile, and Norway).

The lack of direct evidence of hypernutrification and eutrophication may be due to the fact that water exchange rates are usually high (Troell *et al*., 1999a). Troell *et al*. (1999a) suggested that phytoplankton within this enriched water may increase in number some distance from the farm area (away from where impact studies usually are performed). These researchers reiterated conclusions made by Folke *et al*. (1997), who stated that, because natural variability is often large, eutrophication effects cannot be proven without extensive monitoring programs designed specifically to detect such effects. Therefore, the lack of reported effect may be more a function of inadequate study design, low sensitivity, and inappropriate end-point measurements.

The cause of recent outbreaks of fish kills in the US, particularly along the Texas coast, is suspected to be caused by blooms of *Pfiesteria piscicida* and related dinoflagellates (Burkholder and Glasgow, 1997). The authors suggested that toxin production was stimulated by fish excreta-secreta, in addition to inorganic and organic phosphate. Potential links to fish farming require further investigation, given the potential in BC for major expansion of a diversified finfish industry.

Winsby *et al*. (1996) reiterated the assertion by Gowen and Bradbury (1987) that effects of vitimins and other organic waste released into the water by farms are relatively unknown, given a lack of data.

Enclosed Bags vs. Open Netpens

While no known studies have been conducted to date comparing effects of enclosure-type aquaculture facilities to open netpen facilities on local algal communities, empirical evidence inherent in the design of the two facilities promotes the following hypothesis:

- The variable effluent discharge of the enclosed bag system reduces the likelihood of excessive nutrient accumulation in a localized area.

The corollary to this hypothesis, however, is that such output may be more necessary in enclosed bag systems due to higher density fish production and the siting of enclosures in quiet bays, compared to open netpens, which tend to be located in areas of higher current and tidal flushing. In addition, the previous discussion of the spatial extent of eutrophication effects may render the above argument moot.

On another note, researchers have investigated the use of macro-algae (seaweeds) to treat fish farm effluent, with demonstrated success in uptake and removal of dissolved nutrients (Haines, 1975; Vandermeulen & Gordin, 1990; Neori *et al*., 1991; Haglund & Pedersén, 1993; Neori *et al*., 1996; Troell *et al*., 1999a).

Other researchers have investigated and promoted the use of integrated cultures of fish farming and seaweed culture (He *et al*., 1990; Lin *et al*., 1992; Primavera, 1993; Flores-Nava, 1995; Phang *et al*., 1996), given that the high nitrogen content of aquaculture effluent is largely available to these benthic algae for assimilation and growth.

5.0 SYNOPSIS

Major risks of open cage culture include:

- attacks by predators;
- escapes of fish (pen break-up due to storm, currents or, outcome of predator attacks);
- toxic algal blooms; and
- diseases (their etiologic agents) entering from external environment.

Counterbalancing these risks is the cheaper operation of cage culture compared to other systems. Proponents of extra large open cages (e.g., 30 m^2) cite more swimming in the enlarged volume as a performance enhancer (Pennell, pers. com.), though a paucity of published scientific literature was found on this subject. Improved anti-predator systems would reduce the negative aspects of open netpen farming as would the adoption of stronger cages (already occurring with most large BC farming operations), better anchoring systems and avoidance of certain fish transfer procedures deemed of high risk. This trend identifies the need to improve protocols above and beyond actual hardware and tools used.

In response to growing concern regarding waste reduction limitations from open cage and netpen systems, closed systems (either partially closed such as the *in situ* enclosures of Future SEA or Procean, or recirculating tanks on land) have received much attention, given their potential for controlling waste reduction and removal.

Enclosures may reduce some of the risks above although escapement may still occur through damaged bags. Bags provide some control over depth of water for intake (thereby possibly reducing some algae entrainment) and enabling short-term isolation by using oxygen systems. Bags also shield fish from predators. They offer no risk reduction regarding disease pathogens entering the bag.

On-land systems reduce all of the above risks except for algae blooms. Given sufficient oxygen systems they may isolate their systems from intake during a bloom event. These systems have generally proven too expensive (very high capital and operating costs). Risks of equipment failure are countered by back-up systems (gen-sets, oxygen systems, extra pumps, etc.) which are also expensive.

5.1 Closed Systems

Closed recirculating systems have been used in BC to raise fish (in hatcheries) for many decades, and are advantageous as commercial operations. Closed systems have considerable potential for waste removal and treatment, and reduced escape and predation problems; however, these systems are complex and expensive to buy and operate. Many designs exist, particularly in Europe and the US. Advantages of such systems include: reduced land and water requirements; a high degree of environmental control, allowing year-round growth at optimum rates; the feasibility of locating in close proximity to prime markets; and improved waste control and removal. Such systems have often failed to become viable, however, due to poor design, inferior management, or flawed economics (this argument also holds for enclosed systems in certain cases). Closed systems remain perceived as expensive ventures that are as much an art as a science.

5.1.1 Enclosures (Ocean Bag Systems)

Enclosures, such as ocean bag systems (e.g., Future SEA), may provide the waste control of recirculating systems with the advantage of a lower operating cost. While capital costs appear 10 times those of open netpens and one-sixth those of recirculating systems (including capital investment of system and set up costs), cost of production appears only minimally higher than that of open netpens. The principal advantages of bag enclosures over open cages or nets include their potential to reduce escapes and predation, their higher stocking densities, and removal of greater than 80% of solid waste. Pilot studies have demonstrated some promise of a more efficient operation regarding escapes, densities and feed ratios. This result apparently relates, at least in part, to the stronger current of enclosed tanks, which promotes faster swimming. Recent research (DFO and others) has demonstrated that fish perform better when swimming faster. Improvements include lower feed conversion rate (better conversion), higher growth rates, reduced aggression, possibly reduced stress, and higher survival (Pennell, pers. com.). Much of this research has been conducted in Sweden in the early 90s but has since been repeated. With regard to waste treatment, there are no reliable data available (independent third party monitoring) that provide levels of efficiency of present waste traps and concentrators in enclosures over open netpens (which must rely on tidal and current action to disperse waste and do not remove it).

Siting of enclosures, as currently designed, appears to remain limited to more quiescent bays, as they run the danger of collapsing in higher-velocity waters (e.g., Bay of Fundy experience). It remains for the SEA System to be more thoroughly and further tested under commercial conditions to comprehend their actual limitations and advantages. Their potential limitation to more areas with less flushing action may underscore the need for waste treatment of such systems.

Waste removal efficiency in the marine environment requires substantiation through reliable third party study (e.g., government agency).

The prevalent waste removal system encountered for enclosed bag/tank systems is the use of waste traps and concentrators, such as that promoted by Future SEA Technologies, which focusses on particle load, and leaves the dissolved nutrient fraction untreated. Current research has demonstrated that over 70% of the N released by an aquaculture facility (closed or open) occurs in the dissolved fraction. Of this fraction, at least 80% is directly available to aquatic plants (plankton and macrophytes), potentially causing eutrophication and toxic algal blooms. Some innovative alternatives are currently under research and pilot operation, including the use of source-reduction and integrated culture.

Great potential exists for treating and using sludge once removed from an aquaculture facility. Irrigating salt-tolerant crops (halophytes) with saline effluent may be a useful strategy for preventing eutrophication of coastal waters by direct discharge. Halophytes have demonstrated a capacity to act as biofilters of nutrients (particularly nitrate) in aquaculture effluent and are currently being developed as biomass, forage and oilseed crops using saltwater irrigation.

5.1.2 Need for Innovative Alternatives

The present concern regarding continuing deterioration of coastal ecosystems and its subsequent impact on aquaculture and other uses calls for the application of a "precautionary principle" to any development activity that might not be sustainable. Researchers and proponents of the aquaculture industry are currently investigating new techniques, methods, options and tools to increase the cost efficiency and ecological sustainability of aquaculture. Innovative approaches include drawing on experiences of the agriculture industry through use of integrative culturing using polycultures. Other means include source-reduction (e.g., use feeds designed to protect the environment), or adoption of indigenous fish of lower trophic level.

With the recognized economic and ecological limitations of mono-specific operations (both in agriculture and aquaculture), integration of algal cultivation with fish farming, particularly in open sea systems, is gaining much interest and support. Such integration may effectively serve the dual purposes of more efficient waste treatment and reduction of waste treatment cost. Integrated cultures remove and assimilate dissolved nutrients (both N and P) that tend to be transported over distances much greater than particulate nutrients and are not traditionally removed by many current waste removal systems aimed at removing solids. Dissolved nutrients are also often associated with eutrophication and toxic algal blooms. Current research indicates the potential for removal of 50% to 95% of dissolved ammonium released by fish using seaweeds, with increased total income of 18% (not including production costs). Such integration is truly synergistic, in that nutrients provided by the fish-farm provide the cultured seaweeds with required nutrients not otherwise available at certain times in many northern waters.

5.1.3 Ecological Footprints & Sustainability

Rees (1996) defined the aquatic ecological footprint as “the corresponding area of productive aquatic ecosystems required to produce the resources used and to assimilate the wastes produced by a defined population at a specified material standard of living.” Kautsky *et al.* (1996) conceived a narrower definition applicable to the aquaculture industry as the area of open coastal waters required to cancel eutrophication effects of each square metre of aquaculture activity.

The area required to assimilate nutrients released from aquaculture indicates how densely farms can be placed in an area without risking self-pollution, formation of algal blooms, and other adverse impacts.

The footprint for waste assimilation, as well as the strain on the environment, can be reduced by integrating seaweeds in intensive aquaculture. Troell *et al*. (1999a) calculated such a reduction of the footprint for an open cage salmon-*Gracilaria* culture in Chile, which translated to an increased carrying capacity of the area to absorb nutrients with associated potential for higher stocking densities.

Suggestions for sustainable aquaculture (i.e., farming with low ecological footprint) include use of source reduction technology (e.g., increased feed efficiency) and a focus on intensive rather than extensive systems to reduce area use. Others promote use of enclosed systems in which water is filtered for particulate and dissolved nutrients prior to release to the environment. Such treatment may be accomplished through use of seaweeds as biofilters or high-technology cleaning solutions.

More research is required to determine ecological footprints (Rees’s definition) of the various aquaculture types in temperate climates like BC. Small, intensive farming facilities with recirculating systems may incur many hidden costs and impose greater ecological footprints than larger, less intensive facilities.

Aquaculture may contribute to environmental degradation, but, paradoxically remains dependent on the supply of clean waters, seed larvae supply and other ecosystem services. Moreover, aquaculture production should not be viewed as an alternative to fishing unless farms exclusively use herbivorous fish (e.g., tilapia, catfish, carp, oysters, and clams). Many farms, particularly in BC, use carnivores (e.g., salmon, trout) that depend on diets of wild fish (in the form of high protein fishmeal). Such a practice is not sustainable.

5.2 Aquaculture Regulations

As in BC, regulation of salmon aquaculture in each jurisdiction investigated (with the exception of Alaska, where it is illegal) is in a state of flux. The aquaculture industry underwent rapid growth through the 1980s and early 1990s, with the support of governments eager to provide employment in depressed regions, to develop alternative food supplies, and to relieve pressure on wild fisheries. Governments were reluctant to impose heavy regulatory restrictions on the industry, and when issues of environmental concern began to arise more frequently (e.g., disease, waste accumulation, and escapes of exotic species), mechanisms for environmental evaluations and enforceable standards were often not in place. In addition, responsibility for salmon aquaculture has often exhibited considerable overlap between government departments, each with their own set of agenda.

5.2.1 New Brunswick

The New Brunswick aquaculture industry is, at present, overseen by a single agency, the Department of Fisheries and Aquaculture (DFA). DFA responsibilities will soon be divided among the departments of Investment and Exports, Business New Brunswick, Food Production, and Environment and Local Government. Aquacultural waste management in NB is not subject to a specific regulatory framework, but certain provisions of the NB *Aquaculture Act* and the federal *Fisheries Act* are applicable.

The Sustainable Development Section (SDS) of the DFA and the NB Salmon Growers Association are co-operating closely on development of an industry Code of Practice. Protocols being developed will particularly address four waste management components: blood-water and mortalities, viscera and effluent from processing, accumulated waste under cages, and debris at sites, in water or on beaches (DFA, 1999).

The Aquaculture Environmental Coordinating Committee has recently drafted a second Environmental Monitoring Program (EMP) for salmon aquaculture sites in southwest NB (DFA, 1999a), and is also developing an Environmental Remediation Guide (ERG; DFA, 1999b). The EMP is intended to be a cost-effective management tool for obtaining and evaluating basic data and information pertaining to organic enrichment in sediments at individual salmon aquacultural sites annually.

5.2.2 Norway

Regulation of the salmon aquaculture industry in Norway is shared by the ministries of Fisheries, Environment, Agriculture, and Local Government and Labour.

On April 7, 2000, the Government of Norway proposed changes in the *Act Relating to the Breeding of Fish, Shellfish, Etc.*, including ones strengthening environmental provisions. Such changes are seen as representing modernization in attitudes regarding industry co-operation with authorities on environmental issues (Johansen, pers. comm.). The changes detail the responsibility and authority of the Ministry of Fisheries with respect to the aquaculture industry and care of the surrounding environment. Environmental supervision is to be directed by a set of regulations established in co-operation with the Ministry of Environment. Following a public hearing, new regulations may be implemented in 2001 (Johansen, pers. comm.).

Norwegian fisheries and environment authorities have, in co-operation with relevant professional groups, financed development of the regulatory tool and methods for environmental supervision and monitoring. Elements of the procedure, known as MOM (Modelling-Ongrowing Fish Farms-Monitoring), include parameters that should be measured, methods that should be used, frequency of measurements and interpretation of results obtained.

5.2.3 Scotland

Regulation and monitoring of Scottish aquaculture has adapted and grown with the industry, and political changes have brought new environmental regulations. Most notably, Scotland has been granted greater autonomy within the UK, and jurisdiction of the EU has become more established.

The Environment Act 1995 promotes cleanliness of tidal waters, conservation and enhancement of natural beauty and amenity of coastal waters, and conservation of aquatic flora and fauna. The Scottish Environment Protection Agency (SEPA), established under the Act, is the competent authority responsible for regulating pollution from cage fish farms. SEPA sets numeric or descriptive conditions on discharges from fish farms to control their impact in tidal waters, and also defines appropriate environmental monitoring to ensure that Discharge Consents are appropriate. SEPA recently issued a Guidance manual on Regulation and Monitoring of cage fish farms (SEPA, 1998).

Scotland has well-established monitoring programs to ensure compliance with the legislation (e.g., SEPA, 1998). The complexity of regulatory and monitoring issues the aquaculture industry presents has required new techniques be developed, including mathematical modelling to set environmental targets for some medicines. A national approach has been needed that would benefit the industry and the regulators and allow focus to be brought to wider issues requiring research and development.

Monitoring programmes are in place to ensure effective regulation. Shellfish farms are not monitored for environmental impact under the existing legislation. SEPA routinely monitors cage fish farms to ensure compliance with Consents to Discharge, ensure EQSs and other standards are being met, measure effects on the environment, determine any action to be taken and audit results of self-monitoring. SEPA monitors for compliance with Consent conditions through monthly paper or electronic returns from the operator that detail the medicinal treatments undertaken and the biomass of stock held. Fish farm shore bases are also routinely inspected, including records of stock held, medicinal treatments, chemical storage facilities, disposal facilities for dead fish and other solid wastes and facilities for net washing and disposal of net-washings.

5.2.4 Chile

As described by Barton (1997), growth of the Chilean industry has far outpaced the capabilities of the authorities to regulate production, technological developments and controls. This situation has given rise to considerable autonomy for the industry, with questionable results in environmental degradation of production sites, control of disease and incidence of transfer, and use of antibiotics and associated impact on the aquatic system. Though the aquaculture industry relies on a high degree of self-regulation, many companies struggle to undertake such regulation, given increasing competition. The evolution of Chilean salmonid production since the early 1980s has led to state regulations adapting to industrial change in a reactive rather than proactive manner, and lagging behind the development of the industry.

The recently developed Chilean EIA System is applicable to both public and private sector projects and activities, and is intended to ensure environmentally sustainable implementation. The process identifies potential adverse environmental impacts in order to avoid, minimize, or counteract them, and contributes to the decision-making process regarding siting, design and technology. EIA regulations also prescribe abatement, restoration or compensation measures that must be incorporated into projects to prevent adverse impacts. Projects and activities likely to have an environmental impact must undergo a mandatory EIA (CONAMA, 2000b).

Control of diseases by regular treatment is largely unregulated in Chile compared with restrictions in other salmon farming countries. As the use of antibiotics remains the industry's most negative aspect environmentally, due to the impact on marine flora and fauna beyond the production cages, treatment regimes in Chile require closer scrutiny by regulatory authorities (Barton, 1997).

5.2.5 Washington State

In 1985, the Washington State Legislature adopted a policy that "aquaculture is agriculture" and designated the Department of Agriculture (WDOA) the lead state agency for promoting and marketing cultured salmon (Amos and Appleby, 1999). Responsibility of the Washington Department of Fish and Wildlife (WDFW) was limited to administering fish disease control and prevention regulations developed jointly with the WDOA.

Washington State fisheries managers are particularly interested in the consequences of escapes of Atlantic salmon and effects on wild salmon should they co-mingle with other fish and wildlife in waters of the state, given that many Pacific salmon stocks in Washington have recently been listed as *endangered* or *threatened* under the Endangered Species Act.

The WDFW hopes to re-establish its position of actively managing all fish and shellfish of the state, including private sector aquaculture products (Amos and Appleby, 1999). While acknowledging that marketing, commodity boards, and promotion of agriculture products appropriately resides with the DOA, WDFW feels it should be reassigned all aspects of management of live commercial aquaculture fishery products, and be provided with the necessary resources. WDFW also believes that, while it is important to maintain a viable finfish and shellfish industry in the state, it is imperative that commercial aquaculture in no way jeopardizes natural resources of the state, and that only by joining the responsibility of managing both aquaculture and wild resources under one agency will such management goals be achieved.

5.2.6 Alaska

Salmon aquaculture is highly restricted in Alaska. Section 16.40.100, "Aquatic farm and hatchery permits," under Alaska Statute Title 16, *Fish and Game Code*, states, "Notwithstanding other provisions of law, the commissioner may not issue a permit under this section for the farming of, or hatchery operations involving, Atlantic salmon."

5.2.7 Implications & Opportunities for BC

The development and adherence to a "performance based management" system would allow the industry to develop within clear guidelines and procedures.

5.3 Toxic Algal Blooms

During the past decade, there has been a worldwide increase in marine microalgae that are harmful to finfish, shellfish, and human consumers. Correlative field data, coupled with experimental evidence, suggest that some algal species not normally toxic may become so when exposed to altered nutrient regimes from overenrichment. Outbreaks of some species have also coincided with *El Niño* events, suggesting that global climate change and warming trends may also encourage their growth. Approximately 20 of the 5,000 known phytoplankton species along the west coast produce toxins or are directly lethal to fish (Taylor, 1990), while an estimated 25 additional species are responsible for other problems, such as water discolouration or "red tides".

Paralytic shellfish poisoning (PSP) results from a number of saxitoxin derivatives produced by dinoflagellates of the genus *Alexandrium*. Domoic acid poisoning (DAP; also called amnesic shellfish poisoning, ASP) is caused by the pennate diatom, *Pseudo-nitzchia pungens* and related species. Though other toxic species associated with diarrhetic shellfish poisoning (DSP) are present in BC (e.g., *Dinophysis* spp.), DSP has not yet been reported (Horner *et al*., 1997; Burkholder, 1998).

Along coastal BC, upwelling during spring and summer in response to strong and persistent northwest winds may bring cold, nutrient-rich waters that support rich phytoplankton blooms in the surface layer. Along the coast of BC, Washington and Oregon, surface nutrient concentrations are generally high everywhere during the winter, but are higher nearest the coast in summer when phytoplankton blooms may occur. The Columbia and Fraser Rivers are sources of high nitrate, phosphate and silicate in both winter and summer (Horner *et al*., 1997).

Effects of nuisance blooms on the aquaculture industry can be devastating, with economic losses in BC estimated at $20 million (Taylor, 1993), attributable particularly to the chloromonad flagellate *Heterosigma* (Whyte *et al*., 1998). One method of bloom avoidance by netpen fish farms is to skirt the perimeter of pens with polyester tarps, preventing advection of the surface blooming of *Heterosigma* into the pens.

Closed systems are generally recognized as being more protected from nuisance algal blooms than open cage systems, due to the optional positioning of water intakes in most enclosed and closed recirculating systems. A unique feature of the SEA System™ is its ability to draw water from varying depths using an adjustable intake (Brenton, 2000). This feature apparently enables the aquaculture facility to consider and avoid algal blooms, which can be depth-dependent.

Aquaculture facilities may release dissolved and solid nutrients to the aquatic environment, causing hypernutrification and eutrophication. Alongside the increase of phytoplankton production, eutrophication may cause additional effects that may be more sensitive and relevant indicators of receiving-environment impact, such as changes in energy and nutrient fluxes, pelagic and benthic biomass and community structure, fish stocks, sedimentation, nutrient cycling, oxygen depletion, and shifts between perennial and filamentous benthic algae (Folke *et al*., 1997). The potential for excessive N and P discharge from aquaculture operations (hypernutrification) may stimulate algal blooms and create nuisance conditions (Chen *et al*., 1999). Salmon farms may contribute ammonium, phosphate and organic nutrients to the water column exploited by phytoplankton.

In their 1995 review, Winsby *et al*. (1996) concluded that no significant links could be established between marine open netpen fish farming and harmful phytoplankton blooms or general phytoplankton composition, biomass or productivity (Black, 1993; Taylor and Horner, 1994). Taylor (2000, pers. comm.) further generalized that small, shallow and nearly-enclosed environments (such as aquaculture sites used in New Zealand, Scotland and Ireland) are more likely to exhibit adverse effects than deep, well-flushed systems (corresponding to most sites in BC, Chile, and Norway).

The lack of direct evidence of hypernutrification and eutrophication may be due to the fact that water exchange rates are usually high (Troell *et al*., 1999a). Troell *et al*. (1999a) suggested that phytoplankton within this enriched water may increase in number some distance from the farm area (away from where impact studies usually are performed). These researchers reiterated conclusions made by Folke *et al*. (1997), who stated that, because natural variability is often large, eutrophication effects cannot be proven without extensive monitoring programs designed specifically to detect such effects. Therefore, the lack of reported effect may be more a function of inadequate study design, low sensitivity, and inappropriate end-point measurements.

LITERATURE SOURCES

Ackefors, H., and M. Enell. 1990. Discharge of nutrients from Swedish fish farming to adjacent sea areas. Ambio. 19:28-35.

Ackefors, H., and M. Enell. 1994. The release of nutrients and organic matter from aquaculture systems in Nordic countries*.* J. Appl. Ichthyol. 10:225-241.

Alberta Ministry of Agriculture, Food and Rural Development 1996. Fresh Water Aquaculture Industry. http://www.agric.gov.ab.ca/agdex/400/8583001a.html

Amos, K.H., and A. Appleby. 1999. Atlantic salmon in Washington State: A fish management perspective. Washington Department of Fish and Wildlife, Olympia. http://www.wa.gov/wdfw/fish/atlantic/manage.html.

Anderson, D.M. (ed.). 1995. ECOHAB – the ecology and oceanography of harmful algal blooms, a national research agenda. National Science Foundation and National Oceanic and Atmospheric Administration. Washington, DC.

Andrew, P. 2000. Press Release, June 9. Trial of SEA System™ in Lime Kiln Bay, New Brunswick interrupted for one year. Future SEA Technologies. Nanaimo; 1 p.

Aquaculture Technologies New Zealand Ltd. 1999. New multi-species recirculating bio-filtration systems for onshore farms. http://aquaculturenewzealand.hypermart.net/AquacultureTechnologies-Products.htm

Arulampalam, P., F.M. Yusoff, M. Shariff, A.T. Law, and P.S. Srinivasa Rao. 1998. Water quality and bacterial populations in a tropical marine cage culture farm. Aquacul. Res*.* 29:617-624.

Aure, J., and A. Stigebrandt. 1990. Quantitative estimates of eutrophication effecgts on fjords of fish farming. Aquaculture 90:135-156.

Babaran, R.P., R.A. Espinosa, and T.U. Abalos. 1998. Initiating and triggering mechanisms causing harmful algal blooms. J. Shell. Res*.* 17(5):1623-1626.

Barton, J.R. 1997. Environment, sustainability and regulation in commercial aquaculture: The case of Chilean salmonid production. Geoforum 28(3/4):313-328.

Bates, S.S., A.S.W. de Freitas, J.E. Milley, R. Pocklington, M.A. Quilliam, J.C. Smith, and J. Worms. 1991. Controls on domoic acid production by the diatom *Nitzschia pungens* f. *multiseries* in culture: nutrients and irradiance. Can. J. Fish. Aquat. Sci*.* 48:1136-1144.

BCEAO. See British Columbia Environmental Assessment Office.

BC Salmon Farmer's Association. 1998. http://www.bcsamonfarms.bc.ca/network/network.html

Berg, H., P. Michélson, M. Troell, C. Folke, and N. Kautsky. 1996. Managing aquaculture for sustainability in tropical Lake Kariba, Zimbabwe. Ecol. Econ. 18:141-159.

Beveridge, M.C.M., L.G. Lindsay, and A.L. Kelly. 1994. Aquaculture and biodiversity. Ambio. 23:497-502.

Black, E. 1993. Fish farms as the initiator of algae blooms. Fish Aquaculture Interactions Bullpen, Audience Notes. Ministry of Agriculture, Fisheries and Food. Victoria; 2pp.

Blackburn, T.H., and N.D. Blackburn. 1992. Model of nitrification and denitrification in marine sediments. FEMS Microbiol. Lett*.* 100:517-522.

Brenton, C. (ed.). 1999. The Aquatas Story. *In:* Fish Tale Press, No. 12, Future SEA Technologies, October. Nanaimo, BC.

Brenton, C. (ed.). 2000. Fresh water lensing in Alaska. *In:* Fish Tale Press, No. 13, Future SEA Technologies, January. Nanaimo, BC.

British Columbia Environmental Assessment Office. 1997a. The Salmon Aquaculture Review Final Report. Volume 1: Environmental Assessment Office. BCEAO. http://www.eao.gov.bc.ca/PROJECT/AQUACULT/SALMON/report

British Columbia Environmental Assessment Office. 1997b. The Salmon Aquaculture Review Final Report. Volume 2: First Nations Perspectives. http://www.eao.gov.bc.ca/PROJECT/AQUACULT/SALMON/report

British Columbia Environmental Assessment Office. 1997c. Salmon Aquaculture Review Final Report. Volume 3: Technical Advisory Team Discussion Papers. Part A: Summary of Technical Advisory Team Recommendations. http://www.eao.gov.bc.ca/PROJECT/AQUACULT/SALMON/report

British Columbia Environmental Assessment Office. 1997d. Salmon Aquaculture Review Final Report. Summary Report and Consolidated List of Recommendations. http://www.eao.gov.bc.ca/PROJECT/AQUACULT/SALMON/report

British Columbia Environmental Assessment Office. 1997e. Salmon Aquaculture Review Final Report. Report to the Provincial Environmental Assessment Review of Salmon Aquaculture in British Columbia. Response to Technical Advisory Team Papers. Fisheries and Oceans Canada. http://www.eao.gov.bc.ca/PROJECT/AQUACULT/SALMON/report

British Columbia Environmental Assessment Office. 1997f. Salmon Aquaculture Review. Volume 4 – Part D. Overview of Existing and developing technologies for commercial salmon culture. Prepared for the EAO by Kent Gustavson, Gustavson Ecological Resource Consulting, Victoria, B.C. Fisheries and Oceans Canada. http://www.eao.gov.bc.ca/PROJECT/AQUACULT/SALMON/report/v4d_toc.htm

Brown, J.J., and E.P. Glenn. 1999. Reuse of highly saline aquaculture effluent to irrigate a potential forage halophyte, *Suaeda esteroa*. Aquac. Eng. 20:91-111.

Burkholder, J.M., and H.B. Glasgow, Jr. 1997. *Pfiesteria piscicida* and other Pfiesteria-like dinoflagellates: behavior, impacts and environmental controls. Limnol and Oceanogr. 42:1052-1075.

Burkholder, J.M. 1998. Implications of harmful microalgae and heterotrophic dinoflagellates in management of sustainable marine fisheries. Ecol. Appl. 8(1):537-562.

Carlsson, P., E. Granéli, and P. Olsson. 1990. Grazer elimination through poisoning: one of the mechanisms behind *Chrysochromulina polylepis* bloom. *In:* E. Granéli, B. Sundström, and D. Andersson (eds.). Toxic Marine Phytoplankton. Elsevier Science Publishing Co. New York; pp. 116-122.

Chen, S. 1998. Aquacultural Waste Management. Aquaculture Magazine:63-69.

Chen, Y.-S., M.C.M. Beveridge, and T.C. Telfer. 1999. Short Communication: Settling rate characteristics and nutrient content of the faeces of Atlantic salmon, *Salmo salar* L., and the implications for modelling of solid waste dispersion. Aquaculture Research 30:395-398.

Chopin, T., Y. Charles, R. Wilkes, E. Belyea, S. Lu, and A. Mathieson. 1999. Developing Porphyra/salmon integrated aquaculture for bioremediation and diversification of the aquaculture industry. J. Appl. Phycol. 11:463-472.

Clarke, C. (ed.). 1997. Coho growth test in SEA System™ bag in Departure Bay. Aquaculture Update # 79. Department of Fisheries and Oceans, Aquaculture Division, Pacific Biological Station. Nanaimo, BC.

Clarke, C. (ed.). 1998b. Harvest quality of coho salmon raised in SEA System™. Aquaculture Update # 84. Department of Fisheries and Oceans, Aquaculture Division, Pacific Biological Station. Nanaimo, BC.

Clarke, C. (ed.). 1998a. Seawater growth of Atlantic salmon in SEA System™ floating bag. Aquaculture Update # 81. Department of Fisheries and Oceans, Aquaculture Division, Pacific Biological Station. Nanaimo, BC.

Clarke, C. (ed.). 1999. Observations on sea lice in a SEA System™ floating bag and a conventional netpen. Aquaculture Update # 86. Department of Fisheries and Oceans, Aquaculture Division, Pacific Biological Station. Nanaimo, BC.

Communications New Brunswick. 2000. New government structure meets 21st century priorities. Online News Release NB 237, March 23. http://www.gov.nb.ca/cnb/news/pre/2000e0237pr.htm.

CONAMA. 2000a. General Environment Law Number 19,300. http://conama.cl/version_ingles/ins_framework/law_19300/.

CONAMA 2000b. Provisions of the Environmental Impact Assessment System and Community Participation under General Environment Law Number 19,300. http://www.conama.cl/seia/

Coopers & Lybrand. 1997. Economic impacts of the British Columbia salmon farming industry. Prepared for the BC Salmon Farmers Association.

Cripps, S.J. 1994. Minimizing outputs: treatment. J. Appl. Ichthyol. 10:284-294.

DFA (New Brunswick Department of Fisheries and Aquaculture). 1999a. 1998-1999 Annual Report. Fredericton, NB. 49 pp.

DFA. 1999b (Draft). Environmental Monitoring Program. Fredericton; 8 pp.

DFA. 1999c (Draft). Bay of Fundy salmon aquaculture environmental remediation guide. Fredericton; 8 pp.

DFA. 2000. New Brunswick fisheries and aquaculture industry profile and statistics. http://www.gov.nb.ca/dfa/profilee.htm

DFAIT (Canadian Department of Foreign Affairs and International Trade). 2000. Market Opportunities, Chile and the Environment. http://strategis.ic.gc.ca/SSG/ea01747e.html

Drum, A.S., T.L. Siebens, E.A. Crecelius, and R.A. Elston. 1993. Domoic acid in the Pacific razor clam *Silqua patula* (Dixon 1789). J. Shellfish Res. 12:443-450.

Ebeling, J. 1998. Computer monitoring and control technology, part II: putting it together. *Aquacul. Mag*. November/December, pp. 80-87.

Ebeling, J., G. Jensen, T. Losardo, M. Masser, J. McMullen, L. Pfeiffer, J. Rakocy, and M. Sette. 1995. Model Aquaculture Recirculation System (MARS). Engineering and operations manual. Aquaculture Education Project, National Council for Agricultural Education. Alexandria, Virginia.

Ehman, K. 1998. Cape Breton firm swings into operation. Atlantic Fish Farming 11(9):9.

Enander, M. and M. Hasselström. 1994. An experimental wastewater treatment system for a shrimp farm. INFOFISH Int. 4/94:56-61.

EPA (US Environmental Protection Agency). 1999. Effluent guidelines plan update and notice of public meeting. http://www.epa.gov/reg3wapd/pretreatment/pdfs_txt/effplan.txt

EPA. 2000. Internet site, various links. http://www.epa.gov

Evardsen, B., F. Moy, and E. Paasche. 1990.Hemolytic activity in extracts of Chrysochromulina polylepis grown at different levels of selenite and phosphate. *In:* E. Graneli, B. Sundstrom, L. Edler, and D.M. Anderson (eds.). Toxic marine phytoplankton. Elsevier. New York; pp. 284-289

Epstein, P.R., T.E. Ford, and R.R. Colwell. 1994. Marine ecosystems. *In:* Health and climate change. Lancet, special issue, pp.14-17.

FAO. 1997. Aquaculture production statistics 1985-1995. FAO Fisheries Circular No. 815, Revision 9. Rome.

Flores-Nava, A. 1995. Some conclusions on sustainable shrimp mariculture. Jaina 6:8.

Folke, C., N. Kautsky, and M. Troell. 1997. Salmon farming in context: response to Black *et al*. J. Environ. Manage. 50:95-103.

Fundación Chile. 2000. Compendio y directorio de la acuicultura y la pesca de Chile. Aqua Noticias 2000; TechnoPress S.A. Santiago.

Garrison, S., M. Conrad, P.P. Eilers, and E.M. Waldron. 1992. Confirmation of domoic acid production by *Pseudonitzschia australis* (Bacillariophyceae) cultures. J. Phycol. 28:604-607.

Glenn, E.P., J.W. O'Leary, M.C. Watson, T.L. Thomas, and R.O. Kuehl. 1991. *Salicornia bigelovii* Torr: an oilseed halphyte for seawater irrigation. Science 251:1065-1067.

Glenn, E.P., R.S. Swingle, J.J. Riley, and V.R. Squires. 1994. North American halophytes grown with seawater in the Sonoran Desert. J. Arid. Environ. 9:81-91.

Glenn, E.P., R. Pfister, J..J. Brown, T.L. Thompson, and J. O'Leary. 1996. Na and K accumulation and salt tolerance of *Atriplex canascens* (Chenopodiaceae) genotypes. Am. J. Botony 83(8):997-1005.

Glenn, E.P., S. Miyamoto, D. Moore, J.J. Brown, T.L. Thompson, and P. Brown. 1997. Water requirements for cultivating *Salicornia bigelovii* Torr. with seawater on sand in a coastal desert environment. J. Arid Environ. 36:711-730.

Goldburg, R., and T. Triplett. 1997. Murky Waters; Environmental Effects of Aquaculture in the United States. The Environmental Defense Fund. Washington, DC. 198 pp. http://www.edf.org/pubs/Reports/Aquaculture/index.html.

Goldman, R.J., K. Tenore, and H. Stanley. 1973. Inorganic nitrogen removal from wastewater: effect on phytoplankton growth in coastal marine waters. Science 180:955-956.

Gormican, S.J. 1989. Water circulation, dissolved oxygen and ammonia concentrations in fish net-cages. M.Sc. thesis, University of British Columbia. Vancouver, BC.

Government of New Brunswick. 1988. Chapter A-9.2. Aquaculture Act. Consolidated to December 31, 1996. http://www.gov.nb.ca/justice/acts/acts/a%2D09%2D2.html

Government of New Brunswick. 1991. New Brunswick Regulation 91-158 under the Aquaculture Act (O.C. 91-806. Consolidated to March 31, 2000. http://www.gov.nb.ca/justice/regs/91%2D158.htm

Gowen, R. 1990. An assessment of the impact of fish farming on the water column and sediment ecosystems of Irish coastal waters. Prepared for the Dept. of the Marine, Dublin. Natural Environemnt Research Council, Dunstaffnage Marine Laboratory. Argyll, UK; 75 pp.

Gowen, R.J., and N.B. Bradbury. 1987. The ecological impact of salmonid farming in coastal waters: a review. Oceanogr. Mar. Biol. Ann. Rev. 25:563-575.

Gowen, R.J., J. Brown, N. Bradbury, and D.S. McLuskey. 1988. Investigations into benthic enrichment, hypernutrification and eutrophication associated with mariculture in Scottish coastal waters (1984-1988). Report to Scottish Highlands and Islands Development Board. 157pp.

Gowen, R.J., D.P. Weston, and A. Ervik. 1991. Aquaculture and the benthic environment. *In*: C.B. Cowey and C.Y. Cho (eds.). Nutritional strategies and aquaculture waste. University of Guelph. Guelph, Ontario; pp. 187-205.

Haglund, K., and M. Pedersén. 1993. Outdoor pond cultivation of the subtropical marine red alga *Gracilaria tenuistipitata* in brackish water in Sweden. Growth, nutrient uptake, co-cultivation with rainbow trout and epiphyte control. J. Appl. Phycol. 5:271-284.

Haigh, R., F.J.R. Taylor, and T.F. Sutherland. 1992. Phytoplankton ecology of Sechelt Inlet, a fjord system on the British Columbia coast. I. General features of the nano- and microplankton. Mar. Ecol. Prog. Ser. 89:117-134.

Haines, K.C. 1975. Growth of the carrageenan-producing tropical red seaweed *Hypnea musciformis* in surface water, 870 m deep water effluent from a clam mariculture system, and in deep water enriched with artificial fertilizers or domestic sewage. *In*: G. Persson and E. Jaspers (eds.). Proc. 10th Eur. Symp. Mar. Biol., Ostend, Belgium, Sept. 17-23, Universa Press. Wetteren; Vol. 1:207-220.

Hall, P.O.J., O.Holby, S.Kollberg, and M.O. Samuelsson. 1992. Chemical fluxes and mass balances in a marine fish cage farm. IV. Nitrogen. Mar. Ecol. Progr. Ser. 89:81-91.

Hallengraeff, G.M. 1993. A review of harmful algal blooms and their apparent global increase. Phycologia 32:79-99.

Hansen, P.K., A. Ervic, J. Aure, P. Johannessen, T. Jahnsen, A. Stigebrandt, and M. Schaanning. 1997. MOM (Modelling-Ongrowing Fish Farms-Monitoring), Concept and revised edition of monitoring programme. Havforskningsinstituttet (Institute of Marine Research), Norway. 51 pp.

Hardy, R.W., and others. 1995. Domoic acid in rainbow trout (*Onchorhynchus mykiss*) feeds. Aquaculture 131:253-260.

Hargrave, B.T. 1994. Preface. *In:* B. T. Hargrave (ed.). Modeling Benthic Impact of Organic Enrichment from Marine Aquaculture. Canadian Technical Report of Fisheries and Aquatic Sciences 1949. Department of Fisheries and Oceans, Bedford Institute of Oceanography, Nova Scotia. pp. vi-x.

Hatt, J. 1999. New bag system put to test in Arichat, NS. Northern Aquaculture 5(1).

He, X., T. Peng, S. Liu, J. Huang, Z. He, Q. Hu, and L. Huang. 1990. Studies on the elilmination of stress factors in *Peneaus* diseases. Trop. Oceanol./Redai Haiyang 9:61-67 (Chinese with English abstract).

Heinen, J.M., J.A. Hankins, and P.R. Adler. 1996. Water quality and waste production in a recirculating trout-culture system with feeding of a higher-energy or a lower-energy diet. Aquacul. Res. 27:699-710.

Henderson, A., and I.M. Davies. 2000 (Draft). Review of aquaculture, its regulation and monitoring in Scotland. Scottish Environment Protection Agency West (Glasgow) and Fisheries Research Services Marine Laboratory (Aberdeen). 22 pp.

Hershberger, P.K., J.E. Rensel, A.L. Matter, and F.B. Taub. 1997. Vertical distribution of the chloromonad flagellate *Heterosigma carterae* in columns: implications for bloom development. Can. J. Fish. Aquat. Sci. 54:2228-2234.

Holby, O., and P.O.J. Hall. 1991. Chemical fluxes and mass balance in a marine fish cage farm II: Phosphorus. Mar. Ecol. Prog. Series 70:263-272.

Horner, R.A., L. Hanson, C.L. Hatfield, and J.A. Newton. 1996. Domoic acid in Hood Canal, Washington, USA. *In:* Harmful and toxic algal blooms. Proc. 7th Int. Conf. on Toxic Phytoplankton. Intergov. Oceanogr. Comm. UNESCO; pp.127-130.

Horner, R.A., D.L. Garrison, and F.G. Plumley. 1997.Harmful algal blooms and red tide problems on the US west coast. Limnol. and Oceanogr. 42:1076-1088.

Iwama, G.K., and A.F. Tautz. 1981. A simple growth model for salmonids in hatcheries. Can. J. Fish. Aquat. *Sci.* 38:649-656.

Iwama, G.K. 1991. Interactions between aquaculture and the environment, critical reviews in environmental control 21 (2):177-216.

Iwama, G.K. 1996. Growth of salmonids. *In:* W. Pennel and B.A. Barton (eds.). Developments in aquaculture and fisheries science 29: Principles of salmonid culture. Elsevier. Amsterdam; pp. 467-515.

Kaartvedt, S., T.M. Johnsen, D.L. Aksnes, U. Lie, and H. Svensdsen. 1991. Occurrence of the toxic phytoflagellate *Prymesium parvum* and associated fish mortality in a Norwegian fjord systaem. Can. J. Fish. Aquat. Sci. 48:2316-2323.

Kasper, H.F., G.H. Hall, and A.J. Holland. 1988. Effects of sea cage salmon farming on sediment nitrification and dissimilatory nitrate reductions. Aquaculture 70:333-344.

Kautsky, N., H. Berg, A. Buschmann, C. Folke, and M. Troell. 1996. Ecological footprint, resource use and limitations to aquaculture development. IX Congreso Latinoamericano de Acuicultura, Book of Abstracts: 193.

Kautsky, N., M. Troell, and C. Folke. 1997a. Ecological engineering for increased production and environmental improvement in open sea aquaculture. *In:* Etnier, C., and B. Guterstam (eds.). Ecological Engineering for Waste Water Treatment. Lewis Publishers. Chelsea; pp. 387-393.

Kautsky, N., C. Folke, H. Berg, A. Jansson, and M. Troell. 1997b. The ecological footprint concept for sustainable seafood production: a review. Ecol. Apps. 8:S63-S71.

Khan, S., O. Arakawa, and Y. Onoue. 1997. Neurotoxins in a toxic red tide of *Heterosigma akashiwo* (Raphidophyceae) in Kagoshima Bay, Japan. Aquacul. Res. 28:9-14.

Korman, J. 1989. Enriching effects of salmon farms in B.C. coastal waters. M.Sc. thesis, University of BC. Vancouver; 94 pp.

Kupka-Hansen, P., K. Pittman, and A. Ervik. 1991. Organic waste from marine fish farms – effect on the seabed. Mar. Aquacult. Env. Nord. 22:105-119.

Lift-UP-Akva Ltd. undated. Lift-UP fish feed and dead fish collection systems. Internet site visited 2000-05-24. http://www.havbruk.no/lift-up/index.html

Lin, C.K., P. Ruamthaveesub, P. Wanuchsoontorn, and C. Pokaphand. 1992. Integrated culture of green mussel (*Perna viridis*) and marine shrimps (*Penaeus monodon*). Book of abstracts and schedule, Aquaculture '92, 21-25 May. Orlando, FL.

Løland, G. 1993. Current forces on, and water flow through and around, floating fish farms. Aquacult. Int. 1: 72-89.

Losordo, T.M., M.P. Masser, and J.E. Rakocy. 1998. Recirculating aquaculture tank production systems, an overview of critical considerations. Southern Regional Aquaculture Center. SRAC Publ. No. 451.

Losordo, T.M., M.P. Masser, and J.E. Rakocy. 1999. Recirculating aquaculture tank production systems, a review of component options. Southern Regional Aquaculture Center. SRAC Publication No. 453.

Marvin Shaffer & Associates Ltd., Pierce Lefebvre Consulting, Will McKay & Co. Ltd., and G. Holman. 1997. Socio-economic impacts of existing salmon farming operations in British Columbia. Prepared for BCEAO. 43 pp. http://www.eao.gov.bc.ca/project/aquacult/salmon /socioeco.htm

Maryland Department of Agriculture and National Association of State Aquaculture Coordinators. 1995. State/territory permits and regulations impacting the aquaculture industry. http://www.isodata.com/aquaciti/govt/permits.htm

Masser, M. P., J. Rakocy, and T.M. Losordo. 1999. Recirculating aquaculture tank production systems, management of recirculating systems. Southern Regional Aquaculture Center, SRAC Publication No. 452.

Menasveta, P. 1997. Intensive and efficient shrimp culture system, the Thai way, can save mangroves. Aquacult. Asia 2:72-89.

Minnesota Department of Agriculture and University of Minnesota. 1997. Evaluation of Recirculating Aquaculture Systems. http://www.mda.state.mn.us/DOCS/MKTG/Aquacult/Recirc.htm

Miyamoto, S., E.P. Glenn, and M.W. Olsen. 1996. Growth, water use and salt uptake of four halophytes irrigated with highly saline water. J. Arid Environ. 32:141-159.

Mulholland, M. 1998. Large versus small cage systems – consideration and implications. Mulholland, Lang Consulting Ltd. Canadian Aquaculture. Vancouver; pp. 48-51.

Nature Conservancy Council (NCC). 1990. Fish farming in the Scottish Freshwater Environment. Institute of Aquaculture, University of Stirling. Stirling, UK.

Neori, A., I. Cohen, H. Gordin. 1991. *Ulva lactuca* biofilters for marine fishpond effluent. II Growth rate, yield and C:N ratio. Bot. Mar. 34:483-489.

Neori, A., M.D. Krom, S.P. Ellner, C.E. Boyd, D. Popper, R. Rabinovitch, P.J. Davidson, O. Divr, D. Zuber, M. Ucko, D. Angel, and H. Gordin. 1996. Seaweed biofilters as regulators of water quality in integrated fish-seaweed culture units. Aquaculture 141:183-199.

Nitishitani, L., and K.K. Chew. 1984. Recent developments in paralytic shellfish poisoning research. Aquaculture 39:317-329.

NOAA (US National Oceanic and Atmospheric Administration. 1998. NOAA's aquaculture policy. http://swr.ucsd.edu/fmd/bill/aquapot.htm

Norwegian Seafood Export Council. 2000. Export statistics. http://www.seafood.no.

Northern Aquaculture. 1999. Improved water quality a key to success. October; p. 19.

Northern Aquaculture. 2000. Vancouver company launches by-products venture. N. Aqua online archives. http://www.naqua.com/artjun00.html

ODIN (Official Documentation and Information from Norway). 1996. Aquaculture—a motive force in the Norwegian coastal industry. Norwegian Ministry of Fisheries, Report No. 48 to the Storting. http://odin.dep.no/repub/94-95/stmld/48/eindex.html

Olson, G.L. 1991. The use of trout manure as a fertilizer for Idaho crops. Paper presented at National Livestock, Poultry and Aquaculture Waste Management Workshop, July 29-31, Kansas City, MO.

Overcash, M.R., F.J. Humenik, and J.R. Miner. 1983. Livestock waste management, Vol. II. CRC Press, Inc. 244 pp.

PCHB (State of Washington Pollution Control Hearings Board). 1998a. Order of partial dismissal. http://www.eho.wa.gov/1998%20Archive/PCHB%2086-257%20PARTIAL%20DISMISSAL.htm.

PCHB. 1998b. Final findings of fact, conclusions of law and order. http://www.eho.wa.gov/1998%20Archive/PCHB%2096-257%20Final.htm.

PCHB. 1999. Order granting reconsideration amending final findings of fact, conclusions of law and order. http://www.eho.wa.gov/1999%20Archive/PCHB%2096-257%20RECONSIDERATION.htm

Persson, G. 1988. Relationships between feed, productivity and pollution in the farming of large rainbow trout (*Salmo gairdneri*). Swedish Environmental Protection Agency, PM 3534. Stockholm; 48pp.

Persson, G. 1991. Eutrophication resulting from salmonid fish culture in fresh and salt waters: Scandinavian experiences. *In:* C.B. Cowey and C.T. Cho CY (eds.). Nutritional Strategies and Aquaculture Waste. pp. 163-185.

Phang, S.-M., S. Shahauruddin, H. Noraishah, A. Sasekumar. 1996. Studies on Gracilaria changii (Gracilariales, Rhodophyta) from Malaysian mangroves. Hydrobiologia 326/327:347-352.

Pridmore, R.D., and J.C. Rutherford. 1992. Modeling phytoplankton abundance in a small enclosed bay used for salmon farming. Aquacul. Fish. Manage. 23:525-542.

Primavera, J.H. 1993. A critical review of shrimp pond culture in the Philippines. Rev. Fish. Sci. 1:151-201.

Rees, W.E. 1996. Revisiting carrying capacity: area-based indicators of sustainability. *In*: Population and Environment: a journal of interdisciplinary studies, 17(3), January, 1996. http://dieoff.org/page110.htm.

Robertson, A., and M.J. Phillips. 1995. Mangroves as filters of shrimp pond effluents: predictions and biogeochemical research needs. Hydrobiologia 295:311-321.

Rönnbäck, P. (in press) The ecological basis for economic value of seafood production supported by mangrove ecosystems. Ecol. Econ.

Rönnberg, O. K. Ådjers, C. Roukolahti, and M. Bodestam. 1992. Effects of fish farming on growth, epiphytes and nutrient content of *Fucus vesiculosus* L. in the Åland archipelago, northern Baltic Sea. Aquat. Bot. 42:109-120.

Rosenthal, H. 1994. Aquaculture and the environment. World Aquaculture 25(2):4.

Ruokolahti, C. 1988. Effects of fish farming on growth and chlorophyll a content of *Cladophora*. Mar. Poll. Bull. 19:166-169.

Ryther, J., and W. Dunstan. 1971. Nitrogen, phosphorus and eutrophication in the coastal marine environment. Science 171:1008-1013.

SEPA (Scottish Environmental Protection Agency). 1998. Regulation and monitoring of marine cage fish farming in Scotland – a manual of procedures. http://www.sepa.org.uk/publications/fishfarmmanual/fishfarmmanual.htm

Strombom, D.B., and S.M. Tweed. 1992. Business planning for aquaculture – is it feasible? NRAC Fact Sheet No. 150-1992. Worksheets I-IV. Northeastern Regional Aquacultureal Center Factsheet. http://www.unmassd.edu/specialprograms/nrac/factsheets/fact150a.htlm.

Schmidt, S. 1999. Fish and chips. *In:* The Globe and Mail, Technology Section (Report on Business), November 18.

Singh, S., and F.W. Wheaton. 1999. Ozone application in aquaculture. Aquacul. Mag. Jan./Feb.; pp. 58-63.

Smayda, T.J. 1990. Novel and nuisance phytoplankton blooms in the sea: evidence for a global epidemic. *In:* E. Granéli, B. Sundstrom, L. Edler and D.M. Anderson (eds.). Toxic marine phytoplankton. Elsevier. New York; pp. 29-40.

Steidinger, K.A., and D.G. Baden. 1984. Toxic marine dinoflagellates. *In:* D.L. Spector (ed.). Dinoflagellates, Academic, Orlando, Florida; pp. 1-28.

Storey, R., N. Ahmad, and R.G. Wyn Jones. 1977. Taxonomic and ecological aspect of the distriution of glycine betadine and related compounds in plants. Oecologia 27:319-333.

Swingle, R.S., E.P. Glenn, and V.R. Squires. 1996. Growth performance of lambs fed mixed diets containing halophyte ingredients. Anim. Feed Sci. Technol. 63:137-148.

Taylor, F.J.R. 1968. Parasitism of the toxin-producing dinoflagellate *Gonyaulax catenella* by the endoparasitic dinoflagellate *Amoebophrya ceratii*. J. Fish. Res. Bd. Can. 25:2241-2245.

Taylor, F.J.R. 1990. Red tides, brown tides and other harmful algal blooms: the view into the 1990s. *In:* Toxic marine phytoplankton: Proc. 4th Int. Conf. Elsevier; pp. 527-533.

Taylor, F.J.R. 1993. Current problems with harmful phytoplankton blooms in British Columbia waters. *In:* T.J. Smayda and Y. Shimizu (eds). Toxic Phytoplankton Blooms in the Sea. Elsevier; pp. 699-703.

Taylor, F.J.R., and R. Haigh. 1993. The ecology of fish-killing blooms of the chloromonad flagellate *Heterosigma* in the Strait of Georgia, Puget Sound and Juan de Fuca Strait. Can. Fish. Aquat. Sci. Tech. Rep. 1948.

Taylor, F.J.R., and R.A. Horner.1994. Red tides and other problems with harmful algal blooms in Pacific Northwest coastal waters. *In:* review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait. Can. Fish. Aquat. Sci. Tech. Rep. 1948:175-186.

Taylor, F.J.R., R. Haigh, and T.F. Sutherland. 1994. Phytoplankton ecology of Sechelt Inlet, a fjord system on the British Columbia coast. II. Potentially harmful species. Mar. Ecol. Prog. Ser. 103:151-164.

Troell, M. 1996. Intensive fish farming: impacts, resource demands, and increased sustainability through integration. PhD. thesis, Stockholm University, Stockholm. 148 pp.

Troell, M. and J. Norberg. 1998. Modeling output and retention of suspended solids in an integrated salmon mussel culture. Ecol. Modeling 110:65-77.

Troell, M., P. Rönnbäck, C. Halling, N. Kautsky, and A. Buschmann. 1999a. Ecological engineering in aquaculture: use of seaweeds for removing nutrients from intensive mariculture. J. Appl. Phycol. 11:89-97.

Troell, M., N. Kautsky, and C. Folke. 1999b. Comment: Applicability of integrated coastal aquaculture system. Ocean Coast. Manage*.* 42:63-69.

Turner, J., and P.A. Tester. 1997. Toxic marine phytoplankton, zooplankton grazers, and pelagic food webs. Limnol and Oceanogr 42(5, part 2):1203-1214.

US Fish and Wildlife Service. 1995. 715 FW1, Policies and responsibilities. http://www.fws.gov/directives/715fw1.html

Vandermeulen, H., and H. Gordin. 1990. Ammonium uptake using *Ulva* (Chlorophyceae) in intensive fishpond systems: mass culture and treatment of effluent. J. app. Phycol*.* 2:263-374.

Wackernagel, M., and W. Rees. 1995. Our ecological footprint: reducing human impact on the earth. New Society Publishers. Gabriola Island, BC.

Walz, P.M., and others. 1994. Domoic acid producing diatom blooms in Monterey Bay, California: 1991-1993. Nat. Toxins 2:271-279.

Washburn and Gillis Associates. 1995. Environmental management plan for the marine finfish aquaculture industry in the Bay of Fundy. Final Report. Fredericton, NB.

Washington Department of Ecology. 1998. Environmental permits. http://www.wa.gov/ecology/sea/pac/handbook/high/introf/html

Washington Department of Fish and Wildlife (WDFW). 1990. Fish culture in floating netpens - a final programmatic environmental impact statement. Olympia, Washington.

Watanabe, M., K. Kohata, and M. Kunugi. 1988. Phosphate accumulation and metabolism by *Heterosigma akashiwo* (Raphidophyceae) during diel vertical migration in a stratified microcosm. J. Phycol. 24:22-28.

Whyte, J.N.C. 1997. Impacts of harmful algae on the west-coast aquaculture industry and a national research plan by the Phycotoxins Working Group of Fisheries and Oceans Canada to address such issues. Bull. Aquacul. Assoc. Can*.* 3:19-25.

Whyte, J.N.C., N.G. Ginther, and L.J. Keddy. 1998. *Heterosigma carterae*, a major killer of pen-reared salmon in British Columbia. DFO, Pacific Biological Station. Nanaimo, BC.

Wildish, D.J., H.M. Akagi, N. Hamilton, and B.T. Hargrave. 1999. A recommended method for monitoring sediments to detect organic enrichment from mariculture in the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. Ottawa; 31pp.

Winsby, M., B. Sander, D. Archibald, M. Daykin, P. Nix, F.J.R. Taylor, and D. Munday. 1996. The environmental effects of salmon netcage culture in British Columbia. A literature review. Prepared by Hatfield Consultants Ltd. (West Vancouver) and EVS Environmental Consultants (North Vancouver) for BC Ministry of Environment, Lands and Parks.

Wong, K.B., and R.H. Piedrahita. 2000. Settling velocity characterization of aquacultural solids. Aquacul. Eng. 21:233-246.

Work, T.M., and others. 1993. Domoic acid intoxication of brown pelicans and cormorants in Santa Cruz, California. *In:* Toxic phytoplankton blooms in the sea. Proc. 5th Int. Conf. On Toxic Phytoplankton. Elsevier; pp. 643-649.

PERSONAL COMMUNICATIONS

Andrew, Phil. Director of Marketing and Sales, Future SEA Technologies. E-mails and telephone conversations, June/July 2000.

Angus, Gus. Proprietor, Totem Oysters, Sechelt, BC. Telephone conversations, June, 2000.

Brenton, Clayton. Special Projects Manager and editor of Fish Tale Press, Future SEA Technologies, meetings and telephone conversations, March-June, 2000.

Carington Smith, Owen. Managing Director, Aquatas, Tasmania. E-mail, 07/09/2000.

Cards Aquaculture Products, Nanaimo, BC. Telephone conversations, June, 2000.

Cloud, Greg. Washington Department of Ecology. via E-mail, April 24, 2000.

Dubreuil, Michel. Account Manager, Future SEA Technologies. E-mails and telephone conversations, June 2000.

Janowicz, Marianne. New Brunswick Department of Fisheries and Aquaculture; Member of the Aquaculture Waste Management Committee. via E-mail, May 18, 2000.

Johansen, Halvard P. Fisheries Counselor, Royal Norwegian Embassy, Washington, DC. Letter, via facsimile, May 5, 2000.

Lafreniere, Serge, Proprietor, Scotia Rainbow Inc., Nova Scotia. Telephone conversations and e-mails, May 2000.

Pennel, Bill. Aquaculture Program Coordinator, Malaspina College, Nanaimo, BC. E-mails and telephone conversations, June/July 2000.

Shanks, Greg. New Brunswick Department of Environment. Telephone conversation May 23, 2000.

Soares, Manny. Seafood Section Chief, Alaska Department of Environmental Conservation. via E-mail, April 17, 2000.

Sweeney, Bob. Cooke Aquaculture Inc., St. George, New Brunswick; Chairman, Aquaculture Waste Management Committee. Telephone conversation May 12, 2000 and materials via facsimile, May 18, 2000.

Taylor, F.J.R. (Max). Professor of Botany/Earth & Ocean Sciences, University of British Columbia. Telephone conversation, May 2000.

van Rensburg, Johann. President & CEO of Future SEA Technologies. Telephone conversation, June 1, 2000.

Appendices

Appendix 1: Business Planning Reports (NRAC Fact Sheets)

Appendix 2: Future SEA Technologies Costs of Production

- Summary of Enclosed System vs. Caged System
- Weekly COP of Enclosed System
  (including environmental information) vs. Caged System

Appendix 3: Costs of Freshwater Aquaculture Industry
(Alberta Ministry of Agriculture, Food and Rural Development)

Appendix 4: Cost-Benefit of Recirculating Systems

Appendix 1:

Business Planning Reports (NRAC Fact Sheets)

Business Planning For Aquaculture - Is It Feasible?

Dan B. Strombom, Rutgers Cooperative Extension of Cape May County
Stewart M. Tweed, New Jersey Sea Grant Marine Advisory Service

NRAC Fact Sheet No. 150- 1992

Introduction

You have read newspaper or magazine articles persuasively claim that aquaculture has a bright future. The technology, growth process, challenges and potential rewards are exciting. At the same time, however, remember that aquaculture is a demanding and relatively risky business. So, before you take one more step, sign the Aquaculture Business Planning Pledge:

> I solemnly swear to assess thoroughly and honestly the complete organization of my aquaculture enterprise and write it down as a business plan.

____ (Signature, Date)

Inadequate preparation of a business plan will hurt in two very fundamental ways. First, starting in aquaculture without a good business plan will result in mistakes which could have been anticipated and solved on paper. A written business plan exposes thoughts, assumptions and research findings to reason. Can it really work? What resources do I need now and in the future? Only by writing down the answers to these and other questions can you minimize the risks.

Second, without a business plan, finance sources will be limited to those few who have unquestioning faith in you. Investors, public or private, will insist on seeing exactly why they should back you. Despite arguments about the grand potential of aquaculture, you must show in detail how invested money will be used and return a satisfactory profit to investors. You will be competing with many other projects and aquaculture is not familiar to many investors. A demonstration that your enterprise is founded on solid reasoning is an important advantage.

Writing a business plan is not easy. Expect to devote months, not weeks, of disciplined effort. Short-circuiting the steps required, by taking a cookbook approach or by being incomplete, will only reduce chances for success. There will be frustration, but the experience can be extremely rewarding. The business plan is your future on paper, and a mechanism for testing dreams against expected challenges and opportunities.

The numerous facts and figures needed to complete a business plan can be confusing unless you are organized. This fact sheet provides a structured planning process. It identifies information essential to develop a realistic description of the proposed venture.

There are many ways aquaculture can be practiced and each individual will face different challenges. This fact sheet is meant to be generally applicable. You must explore the full implications of the questions to obtain the information your plan will require. Additional questions specific to your enterprise will emerge. Completion of this fact sheet will provide a good sense of how to pursue a successful aquaculture venture and a formal business plan.

A Suggested Approach

As you contemplate, develop, and finalize your responses to the questions below, try to maintain a dialogue with yourself. The purpose is to convince yourself that your goal is reasonable and achievable. If you do not believe in your venture, do not expect others to back you.

To assess progress, regularly challenge yourself. Is this true? What are the alternatives? Is this consistent with other decisions?

Accept what others assert only after thorough examination. What are their credentials? Can someone verify this? Be critical and you will be well prepared.

BASIC STRUCTURE

It has been said that farmers must possess more skills than should be reasonably expected of anyone. This is also true for aquaculturists! You will repair equipment, process and market products, keep books, hire and fire, arrange financing, and carefully watch over stocks of fish or shellfish, to name just a few tasks. All of these responsibilities are overshadowed by three fundamental concerns:

1. Who will buy the product?
2. How will you produce the product?
3. Will revenues adequately exceed costs?

This fact sheet has sections devoted to these concerns, each accompanied by a pull-out worksheet. Make several photocopies of the pull-outs so that answers can be modified as you gain insight. Save a blank copy for the final draft.

SOURCES OF INFORMATION

Perhaps the best sources of information are extension professionals. They are trained to disseminate aquaculture information effectively and have close contacts with industry, university researchers and government regulatory agencies. A few states also maintain government offices to assist aquaculturists.

National, regional and state aquaculture associations exist. Consider becoming an active member to one or more. Visit several aquaculture operations similar to the venture you are contemplating to get a feel for day-to-day operations. Stay abreast of the industry by subscribing to aquaculture magazines or newsletters.

Professional associations and firms affiliated with aquaculture, such as equipment suppliers and restaurant owners, can be excellent sources of information on business trends, current costs and market data.

Finally, visit local chambers of commerce, economic development offices, planning boards, and banks for information on economic development programs and zoning.

SECTION I: EXPECTATIONS

Every business owner wants success, but everyone has a unique definition of success resulting from individual experiences, prospects, and goals. Only you can decide what is to be achieved by your aquaculture venture.

It is useful to establish expectations before developing a plan. This helps to avoid the natural, stubborn tendency to forge ahead even though major undesirable compromises will result.

A clear understanding of your enterprise goals will guide decisions throughout the planning process. For example, an aquaculture business meant to generate an annual income of $40,000 will be different from one expected to yield $140,000 per year.

Besides ensuring that expectations accurately reflect needs, be forthright in assessing how long you are able to wait for rewards. Aquaculture production cycles are longer than in other types of businesses. It will take months, and in most cases several years, before revenues are generated.

SECTION II: MARKETING

All investments made in your aquaculture enterprise - dollars, time, and personal energy - will go down the drain if you cannot find and keep customers. Finding customers requires analyzing potential markets to determine who is willing and able to pay for the product(s). This is the objective of the marketing worksheet.

Market Analysis

A. Determine Market Area

A practical way to analyze potential markets is to define a serviceable geographic area. Whether you are delivering a product or expect to attract customers as in a fee fishing operation, travel distance and time are major considerations.

A one-person operation, for example, might be hard-pressed to allocate even a couple of hours per day for deliveries. An enterprise with a partner or employee responsible for deliveries could market to a wider area. A rule of thumb derived from farm markets is that the majority of customers for on-site sales will come from a ten-mile radius of your location.

B. Identify Market Segments

Within a market area there will be different types of customers. You must determine if there are enough potential buyers of your product to support your business.

The principal customer types ("market segments") for aquaculture products are: wholesalers, restaurants, seafood stores, supermarkets, and consumers buying directly. Other customer types might include sports fishermen at fee fishing operations, institutional buyers, pet stores for ornamental fish, and bait dealers. You must determine which segment(s) you are going to serve.

C. Research Buyers' Needs

Fish and shellfish markets are dynamic; seasonal variability and industry trends are important considerations that affect buyer's needs and expectations. Each market segment has its own buying patterns, based on quantities purchased, product forms, price, and delivery. Talk to as many different buyers as possible to obtain a representative picture of their needs.

Some aquaculture products have well-established markets while others face uncertain markets. A visit to a seafood wholesaler will yield more useful information on oysters than on tilapia.

If the required information is not available from your market area, two alternative approaches can be helpful. First, talk to aquaculturists and buyers in regions where the product is being sold. Second, identify a substitute product which is sold locally and inquire about its market. For example, if you want to market tilapia, a substitute fish for calculations might be flounder because both are mild-flavored, white-fleshed, and relatively expensive.

D. Estimate Area Market Potential

After obtaining a picture of buyer's needs, market potential can be estimated by extrapolating information to the number of buyers within your area. Chambers of commerce, yellow pages of the phone directory, or local economic development offices can be useful sources of business and consumer census data that can help to identify and describe a market.

E. Conclusions

Market analysis may show that your plan has promise - there are enough potential customers - or that the plan will not work. Perhaps you intended to sell whole fish to restaurants and seafood retailers, but found that they want headed and gutted fish. This means more labor and waste disposal, but, possibly, a higher price per pound. You can adjust the plan or scrap it - either way, you have avoided an expensive mistake.

SECTION III: PRODUCTION FEASIBILITY

After determining the practical and market feasibility of your operation, you should examine its production feasibility. The critical question is: "can I efficiently and economically produce my proposed aquaculture product?"

Many approaches are used to select a culture species. A species may be chosen because it is in short supply, a lucrative market exists, or it is easily cultured. Successful production requires as much knowledge as possible about its biological and production requirements.

After considering the culture species and systems, you may determine that permitting, construction, seed and feeding costs at your site will exceed the potential production income. This information will save you money, time, and frustration. This section and accompanying worksheet will help identify problems that limit operational success.

Getting Started

The first step in developing a successful aquaculture production facility is to obtain and critically evaluate the scientific information on the chosen species. Information sources have been discussed in the introduction to this publication.

A personal assessment of your contributions to the project is the basis for identifying needs. What land, facilities, equipment, training, etc. do you possess? The more tools and experience that you bring to the project the greater the chance of success.

Each species has an unique set of biological factors that influence its culture potential. Water quality, predation, and disease problems should be anticipated, but growth variations, food conversion rates and other factors can make or break an operation. Considerable technical information is available from extension specialists and published materials.

Carefully consider site selection. Site selection can be a major determinant of culture success and production costs. Preparing or modifying a site to meet your needs can be a costly undertaking. Federal and State regulations, and local regulations or customs may also be limiting factors at a proposed location.

Fixed and Variable Costs

Business managers often distinguish between fixed costs and variable costs of production. Fixed costs are associated with those inputs which do not change over the short run, such as salaries, overhead, insurance and depreciation (capital expenses). Variable costs are dependent on level of production and will change as you increase or decrease your stock. They include juveniles, feed, chemicals, labor, electricity, etc. Operational expenses and potential profitability for alternative culture systems and scales of operation can be calculated by examining these two kinds of costs.

Inputs

Stock (seed, fingerlings, etc.), feed, and labor costs are the most expensive variable costs of a culture operation. It is important to analyze these costs carefully to ensure they are accurate and manageable.

Production is limited by the number of organisms stocked. Stocking rates, unit costs, growth and potential mortality of culture organisms should be available in the resource materials. These values can be evaluated to determine profitability if higher than expected seed prices or mortalities are encountered.

Feeds

Most fish production systems require supplemental feeding. Because of the volume and price of feeds, the equipment needed, and the labor required, feeds and feeding are costly - up to 40-50 percent of total variable costs. Thus, profitability is often determined by the feeding efficiency.
Amount of feed required is determined by feed conversion rates and can be estimated from formulas such as those in the University of Maryland Fact Sheet "Figuring Production Costs in Finfish Aquaculture" or tables provided by feed manufacturers. If food information is not available for your species or geographic area, formulate estimates from similar species and areas.

Consideration should be given to projections of changing feed costs. How have nutrition, price of ingredients and feed costs changed in recent years? Are bulk purchase and storage available? This information will help you anticipate actual feed costs.

Management

Management of an aquaculture facility often requires more time and expertise than traditional farming activities. Ability to make quick management decisions and take prompt action is crucial, particularly when stocking, feeding, and harvesting fish. Estimate your needs based on experience, from discussions with other growers, or from technical studies. Determine if you have the necessary knowledge, skills, time and labor. If periods of critical decision making conflict with other activities can you hire the necessary assistance? Include realistic estimates of your availability and costs, including resources or the cost to obtain them.

Experience is the best teacher. Successful culturists minimize operational costs by carefully observing changes in feeding habits, water quality, disease and predation. They anticipate and correct problems before losses occur. Learn as much as possible from these growers and incorporate their experiences into your planning.

Be flexible in your estimates. Market demands, biological problems, and culture conditions will alter planned production. It is useful to develop three sets of projections based on high, intermediate, and low potential production. As you gain experience in aquaculture you will be able to anticipate trends or problems and adapt more effectively. In the beginning, it is best to recognize the inherent unpredictability of aquaculture and understand how to modify your plans as needed.

SECTION IV: FINANCIAL FEASIBILITY

Completion of the previous worksheets is equivalent to gathering pieces of a jigsaw puzzle into groups of the same color. In this final section, the overall picture of your business will emerge by constructing a cash flow statement.

Importance of Cash Flow Statement

The cash flow statement is the most important of several financial documents included in a formal business plan. It is a tool for forecasting profits and ensuring that money is available when needed. A business can fail even if it is profitable. If profit comes in after creditors have closed your door, it will be too late.

The cash flow statement shows how much money you need, and when you need it; how much money you are bringing in and when it is available. This is essential information because aquaculture production is often discontinuous. Fish and shellfish take months to grow to market size, and during this time expenses will be incurred. Knowing in advance that a cash gap will occur allows you to budget for it. Cash flow projections also include timing of capital investments, putting idle cash to work and lessening dependence on debt. Interest payments may be minimized by borrowing as needed rather than annually or sporadically.

Basic Structure

Cash flow projections should extend three years or to a point where the operation is consistently in the black, whichever is longer. In hard clam culture, for example, revenues do not arrive until year two or three and profitability may not be achieved for another year or two. In this case, financial plans should be projected to at least year five.

The cash flow statement begins with the cash on hand the day you start business. Do not begin when your operation is stocked as you will be spending money long before this time. To the initial balance, receipts are added and disbursements are subtracted for a prescribed time period. The end balance then becomes the start balance for the next time period.

Some Missing Pieces

In planning the operation start-up, you will not know the beginning balance. This must be determined based on your anticipated financial needs. Therefore, the first step in completing the worksheet is to calculate net and cumulative cash flows for each time period within one year. Net cash flow is the difference between cash receipts and cash disbursements for the period. Cumulative cash flow is the sum of net cash flows from the starting period to the current period.

One essential item not initially available is any loan repayment expense because you will not know how much must be borrowed. An adjustment for this will be made after all other financial needs have been estimated. By adding the time period interest charges and the repayment amount for each time period, the amount needed to start up and operate an enterprise until revenues arrive can be estimated. Your bank can provide tables of interest charges and repayment schedules for varying loan amounts and rates.
As you work through the projections, keep in mind that only actual cash flows are recorded. Sales on credit made in one period but collected later are not entered until the cash materializes. Any prepayment of expenses such as insurance is recorded in full when the payment occurs. Depreciation is a non-cash expense and does not enter the computations of cash flow (except for tax implications at the end of the year).

Monthly time periods are used for the first year cash flow statement. In subsequent years, quarterly projections may be sufficient. You must decide the appropriate level of detail. In some operations, cash expenses and receipts occur in spurts, a flurry of activity associated with stocking, another intense period at harvest, and a lull in between. Shellfish aquaculture might fit this model. For such cases you might choose six month intervals for the inactive periods and monthly estimates for busy times.

Most information needed to complete the cash flow statement can be found in the previous worksheets. The expense categories listed are common to most aquaculture, but be sure that items peculiar to your operation are included. Some estimates will require making reasonable assumptions and minor calculations. Two items in the financial projections require careful thought. The first is estimating revenues; seasonal variability in price and quantities harvested can complicate this calculation. Second, feed expenses will vary with changes in diet as fish grow, feed conversion rates, biomass (number times average weight), and feed price.

Consult financial advisors to estimate expenses for legal, accounting, insurance, and payroll taxes and benefits. To estimate equipment repair and advertising costs, speak to knowledgeable industry sources such as equipment suppliers and other aquaculturists.

Access to a computer spreadsheet program will aid in development of a cash flow statement because corrections and changes in assumptions are much easier to make than with pencil and paper.

CONCLUSION

If the accompanying worksheets have convinced you that an aquaculture venture can meet your personal and financial goals, it is time to set out an action plan. This plan should use the accumulated information. In most cases, the first step will be to arrange for financing.

Outside financing may be available as a loan (debt) or in return for giving up some ownership of the business (equity). Either type of funding or a combination of both should be carefully decided after consulting a trusted accountant and lawyer. Major factors which will affect your options include how much money is required, your credit history, the lending "climate" and your legal responsibilities.

Compared to many businesses, aquaculture is viewed as a risky enterprise by financiers. Do not become disheartened. It is much more common to find financing after being turned down by several investors than to be successful on the first attempt.

After gauging personal financial and other contributions to the venture, most entrepreneurs turn to people they know for a loan. Such arrangements are easier to arrange and terms can be better than commercial interest rates. Be aware, however, that tensions can affect the relationship especially if the business falls on hard times. It is important for tax and other legal reasons that all agreements are written down in detail and signed by all parties.

Additional sources of financing include private investors, banks, and government funding programs, and each has different perspectives, requirements and expectations. Looking at your venture from the viewpoint of potential financiers will help prioritize the search for funds and identify the most likely sources.

If you approach private investors or financial institutions, it will be necessary to prepare a formal business plan. There are a number of excellent published guides to the proper format and content of such a financial proposal. Several are listed at the end of this publication.

Once your aquaculture operation is established, make planning a high priority. There will be new markets to develop, improved culture methods to assess and use, and the need to manage business growth. Your plan should evolve with changing conditions, but always ensure that the core goals remain as the primary measure for your efforts.

USEFUL REFERENCES

Allen, P.G., L.W. Botsford, A.M. Schur, and W.E. Johnston. 1984. Bioeconomics of Aquaculture. Elsevier. New York, NY. 351 pp.

Bangs, D. 1989. Business Planning Guide: Creating a Plan for Success in Your Own Business. Upstart Publishing Co., Inc. Dover, NH. 143 pp.

Cato, J.C. (ed.) and ten others. 1991. Investing in Commercial Hard Clam Culture: A Comprehensive Guide to the South Atlantic States. Florida Sea Grant Program, Report Number 104 (SGR-104), 128 pp. Chaston, I. 1983. Marketing in Fisheries and Aquaculture. Osprey Books Huntington, NY. 143 pp.

Chaston, I. 1984. Business Management in Fisheries and Aquaculture. Osprey Books, Huntington, NY. 130 pp.

Joint Subcommittee on Aquaculture and National Agricultural Library. 1992. Aquaculture: A Guide to Federal Government Programs. National Agricultural Library, Beltsville, MD. 38 pp.

Kevgor Aquasystems. 1989. Starting an Aquaculture Business. P.O. Box 48851, Vancouver V7X1A8, Canada. 60 pp.

Lipton, D. & R. Harrell. 1990. Figuring Production Costs in Finfish Aquaculture. University of Maryland Cooperative Extension Service. 7 pp.

Meade, J. 1989. Aquaculture Management. Van Nostrand Reinhold, NY. 175 pp.

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Processing and Marketing Aquacultured Fish

Joe M. Regenstein, Cornell University;

NRAC Fact Sheet No. 140 - 1992

Aquaculture can provide a controlled.supply of edible fish. Consumers are often willing to gay a premium for aquaculture produced fish because of this control. Everything from selecting the species grown-to manipulation of the culture environment is possible through aquaculture. Superior control should result in products with the flavor, nutrition, color, texture, and size desired by consumers. Everyone involved in this emerging industry must be careful to produce and market the highest quality products possible. The purpose of this fact sheet is to summarize some important handling, processing, and marketing concerns for the starting or expanding aquaculturist.

Handling Live Fish

Before fish are harvested, the aquaculturist should withhold feed so that the intestinal tract is emptied. This facilitates handling and transport as any food in the gut will present quality problems. Typically one to three days is adequate. Longer periods may be necessary for fish maintained at lower temperatures, but excessive time without food will lead to unnecessary weight loss and may adversely affect quality (i.e., a softening of the flesh as protein and/or fat is metabolized and replaced with water).

It may be desirable to maintain fish in clean, fresh water for a few days before harvest to "rinse" them out. A problem encountered in the culture of channel catfish in ponds and fish in recirculating systems is off-flavor. Off flavored fish are safe to eat, but unappealing to customers.

Keeping the fish in clean water for several days to a few weeks before harvest usually improves the flavor. This may be impractical in many situations, but it should be a consideration when designing a facility.

As fish approach market size, samples should be tasted regularly. A sensitive taster - i.e., the person who most readily detects off-flavor in fish -- should assume the responsibility. If fish are off-flavor, they should not be marketed.

Methods used to harvest the fish should be carefully considered when planning an aquaculture operation. The amount of fish harvested should be Limited to what can be processed in one day and marketed within two to three days. Care should be taken with fish are harvested to avoid physical damage, Handling and contact between fish during harvest may lead to physical damage such as bruises, punctures, scratches, and hemorrhages.

Fish should be immediately chilled boxed iced, and transported to the processing plant after harvest Alternatively, fish may be hauled live to the processing plant. In this case clean water and adequate oxygenation are critical. The hauling truck should be equipped with aeration equipment. If fish are moved a long distance, the temperature difference between the transport water and the water from which the fish come should be less than 10 F. Adding about 1% salt by weight to the water can reduce stress. Water can be gradually cooled during transport to chill fish before they arrive at the processing plant. Typically, fish destined for processing are in transit for less than 24 hours and hauled at one to four pounds per gallon of water.

A Small Processing Facility

A small-scale processing plant can be relatively simple and inexpensive to construct It must be designed to meet all local, state, and federal regulations. The basic requirements are tanks for live fish, a storage area for raw fish, cutting tables for two to four persons, hot and cold potable water, ice, waste disposal system, cleaning system (including an area for people to wash properly), proper drainage, refrigerated storage for processed and iced fish, freezer, certified scale(s) to weigh product at various points in the production, and dry storage for packaging materials. Positive pressure in the plant (i.e., the ventilation system forces in clean air) is desirable. More information about the legal requirements for processing facilities can be obtained from your state's Departments of Agriculture and/or Public Health, Materials are also available from the U.S. Food and Drug Administration,

Processors must distinguish between cleaning (removing dirt) and sanitizing killing microorganisms). The latter cannot be done until the former is complete. Both processes must be incorporated into a formal, written. and regularly monitored clean-up program. Most reputable cleaning/sanitizer supplies can provide you with appropriate literature.

Facilities for people (e.g., office space, rest rooms, parking, locker, and lunch room space) may be included. These facilities may take up more space than the actual processing plant. All facilities should be designed with the importance of cleanliness and sanitation in mind.

Killing

Fish can be slaughtered several ways: a blow to the head, electric Stunning, pithing, cutting the throat ahead of the heart, chilling temperature-sensitive species (e.g., tilapia), or simply permitting the fish to die out of the water. Cutting the throat ahead of the heart (the most commonly used method by commercial fishermen), electric stunning, or a blow to the head are probably the easiest and most humane methods. The method used affects fish quality by its effect on the postmortem biology of muscle tissue (e.g., a blow to the head can bruise flesh). The appropriateness of different methods should be determined and consumer perceptions should be included in the assessment process.

Bleeding and Gutting

It is important to bleed and gut fish as soon as possible after harvest and slaughter. Some specialists believe that live fish should be bled, left in a rinse tank for a short period of time (about 20 minutes) and then quickly gutted (two steps). Others believe gutting and bleeding can be done together (one step). Insufficient evidence exists to justify the two step approach, particularly if the fish arrive alive or were recently harvested and iced. Therefore, for aquaculture, these two steps can be combined. This is the routine procedure for fanned channel catfish and rainbow trout.

With some species of fish and for certain markets, bleeding and the subsequent loss of red color in the flesh may be undesirable. However, in most cases bleeding produces a whiter product with a longer shelf-life and better consumer acceptance.

Gilling, Scaling, and Skinning

Fish are processed in various ways-often according to tradition. Traditional methods may reflect industry's perception of what the consumer wants, but may not be correct or optimal for aquaculture products. One opportunity for the aquaculture industry is to determine consumer preferences and present products in the forms desired.

With some species of fish and in some markets, only the gills and guts are removed (e.g., salmon in Japan). In other markets, the fish is sold with only the head removed. Consumer or market preferences can conflict with processing requirements. For example, some filleting equipment requires removal of the head. In contrast, retaining the head facilitates hand filleting by providing a structure to hold onto while the fish is processed.

If fish are sold with their skin on, scaling may be necessary. Scales can be removed by hand, mechanically or semi-mechanically (hand-held electrical scaling equipment). With some fish and markets, skinning rather than scaling is necessary (e.g., bullheads and catfish, skinless fillets). This can be hard work. Other fish must be filleted and deboned. (Note: by definition, a fillet does not guarantee the absence of bones. Depending on the fish, a boneless fillet can be hard to obtain).

Chilling and Storing Whole Fish

Fish must be kept cold throughout the entire processing procedure. They are extremely perishable; quality and shelf-life can be severely compromised by warm temperatures. "Cold water fish" are apt to have bacteria already acclimated to low temperatures and must be handled very carefully to avoid spoilage.

Ice, slush ice (ice in water), or refrigerated water can be used to chill fish. Potable water that meets local and federal regulations must be used. Once made, the ice must be kept clean. Slush ice will cool fish faster than plain ice because it completely surrounds the fish. Sharp edges on the ice can lead to bruising and should be avoided. Once chilled, the fish should be maintained as close to 32 F as possible.

Some people hold fish in a facility where the temperature is slightly warmer than 32 F. The slightly warmer temperature encourages ice melting, which moisturizes the fish and washes bacteria off the fish. However, the ice water must drain away from the fish. Leaving fish in a puddle of bloody water is a sure way to lose quality quickly by increasing bacterial contamination and accelerating decomposition

Throughout the handling process, the fish must not be bruised or battered. Tearing of the skin or removal of scales must be avoided, particularly if fish are sold in the round. Appearance affects price and marketability as much as overall quality and shelf-life.

After processing, fish should be packed on ice and put into boxes for storage and shipping. As a rule of thumb, in summer the weight of ice in the box should equal the weight of fish. In winter, ice should approximate half the weight of the fish, The appropriate amount of ice to use depends on the distance the product is shipped, whether the shipping container is insulated, and/or whether the vehicle is refrigerated. Boxes should not be filled beyond the natural stacking point. If overloaded. the fish will be bruised and damaged when the boxes are stacked and quality will suffer.

Filleting

Fish are filleted on a clean table, typically a plastic cutting board. Use of wood in food plants is being discouraged because it is difficult to sanitize and wood splinters can contaminate the product. Ideally the fillet table should be at a height so that the processor's arm is relaxed. An angle away from the body of about eight degrees on the fillet table will minimize stress and fatigue. The fillet table and work area should be rinsed regularly with water.

Cutting the second fillet is more difficult than cutting the first because the unsupported fish sags on the underside where the first fillet has been removed. This often leads to a measurable decrease in yield. To correct the problem, the cutting board may be notched. The fish head is placed in the notch, which lets the backbone lay flat on the cutting board. This procedure tends to slow down filleting. However, if small quantities of fish (i.e., custom orders) are being filleted, the increased yield might be worth the additional time.

Skin-on fillets require special handling. Enzymes on the skin may degrade the flesh: pigments in the skin may transfer to the fillets and ruin their appearance. Skin-on fillets should be packed flesh to flesh and skin to skin.

Skinning Fillets

For modest numbers of fish, fillets can be skinned with a flexible fillet knife. Small, hand-operated mechanical skinners are also available that can process up to ten fish per minute. Used models are widely available at reasonable prices. In general, hand skinning yields less than machine skinning.

Once skinned, the exposed flesh should not come in contact with ice, water or skin. Ice and water will leach out nutrients and flavor. (However, many processors do wash fish after filleting)!

Effect Of Processing On Yield

Each processing step reduces yield, while input of labor increases. At the same time, more processed products command higher prices. These facts must be considered in determining the price of the final product. Each step should add "value" to the product and lead to greater profitability.

Many of the jobs that prepare fish for sale are relatively simple and do not require skilled labor. However, filleting fish is a real skill--and the differences in yield can make or break an operation. Proper employee training and monitoring are absolutely necessary.

Packaging Processed Fish

Packaging involves more than simply combining ice and fish together in a wet-lock box or a cooler. Plastic or metal tubs that hold 15 to 25 pounds of processed product (without ice) are commercially available. Filled containers can be surrounded by ice or reusable gel ice packs. Ice packs are generally less messy than ice and less expensive if recycling is possible. The blue colored ice gel is attractive and facilitates detection of leaks. Styrofoam trays (often "blue" in color to signify seafood) sealed with a clear plastic wrap can be used to package individual servings of products. These aesthetically pleasing, simple to employ, and relatively inexpensive processing steps can add significant value to the product before retail sale.

Additional Processing

All food plants are subject to regulatory oversight with respect to packaging, labeling, and good manufacturing practices. As products become more "processed," the potential for health risks increase. Small-scale aquaculture operations should be cautious about proceeding into areas of further processing, such as stuffed and precooked products.

Waste Management

"Waste" generated at a processing plant is localized and can be recycled. Fish by-products can be used in many ways. Some can be used for human food. For instance, mechanical deboning can produce minced fish, a hamburger-like product which can be a healthy substitute for red meat. Many fish by-products can be processed into pet food/animal feed products or for non-food products such as gelatin, leather, and fertilizer. Aquaculturists should strive to use fully their fish - the greater the return realized, the more competitive and profitable the operation.

All of the solid waste from the various cleaning operations or unused by-products should be disposed of properly. It is all recyclable organic matter. Sometimes the waste can be sold to renderers. It can also be composted or made into a fish fertilizer. For more ideas and details on management of byproducts and fish waste, see Goldhor and Regenstein (1991).

Fresh Versus Frozen

"Fresh" is more valuable than frozen. For the aquaculturist, therefore, it is almost always preferable to keep the product fresh (i.e., iced, and not frozen). To minimize spoilage, fish should be kept as cold as possible without allowing them to freeze. Even a light ice crust at the surface can lead to undesirable textural changes.

A paradox of popular perception is that high quality fish, quickly frozen, can be superior to fresh fish. Proper freezing and storage less than -5 F with minimal temperature fluctuations during storage) preserve quality and make the products convenient for consumers. By minimizing loss and permitting more efficient distribution of the product, the actual cost to the consumer could be reduced. Unfortunately, too often poor quality fish are frozen and cold storage is not properly regulated/maintained, so further damage occurs. This mistreatment occurs frequently enough that many consumers have had bad experiences. They are rightfully reluctant to purchase frozen fish. Someday the consumer will realize the advantages of properly frozen fish, but in the meantime the premium remains with fresh.

Transport to Market

To transport fish to market, a refrigerated truck is ideal; plastic ice chests or similar containers will work for smaller operations that deliver locally. Cleanliness is extremely important. Delivery schedules must be worked out carefully to minimize transportation time and quality loss.

Hazard Analysis Critical Control Point

The U.S. Food and Drug Administration (FDA) is currently developing a "Hazard Analysis Critical Control Point" (HAACP) program to assure the safety of seafood at all steps in the process from capture or harvest through processing, distribution and sale (NMFS 1991). At time of publication (1992), the approach is being tested and is not yet mandatory. In the future, this will likely change. Aquaculturists are encouraged to organize their processing plans in such a way that HACCP monitoring can be easily established at their plant. Model HACCP plans and additional information are available from the National Marine Fishery Service (Department of Commerce, NMFS/Mississippi Lab, P.O. Drawer 1207, Pascagoula, MS 39567, or NMFS, 1 Blackburn Drive, Gloucester, MA 01930).

For current information on this important topic, contact your local Cooperative Extension System or Marine Advisory Service office.

Being Customer Oriented

An important point for the small operator to remember is customer service or "legendary service," as it sometimes is called. This may be the most important edge for a small operation. Building rapport with end users provides a nice difference from the more anonymous large companies that may treat these same end users as relatively "poor" or "small potatoes" customers. Legendary service takes work and requires "people skills" i.e., the ability to work with people successfully. It requires the ability to listen to your customers so that you can respond and provide the products and services they need. That is part of the edge, part of the control that you have over your business. Attention to details and good luck will put you ahead of your competitors in your quest for success.

References And Suggested Readings

Goldhor, S.H. and Regenstein, J.M. 1991. Improving the Profitability of Finfish Processing Waste: Options for Fish Processors with an Emphasis on Mechanical Deboning (Mincing), Hydrolysis (Liquid Fertilizer Production), and Composting, NY Sea Grant Institute, Stony Brook, NY.

National Marine Fisheries Service. 1991. Model Seafood Surveillance Project: HACCP Regulatory Model - Aquaculture. Pascagoula, MS.

Regenstein, J.M. and Regenstein, C.E. 1991. Introduction to Fish Technology. Van Nostrand Reinhold. New York, NY.

Wheaton. F.W. and Lawson, T.B. 1985. Processing Aquatic Food Products. Wiley-Interscience. New York.

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Appendix 2:

Future SEA Technologies Costs of Production

- Summary of Enclosed System vs. Caged System
- Weekly COP of Enclosed System
  (including environmental information) vs. Caged System

PRODUCTION COST ANALYSIS
ATLANTIC SALMON SMOLTS

CLIENT: North American
SITE: British Columbia
DATE: 1/31/01

Line Number	ASSUMPTIONS	SEA SYSTEM REARING	LAND BASED REARING
1	Introduction weight in grams	**5**	**5**
2	Harvest weight in grams	**80**	**80**
3	Feed Price per Kilogram-Smolt Feed	**$2.00**	**$2.00**
4	EFCR	**1.1**	**1.2**
5	Fry cost per fry	**$0.45**	**$0.45**
6	Labour Cost per man-day	**$160.00**	**$160.00**
7	Labour-kilograms of feed per man/day	**125**	**125**
8	Labour - Annual Salary Site Manager	**$48,000**	**$48,000**
9	Pumping power- kW per hour per 1000m3 of capacity	**7.5**	**32.00**
10	Kilowatt rate	**$0.07**	**$0.07**
11	LOX Cost $/Kg Avg. Biomass	**$0.06**	**$0.06**
12	Rearing Period - years	**0.50**	**0.50**
13	Heating Requirements per 1000m3 of capacity	**0.00**	**18.80**
14	Survival Rate	**70.00%**	**70.00%**
15	Vaccination	**$0.14**	**$0.14**
16	Transportation	**$0.22**	**$0.22**
17	Market Price of Smolts	**$2.50**	**$2.50**
18	Depreciation Rate (Annual)	**10.00%**	**10.00%**
19	Nominal Volume (cubic metres)	**6000**	**6000**
20	Start number of Fish	**3,000,000**	3,000,000
	BIOLOGICAL MODEL		
20	Start Average weight per fish in Kg.	0.005	0.005
21	Start Biomass of Fish	15000	15000
22	Closing Number of Fish	2100000	2100000
23	Closing Weight of fish	0.08	0.08
24	Closing Biomass	168000	168000
25	Increase in Biomass	153000	153000
26	Mean of Biomass	84000	84000
27	Final Density Kg/M^3	28.00	28.00

	FIXED COSTS		
28	Land Based Facility ($1000/m3)	$0	$6,000,000
29	SEA SYSTEM^{tm} 12 each -12 metre x 5 metre bags	$1,424,493	$0
30	Additional fixed costs for infrastructure	$0	$0
31	Total Fixed Costs	$1,424,493	$6,000,000
	VARIABLE COSTS		
32	Fry	1350000	1350000
33	Feed	336600	336600
34	Labour - Manual Feeding 125 Kg/day/man	215424	215424
35	Labour - Site Manager	24000	24000
36	Pumping/Power	12812	54662
37	Heating Costs	0	32114
38	Oxygen	5040	5040
39	Other direct operating costs	59388	66784
40	Vaccination	294000	294000
41	Transportation	462000	462000
42	Total Variable Costs	1409263	1490625
	TOTAL COSTS		
43	Capital Depreciation	$142,449	$600,000
44	Variable Costs	$1,409,263	$1,490,625
45	Total Costs	$1,551,712	$2,090,625
46	**Cost per smolt including equipment depreciation**	**$0.74**	**$1.00**
47	Total Revenue	5,250,000	5,250,000
48	Production Costs (excluding depreciation)	1,551,712	1,490,625
49	Gross Profit	3,840,737	3,759,375
50	**ROCE**	**133.83%**	**58.20%**

Future SEA Kisutch Inlet : Seawater Growout

Coho 2000YC Reared in 6 SS 15x12.5 - Quote# 003-01

(All Values in CDN Dollars)

Physical System				
Type		SS 15x12.5		
Number of Units		6		
Volume	*m3*	12,000		
Initial Production Values				
Start Date		1-Jun-97		
Start Population		120,000		
Start Weight	*g*	10		
Stocking Density	*kg/m3*	0.10		
Ending Production Values				
End Date		31-Oct-98		
ATU	*celsius*	6,804		
Production Cycle	*month*	17.0	*517*	*days*
Harvest Time	*week*	3		
Harvest Number	*pieces*	110,986		
Survival	*%*	92.5%		
Feed	*kg*	630,077		
SDE	*days*	4		
End Weight	*kg*	4,798.0		
Harvest Biomass	*rnd kg*	511,404		
Mean Harvest Weight	*rnd g*	4,607.8		
Harvest Biomass	*dr lbs*	991,879		
Mean Harvest Weight	*dr lbs*	8.9		
Mort Biomass	*kg*	9,823		
Max Density	*kg/m3*	40.3		
Environmental				
Mean Temperature	*celsius*	13.16		
Mean Salinity	*ppt*	30.00		
Mean Oxygen (Ambient)	*mg/l*	7.52		
Supplemental O2	*m3*	103,713		
Oxygen need	*kgO2/rnd kg produced*	0.27		
Biological Performance				
Mortality Rate		7.5%		
Yield	*Kg/Smolt*	4.26		
EFCR		1.23		
BFCR		1.21		
SGR		1.19%		
Gc (TGC, GF3)		2.13		

Economic Performance - Cost of Production ($CDN)		**Total**	**% of DFC**	**DFC /dr lb**	**% of COP**	**COP /rnd kg**
Seed stock - Smolt/fry	$	120,000	8%	$ 0.12	7%	$ 0.23
Feed	$	819,100	58%	$ 0.83	47%	$ 1.60
Labour	$	155,881	11%	$ 0.16	9%	$ 0.30
Oxygen	$	82,970	6%	$ 0.08	5%	$ 0.16
Pumping	$	34,961	2%	$ 0.04	2%	$ 0.07
Health/Vaccine	$	5,114	0%	$ 0.01	0%	$ 0.01
Other Direct Costs	$	163,937	12%	$ 0.17	9%	$ 0.32
Insurance	$	41,049	3%	$ 0.04	2%	$ 0.08
Direct Farm Costs (DFC)	**$**	**1,423,011**	**100%**	**$ 1.43**	**81%**	**$ 2.78**
Depreciation	$	193,157			11%	$ 0.38
Interest - Operating Cost	$	68,720			4%	$ 0.13
Interest - Capital Investments	$	75,308			4%	$ 0.15
Total Cost of Production (COP)	**$**	**1,760,196**			**100%**	**$ 3.44**
COP per fish	**$**	**15.86**				
COP per Rnd Kg	**$**	**3.44**				
COP per Dr Lb	**$**	**1.77**				

DESCRIPTION OF LINE ITEMS

Line Item	Description
1	Typical sizefor species- Source Smolt Survey
2	Client supplied
3	Based on Moore Clark price list
4	Typical Performance
5	Fry Cost - Market price supllied by West Coast Fish Culture 6/12/98
6	Labour rate from discussion with BCSFA, $57,600 per 2 men per year, 7/7 divided by 365 for daily rate
7	Production estimates provided by A. Clark based on time & motion study at Aquimarine
8	Managerial labour rate provided by client for smolt production facility
9	SEA System power consumption from data at PBS site, Recirc. consumption from Ji, Ying
10	Power Cost - BC Hydro $.067 per KWhr, Diesel generated power, $.13 per kWhr based on PBS costs
11	LOX cost based on FS experience
12	Rearing period varies 6 months typical in BC
13	Ying Ji reports commercial scale heating costs in land based systems at 4.29 kW per 60,000 US gallons
14	Survival rates based on client experience in BC
15	Vaccination costs from confidential client data
16	Transportation costs from confidential client data
17	Market price of smolts based on actual price paid to West Coast Fish Culture
18	Depreciation rate utilized by confidential client on internal basis
19	Volume based on production model
20	Start number of fish is selectable typical smolt producers in BC will produce 2,000,000 smolts per year
21	Typical sizefor species- Source Smolt Survey
22	Calculated value
23	Typical value client supplied
24	Final weight of smolts at time of harvest
25	Increase in weight of live fish at time of harvesting
26	Final biomass divided in half
27	Final biomass divided by volume of system
28	Based on estimates from various sources, Aquatic Designs $1,000 m3, PRA $1,200 m3, DG Vincent Consulting $200 to $450 plus land/site development, Kinloch Damph $2,000 m3
29	Based on FST production model
30	Additional costs such as barges, walkways, land
31	Sum of fixed costs
32	Feed costs x feed conversion ratio x increase in biomass
33	Fry Cost -number of Fry times price per fry
34	kilograms of feed divided by amount per man day times daily labour rate
35	Based on pump ratings for SEA System. Land based system costs are $.087 per m3 per day according to "Evaluation of Recirculating Aquaculture Systems, Ying Ji
36	kW rating x cost per kWh x 24 hours x days FST data from PBS test site, Ying Ji
37	Heat kW rating x cost per kWh x 24 hours x days FST data from PBS test site, Ying Ji, reference NorAm article
38	Based on FST experimentally derived factor applied to biomass
39	Estimated at 10% of other variable costs based on experience
40	Vaccination cost times number of smolts produced (confidential client data)
41	Transportation cost per smolt produced 9confidential client data)
42	Sum of variable costs
43	Depreciation rate applied to total capital cost
44	Total of variable costs
45	Sum of variable and fixed costs
46	Total costs divided by the number of smolts
47	Total revenue based on selling price of smolts multiplied by number of smolts
48	Production costs are the sum of variable costs plus depreciation
49	Gross profit is revenue minus variable costs
50	Return on Capital Employed is the gross profit received from the sale divided by the total fixed costs plus the variable cost. (Before interest, depreciation,and taxes)

Future SEA Kisutch Inlet : Seawater Growout
Coho 2000YC Reared in 6 SS 15x12.5 - Quote# 003-01
(All Values in CDN Dollars)

Production Characteristics

Company/Site	**Future SEA**		Quote# 003-01
Location	**Kisutch Inlet**		
Type			
Site			

Stocking Parameters

Species			
Strain *			
BY / YC	**2000**		
Start Date	**1-Jun-97**		t_0
Start Weight	**10.0**	Grams	W_0
Start Population	**120,000**	Pieces	N_0
Target Weight	**4,500**	Grams	Wt
Min Harvest Pieces	**24,000**	Pieces	
Max Harvest Pieces	**48,000**	Pieces	

System Characteristics and Management Parameters

SEA System^{TM} Model				
Volume	2,000	m3		
Number of Units	**6**			
Rearing Volume	12,000	m3		
Max Rearing Density	**40**	kg/m3		
Max Flow per Unit	80,000	l/min		
Min Flow per Unit	33,333	l/min		
Desirable Oxygen at the Outlet	**6.5**	mg/l		
O2 Transfer Efficiency	**80%**			
O2 Saturation	**85%**			
Max[TAN]	0.50	mg/l		
Early Monthly Mortality Rate	**2.00%**	for the first	**1**	month(s)
Later Monthly Mortality Rate	**0.40%**	thereafter		

Water Temperature

Set for Northern Hemisphere

	Date	*Surface (Upper Layer/Above Thermocline)* Degree Celsius		*Depth (Bottom Layer/Below Thermocline)* Degree Celsius	
High	**15-Aug-98**	**17**	deg C	**16**	deg C
Mid	16-May-98	12.1	deg C	11.6	deg C
Low	**15-Feb-98**	**7.2**	deg C	**7.2**	deg C

Financial Assumptions

	$US/$CDN			
All Numbers in Canadian $	**$ 0.6967**	☐ Use US Currency		
Variable Costs				
Feed Cost	**$ 1.30**	per kg		
Oxygen Cost	**$ 0.80**	per m3		
Pumping Cost	**$ 0.07**	per kWhr		
Insurance Premium	3.0%			
Fixed Costs				
Site Manager	**$ 3,175**	per month	$ 38,100	per year
Technician	**$ 2,500**		$ 30,000	per year
Minimum Number of Technicians (F/T)	**2.0**			
Additional Technician	**137.5**	tons of production		
Benefits (%Wages)	**10%**			
Direct Costs as % of other Op. Cost	**15%**			
Smolt Unit Cost	**$ 1.00**			

	Years	Annual Depreciation Rate
Depreciation - Bag	**5**	20%
Depreciation - Other	**10**	10%

Capital Cost

SEA System	**$ 1,050,000**
Shipping/insurance	**$ -**
Mooring	**$ 21,000**
Walkway	**$ -**
Feed System	**$ -**
Feed Boat	**$ -**
Barge with Building	**$ -**
Barge	**$ -**
Building	**$ -**
	$ 1,071,000
Replacement Bag	$ 286,321

Interest Rate

Operating Expenses	**9%**
Capital Investments	**8%**

Future SEA Kisutch Inlet : Seawater Growout
Coho 2000YC Reared in 6 SS 15x12.5 - Quote# 003-01

Feeding Efficiency

FCR Level	Causes	Base Units	Deviation	Conversion Ratio	Improvement Factor Over Reference (%)
	Externalities				
TFCR				**0.85**	
	Feeding	0.20	23%		0
	Disease	0.10	12%		0
	Site	0.04	5%		0
	Lice	0.00	0%		0
	Other	0.08	9%		6
	Dust	0.01	1%		1
	Total	0.43	50%		
BFCR				**1.275**	
Extrinsic Factor (EF - Deviation of BFCR from TFCR)			50%		

Growth Cycle	Month	0.2	0.4	0.7	0.9	1.1	1.3	1.6	1.8	2.0	2.3	2.5	2.7	3.0	3.2	3.4	3.6
Week	StartDate is 1/6/1997	7-Jun-97	14-Jun-97	21-Jun-97	28-Jun-97	5-Jul-97	12-Jul-97	19-Jul-97	26-Jul-97	2-Aug-97	9-Aug-97	16-Aug-97	23-Aug-97	30-Aug-97	6-Sep-97	13-Sep-97	20-Sep-97
Environmental																	
Model Temperature	*Celsius*	**13.87**	**14.41**	**14.91**	**15.37**	**15.79**	**16.15**	**16.45**	**16.69**	**16.86**	**16.97**	**17.00**	**16.96**	**16.85**	**16.68**	**16.43**	**16.13**
Upper Layer Temperature	*Celsius*	13.87	14.41	14.91	15.37	15.79	16.15	16.45	16.69	16.86	16.97	17.00	16.96	16.85	16.68	16.43	16.13
Bottom Layer Temperature	*Celsius*	13.19	13.67	14.12	14.54	14.91	15.24	15.51	15.72	15.88	15.97	16.00	15.97	15.87	15.71	15.49	15.21
Salinity	*ppt*	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**
ATU	*Celsius*	**83**	**184.10**	**288.48**	**396.09**	**506.61**	**619.65**	**734.81**	**851.65**	**969.69**	**1,088.46**	**1,207.46**	**1,326.19**	**1,444.16**	**1,560.90**	**1,675.92**	**1,788.80**
Growth																	
Round Wt	*g*	**12.9**	**17.1**	**22.4**	**28.8**	**36.6**	**45.9**	**56.8**	**69.6**	**84.3**	**101.0**	**119.9**	**140.9**	**164.0**	**189.3**	**216.6**	**245.9**
Sample Wt	*g*																
Dr. Wt	*lbs*	0.03	0.03	0.04	0.06	0.07	0.09	0.11	0.13	0.16	0.20	0.23	0.27	0.32	0.37	0.42	0.48
Harvest Round Wt	g																
Month Gc	*1*		1.26	1.64	1.82	1.92	1.99	2.04	2.07	2.10	2.12	2.14	2.15	2.17	2.18	2.18	2.19
Gc Factor	*%*																
Growth	*% per Week*		32.7%	30.6%	28.7%	27.0%	25.4%	23.9%	22.5%	21.1%	19.9%	18.7%	17.5%	16.4%	15.4%	14.4%	13.5%
Sgr		4.26%	4.04%	3.82%	3.61%	3.41%	3.23%	3.06%	2.89%	2.74%	2.59%	2.45%	2.31%	2.18%	2.05%	1.93%	1.81%
Inventory																	
Mort Rate	*% per Week*	0.46%	0.46%	0.46%	0.46%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%
Survival	*%*	99.91%	99.45%	99.00%	98.54%	98.45%	98.36%	98.27%	98.18%	98.09%	98.00%	97.91%	97.82%	97.73%	97.64%	97.55%	97.46%
Close Inventory		119,891	119,341	118,794	118,249	118,140	118,031	117,922	117,813	117,704	117,595	117,487	117,379	117,271	117,163	117,055	116,947
Harvest	*#*		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass																	
Harvest Biomass	*Dr Lb*		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	*kg*	1,548	2,044	2,658	3,406	4,321	5,413	6,699	8,196	9,918	11,877	14,082	16,535	19,237	22,182	25,360	28,756
Mort Biomass	*Kg*		8	11	14	4	4	6	7	8	10	12	14	16	19	22	25
Density																	
Density	*kg/m3*	**0.13**	**0.17**	**0.22**	**0.28**	**0.36**	**0.45**	**0.56**	**0.68**	**0.83**	**0.99**	**1.17**	**1.38**	**1.60**	**1.85**	**2.11**	**2.40**
Number of Bags Required	*#*	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Feed																	
Feed Rate	*%Bwt/day*	4.42%	4.31%	4.07%	3.85%	3.64%	3.45%	3.27%	3.10%	2.93%	2.78%	2.63%	2.49%	2.35%	2.22%	2.10%	1.98%
Feed Rate (maintenance)	*%Bwt/day*	1.19%	1.20%	1.15%	1.11%	1.07%	1.03%	0.99%	0.96%	0.92%	0.89%	0.85%	0.82%	0.79%	0.76%	0.73%	0.69%
Starve days	*day*																
Feed	*Kg*	318	467	582	716	868	1,043	1,238	1,452	1,684	1,930	2,188	2,455	2,726	2,996	3,261	3,515
Performance																	
Yield per Fish	*kg/smolt*	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.10	0.12	0.14	0.16	0.18	0.21	0.24
EFCR			0.94	0.95	0.95	0.95	0.95	0.95	0.96	0.96	0.97	0.97	0.98	0.98	0.99	0.99	1.00
BFCR			0.94	0.94	0.94	0.94	0.94	0.95	0.95	0.96	0.96	0.97	0.97	0.98	0.98	0.99	0.99
Labour																	
Additional Labour Requirement		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cost of Production																	
Smolt Cost		$ 120,000															
Feed Cost		$ 414	$ 607	$ 757	$ 931	$ 1,129	$ 1,356	$ 1,610	$ 1,888	$ 2,189	$ 2,509	$ 2,845	$ 3,191	$ 3,543	$ 3,895	$ 4,239	$ 4,569
Labour Cost		$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064
Cost of Oxygen		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 14
Pumping Cost		$ 174	$ 204	$ 260	$ 407	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489
Health/Vaccine		*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*
Other Direct Costs		$ 398	$ 431	$ 462	$ 510	$ 552	$ 586	$ 624	$ 666	$ 711	$ 759	$ 810	$ 862	$ 914	$ 967	$ 1,019	$ 1,070
Insurance		$ 71	$ 73	$ 75	$ 77	$ 80	$ 82	$ 85	$ 88	$ 179	$ 186	$ 192	$ 200	$ 208	$ 216	$ 225	$ 234
Total Operating Cost		**$ 123,121**	**$ 3,379**	**$ 3,618**	**$ 3,989**	**$ 4,313**	**$ 4,577**	**$ 4,872**	**$ 5,194**	**$ 5,631**	**$ 6,006**	**$ 6,399**	**$ 6,805**	**$ 7,218**	**$ 7,630**	**$ 8,035**	**$ 8,440**
(All Values in CDN Dollars)																	
Depreciation (over rearing period)		$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610
Interest - ShortTerm Loans		$ 182	$ 219	$ 225	$ 232	$ 240	$ 248	$ 257	$ 266	$ 276	$ 287	$ 298	$ 310	$ 323	$ 336	$ 350	$ 365
Interest - Long Term Loans		$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7
Total Financial Costs		$ 3,810	$ 3,847	$ 3,853	$ 3,860	$ 3,868	$ 3,876	$ 3,885	$ 3,894	$ 3,904	$ 3,915	$ 3,926	$ 3,938	$ 3,951	$ 3,964	$ 3,978	$ 3,993
			-$ 384,724														
Monthly Cost of Production		**$ 126,931**	**$ 7,225**	**$ 7,471**	**$ 7,849**	**$ 8,181**	**$ 8,454**	**$ 8,757**	**$ 9,089**	**$ 9,536**	**$ 9,921**	**$ 10,325**	**$ 10,743**	**$ 11,169**	**$ 11,594**	**$ 12,013**	**$ 12,433**
Cumulative COP		$ 126,931	$ 134,157	$ 141,628	$ 149,477	$ 157,658	$ 166,111	$ 174,868	$ 183,956	$ 193,492	$ 203,413	$ 213,738	$ 224,481	$ 235,650	$ 247,244	$ 259,257	$ 271,689
COP per fish		**$ 1.06**	**$ 1.12**	**$ 1.19**	**$ 1.26**	**$ 1.33**	**$ 1.41**	**$ 1.48**	**$ 1.56**	**$ 1.64**	**$ 1.73**	**$ 1.82**	**$ 1.91**	**$ 2.01**	**$ 2.11**	**$ 2.21**	**$ 2.32**
COP per Kg (rnd wt)		**$ 82.01**	**$ 65.62**	**$ 53.28**	**$ 43.89**	**$ 36.48**	**$ 30.69**	**$ 26.10**	**$ 22.44**	**$ 19.51**	**$ 17.13**	**$ 15.18**	**$ 13.58**	**$ 12.25**	**$ 11.15**	**$ 10.22**	**$ 9.45**
COP per lb (HOG dr wt)		**$ 41.35**	**$ 32.42**	**$ 25.83**	**$ 20.92**	**$ 17.12**	**$ 14.20**	**$ 11.93**	**$ 10.14**	**$ 8.73**	**$ 7.59**	**$ 6.67**	**$ 5.93**	**$ 5.32**	**$ 4.81**	**$ 4.39**	**$ 4.04**

3.9	**4.1**	**4.3**	**4.6**	**4.8**	**5.0**	**5.2**	**5.5**	**5.7**	**5.9**	**6.2**	**6.4**	**6.6**	**6.9**	**7.1**	**7.3**	**7.5**	**7.8**	**8.0**
27-Sep-97	**4-Oct-97**	**11-Oct-97**	**18-Oct-97**	**25-Oct-97**	**1-Nov-97**	**8-Nov-97**	**15-Nov-97**	**22-Nov-97**	**29-Nov-97**	**6-Dec-97**	**13-Dec-97**	**20-Dec-97**	**27-Dec-97**	**3-Jan-98**	**10-Jan-98**	**17-Jan-98**	**24-Jan-98**	**31-Jan-98**
15.76	**15.34**	**14.88**	**14.37**	**13.83**	**13.27**	**12.69**	**12.10**	**11.51**	**10.93**	**10.37**	**9.83**	**9.32**	**8.86**	**8.44**	**8.07**	**7.77**	**7.52**	**7.35**
15.76	15.34	14.88	14.37	13.83	13.27	12.69	12.10	11.51	10.93	10.37	9.83	9.32	8.86	8.44	8.07	7.77	7.52	7.35
14.89	14.51	14.09	13.64	13.16	12.65	12.13	11.60	11.07	10.55	10.04	9.56	9.11	8.69	8.31	7.99	7.71	7.49	7.33
30	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**
1,899.12	**2,006.51**	**2,110.65**	**2,211.25**	**2,308.08**	**2,400.97**	**2,489.79**	**2,574.49**	**2,655.07**	**2,731.58**	**2,804.15**	**2,872.95**	**2,938.21**	**3,000.22**	**3,059.30**	**3,115.82**	**3,170.20**	**3,222.86**	**3,274.29**
276.9	**309.4**	**343.3**	**378.2**	**408.7**	**428.9**	**448.9**	**483.6**	**518.3**	**552.6**	**586.5**	**619.8**	**652.4**	**684.4**	**715.7**	**746.5**	**776.8**	**806.9**	**836.9**
0.54	0.60	0.67	0.73	0.79	0.83	0.87	0.94	1.01	1.07	1.14	1.20	1.27	1.33	1.39	1.45	1.51	1.57	1.62
2.20	2.20	2.21	2.21	2.20	2.16	2.13	2.14	2.14	2.15	2.15	2.15	2.15	2.16	2.16	2.16	2.16	2.16	2.16
12.6%	11.8%	10.9%	10.2%	8.1%	4.9%	4.6%	7.7%	7.2%	6.6%	6.1%	5.7%	5.3%	4.9%	4.6%	4.3%	4.1%	3.9%	3.7%
1.70%	1.59%	1.48%	1.39%	1.11%	0.69%	0.65%	1.07%	0.99%	0.92%	0.85%	0.79%	0.73%	0.68%	0.64%	0.60%	0.57%	0.54%	0.52%
0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%
97.37%	97.28%	97.19%	97.10%	97.01%	96.92%	96.83%	96.74%	96.65%	96.56%	96.47%	96.38%	96.29%	96.20%	96.12%	96.03%	95.94%	95.85%	95.76%
116,839	116,731	116,623	116,515	116,408	116,301	116,194	116,087	115,980	115,873	115,766	115,659	115,552	115,445	115,339	115,233	115,127	115,021	114,915
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32,350	36,119	40,036	44,071	47,580	49,887	52,155	56,144	60,111	64,035	67,897	71,684	75,389	79,010	82,551	86,021	89,435	92,811	96,175
28	32	35	39	42	45	47	50	54	57	61	65	68	72	74	77	81	84	87
2.70	**3.01**	**3.34**	**3.67**	**3.97**	**4.16**	**4.35**	**4.68**	**5.01**	**5.34**	**5.66**	**5.97**	**6.28**	**6.58**	**6.88**	**7.17**	**7.45**	**7.73**	**8.01**
1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**
1.86%	1.75%	1.65%	1.55%	1.31%	0.98%	0.92%	1.21%	1.13%	1.05%	0.98%	0.91%	0.85%	0.80%	0.75%	0.71%	0.67%	0.65%	0.62%
0.66%	0.63%	0.60%	0.58%	0.54%	0.51%	0.48%	0.47%	0.45%	0.42%	0.40%	0.37%	0.35%	0.33%	0.32%	0.30%	0.29%	0.28%	0.27%
				1	**3**	**3**												
3,753	3,971	4,165	4,331	4,039	3,251	3,229	4,418	4,434	4,424	4,392	4,344	4,284	4,219	4,156	4,100	4,059	4,039	4,046
0.27	0.30	0.33	0.37	0.40	0.42	0.43	0.47	0.50	0.53	0.57	0.60	0.63	0.66	0.69	0.72	0.75	0.77	0.80
1.00	1.01	1.01	1.02	1.03	1.05	1.06	1.07	1.07	1.07	1.08	1.08	1.09	1.09	1.09	1.10	1.10	1.10	1.11
1.00	1.00	1.01	1.01	1.02	1.04	1.06	1.06	1.06	1.06	1.07	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$ 4,879	$ 5,163	$ 5,415	$ 5,630	$ 5,250	$ 4,226	$ 4,197	$ 5,744	$ 5,764	$ 5,751	$ 5,710	$ 5,647	$ 5,569	$ 5,485	$ 5,402	$ 5,330	$ 5,277	$ 5,251	$ 5,260
$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489
$ -	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*
$ 1,115	$ 1,157	$ 1,195	$ 1,227	$ 1,170	$ 1,017	$ 1,012	$ 1,244	$ 1,247	$ 1,246	$ 1,239	$ 1,230	$ 1,218	$ 1,206	$ 1,193	$ 1,182	$ 1,174	$ 1,171	$ 1,172
$ 244	$ 254	$ 264	$ 275	$ 286	$ 295	$ 304	$ 314	$ 325	$ 336	$ 347	$ 358	$ 369	$ 380	$ 390	$ 401	$ 411	$ 422	$ 432
$ 8,790	**$ 9,126**	**$ 9,426**	**$ 9,685**	**$ 9,258**	**$ 8,090**	**$ 8,066**	**$ 9,855**	**$ 9,889**	**$ 9,885**	**$ 9,849**	**$ 9,787**	**$ 9,709**	**$ 9,622**	**$ 9,538**	**$ 9,466**	**$ 9,415**	**$ 9,395**	**$ 9,416**
$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610
$ 380	$ 396	$ 413	$ 430	$ 446	$ 460	$ 475	$ 492	$ 509	$ 527	$ 544	$ 561	$ 578	$ 595	$ 612	$ 629	$ 646	$ 662	$ 679
$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7
$ 4,008	$ 4,024	$ 4,041	$ 4,058	$ 4,074	$ 4,088	$ 4,102	$ 4,120	$ 4,137	$ 4,155	$ 4,172	$ 4,189	$ 4,206	$ 4,223	$ 4,240	$ 4,257	$ 4,274	$ 4,290	$ 4,307
$ 12,798	**$ 13,150**	**$ 13,467**	**$ 13,743**	**$ 13,333**	**$ 12,179**	**$ 12,169**	**$ 13,975**	**$ 14,026**	**$ 14,040**	**$ 14,021**	**$ 13,976**	**$ 13,915**	**$ 13,846**	**$ 13,778**	**$ 13,723**	**$ 13,689**	**$ 13,686**	**$ 13,723**
$ 284,488	$ 297,638	$ 311,105	$ 324,848	$ 338,180	$ 350,359	$ 362,528	$ 376,503	$ 390,529	$ 404,569	$ 418,589	$ 432,565	$ 446,480	$ 460,326	$ 474,104	$ 487,827	$ 501,516	$ 515,201	$ 528,924
$ 2.43	**$ 2.55**	**$ 2.67**	**$ 2.79**	**$ 2.91**	**$ 3.01**	**$ 3.12**	**$ 3.24**	**$ 3.37**	**$ 3.49**	**$ 3.62**	**$ 3.74**	**$ 3.86**	**$ 3.99**	**$ 4.11**	**$ 4.23**	**$ 4.36**	**$ 4.48**	**$ 4.60**
$ 8.79	**$ 8.24**	**$ 7.77**	**$ 7.37**	**$ 7.11**	**$ 7.02**	**$ 6.95**	**$ 6.71**	**$ 6.50**	**$ 6.32**	**$ 6.17**	**$ 6.03**	**$ 5.92**	**$ 5.83**	**$ 5.74**	**$ 5.67**	**$ 5.61**	**$ 5.55**	**$ 5.50**
$ 3.75	**$ 3.50**	**$ 3.30**	**$ 3.12**	**$ 3.00**	**$ 2.96**	**$ 2.92**	**$ 2.81**	**$ 2.72**	**$ 2.64**	**$ 2.57**	**$ 2.51**	**$ 2.46**	**$ 2.42**	**$ 2.38**	**$ 2.35**	**$ 2.32**	**$ 2.29**	**$ 2.27**

8.2	8.5	8.7	8.9	9.1	9.4	9.6	9.8	10.1	10.3	10.5	10.8	11.0	11.2	11.4	11.7	11.9	12.1	12.4
7-Feb-98	14-Feb-98	21-Feb-98	28-Feb-98	7-Mar-98	14-Mar-98	21-Mar-98	28-Mar-98	4-Apr-98	11-Apr-98	18-Apr-98	25-Apr-98	2-May-98	9-May-98	16-May-98	23-May-98	30-May-98	6-Jun-98	13-Jun-98
7.24	7.20	7.23	7.34	7.51	7.75	8.05	8.41	8.83	9.29	9.79	10.33	10.89	11.47	12.06	12.65	13.23	13.79	14.33
7.24	7.20	7.23	7.34	7.51	7.75	8.05	8.41	8.83	9.29	9.79	10.33	10.89	11.47	12.06	12.65	13.23	13.79	14.33
7.23	7.20	7.23	7.32	7.48	7.69	7.96	8.29	8.66	9.08	9.53	10.01	10.51	11.03	11.56	12.09	12.61	13.12	13.61
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
3,324.96	3,375.36	3,425.99	3,477.35	3,529.91	3,584.15	3,640.51	3,699.39	3,761.18	3,826.20	3,894.73	3,967.03	4,043.25	4,123.54	4,207.94	4,296.47	4,389.07	4,485.63	4,585.96
867.1	897.9	929.4	962.0	996.2	1,032.3	1,070.7	1,111.8	1,156.0	1,203.8	1,255.6	1,311.8	1,372.9	1,439.1	1,511.0	1,588.9	1,673.0	1,763.8	1,861.3
				627.0														
1.68	1.74	1.80	1.87	1.93	2.00	2.08	2.16	2.24	2.33	2.44	2.54	2.66	2.79	2.93	3.08	3.24	3.42	3.61
2.16	2.16	2.16	2.16	2.16	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17
3.6%	3.5%	3.5%	3.5%	3.6%	3.6%	3.7%	3.8%	4.0%	4.1%	4.3%	4.5%	4.7%	4.8%	5.0%	5.2%	5.3%	5.4%	5.5%
0.51%	0.50%	0.49%	0.49%	0.50%	0.51%	0.52%	0.54%	0.56%	0.58%	0.60%	0.63%	0.65%	0.67%	0.70%	0.72%	0.74%	0.75%	0.77%
0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%
95.67%	95.59%	95.50%	95.41%	95.32%	95.23%	95.15%	95.06%	94.97%	94.88%	94.80%	94.71%	94.62%	94.53%	94.45%	94.36%	94.27%	94.19%	94.10%
114,809	114,703	114,597	114,491	114,385	114,280	114,175	114,070	113,965	113,860	113,755	113,650	113,545	113,440	113,335	113,231	113,127	113,023	112,919
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
99,556	102,987	106,503	110,145	113,953	117,971	122,246	126,822	131,746	137,067	142,832	149,088	155,881	163,254	171,251	179,910	189,265	199,345	210,173
90	94	97	100	104	106	110	115	119	124	129	135	141	148	155	161	170	179	189
8.30	8.58	8.88	9.18	9.50	9.83	10.19	10.57	10.98	11.42	11.90	12.42	12.99	13.60	14.27	14.99	15.77	16.61	17.51
2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3
0.61%	0.60%	0.59%	0.60%	0.60%	0.62%	0.63%	0.65%	0.68%	0.71%	0.73%	0.76%	0.79%	0.82%	0.85%	0.88%	0.90%	0.92%	0.94%
0.26%	0.26%	0.26%	0.26%	0.27%	0.27%	0.28%	0.29%	0.30%	0.31%	0.32%	0.34%	0.35%	0.36%	0.38%	0.39%	0.40%	0.41%	0.42%
4,085	4,161	4,279	4,442	4,653	4,916	5,231	5,601	6,026	6,507	7,044	7,636	8,282	8,980	9,729	10,524	11,363	12,240	13,150
0.83	0.86	0.89	0.92	0.95	0.98	1.02	1.06	1.10	1.14	1.19	1.24	1.30	1.36	1.43	1.50	1.58	1.66	1.75
1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.13	1.14	1.14	1.14	1.15	1.15	1.15	1.16	1.16	1.16	1.17	1.17
1.10	1.10	1.10	1.11	1.11	1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.13	1.13	1.14	1.14	1.14	1.15	1.15
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$ 5,310	$ 5,409	$ 5,562	$ 5,774	$ 6,049	$ 6,390	$ 6,800	$ 7,281	$ 7,834	$ 8,459	$ 9,157	$ 9,926	$ 10,766	$ 11,674	$ 12,647	$ 13,682	$ 14,772	$ 15,912	$ 17,094
$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 67	$ 353	$ 1,218	$ 1,516	$ 2,360
$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 1,179	$ 1,194	$ 1,217	$ 1,249	$ 1,290	$ 1,341	$ 1,403	$ 1,475	$ 1,558	$ 1,652	$ 1,756	$ 1,872	$ 1,998	$ 2,134	$ 2,290	$ 2,488	$ 2,781	$ 2,997	$ 3,301
$ 442	$ 453	$ 463	$ 474	$ 486	$ 497	$ 509	$ 522	$ 536	$ 550	$ 565	$ 581	$ 598	$ 616	$ 636	$ 657	$ 680	$ 706	$ 734
$ 9,485	$ 9,609	$ 9,796	$ 10,050	$ 10,378	$ 10,782	$ 11,265	$ 11,831	$ 12,480	$ 13,213	$ 14,030	$ 14,931	$ 15,914	$ 16,977	$ 18,193	$ 19,733	$ 22,005	$ 23,684	$ 26,041
$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610
$ 696	$ 713	$ 730	$ 748	$ 766	$ 786	$ 805	$ 826	$ 849	$ 872	$ 897	$ 923	$ 951	$ 981	$ 1,013	$ 1,048	$ 1,087	$ 1,128	$ 1,174
$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7
$ 4,324	$ 4,341	$ 4,358	$ 4,376	$ 4,394	$ 4,413	$ 4,433	$ 4,454	$ 4,476	$ 4,500	$ 4,525	$ 4,551	$ 4,579	$ 4,609	$ 4,641	$ 4,676	$ 4,714	$ 4,756	$ 4,802
$ 13,808	$ 13,950	$ 14,154	$ 14,426	$ 14,772	$ 15,195	$ 15,699	$ 16,285	$ 16,956	$ 17,713	$ 18,555	$ 19,482	$ 20,493	$ 21,586	$ 22,834	$ 24,408	$ 26,719	$ 28,440	$ 30,843
$ 542,732	$ 556,682	$ 570,835	$ 585,262	$ 600,034	$ 615,229	$ 630,927	$ 647,212	$ 664,168	$ 681,881	$ 700,436	$ 719,918	$ 740,411	$ 761,997	$ 784,831	$ 809,240	$ 835,959	$ 864,398	$ 895,241
$ 4.73	$ 4.85	$ 4.98	$ 5.11	$ 5.25	$ 5.38	$ 5.53	$ 5.67	$ 5.83	$ 5.99	$ 6.16	$ 6.33	$ 6.52	$ 6.72	$ 6.92	$ 7.15	$ 7.39	$ 7.65	$ 7.93
$ 5.45	$ 5.41	$ 5.36	$ 5.31	$ 5.27	$ 5.22	$ 5.16	$ 5.10	$ 5.04	$ 4.97	$ 4.90	$ 4.83	$ 4.75	$ 4.67	$ 4.58	$ 4.50	$ 4.42	$ 4.34	$ 4.26
$ 2.25	$ 2.22	$ 2.20	$ 2.18	$ 2.16	$ 2.14	$ 2.12	$ 2.09	$ 2.07	$ 2.04	$ 2.01	$ 1.98	$ 1.95	$ 1.92	$ 1.89	$ 1.86	$ 1.83	$ 1.80	$ 1.77

12.6	12.8	13.0	13.3	13.5	13.7	14.0	14.2	14.4	14.7	14.9	15.1	15.3	15.6	15.8	16.0	16.3	16.5	16.7
20-Jun-98	27-Jun-98	4-Jul-98	11-Jul-98	18-Jul-98	25-Jul-98	1-Aug-98	8-Aug-98	15-Aug-98	22-Aug-98	29-Aug-98	5-Sep-98	12-Sep-98	19-Sep-98	26-Sep-98	3-Oct-98	10-Oct-98	17-Oct-98	24-Oct-98
14.84	15.31	15.73	16.10	16.41	16.66	16.84	16.96	17.00	16.97	16.87	16.71	16.47	16.17	15.82	15.40	14.95	14.45	13.91
14.84	15.31	15.73	16.10	16.41	16.66	16.84	16.96	17.00	16.97	16.87	16.71	16.47	16.17	15.82	15.40	14.95	14.45	13.91
14.06	14.48	14.86	15.19	15.47	15.70	15.86	15.96	16.00	15.97	15.89	15.74	15.52	15.26	14.94	14.57	14.16	13.71	13.23
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
4,689.86	4,797.03	4,907.15	5,019.86	5,134.75	5,251.37	5,369.27	5,487.97	5,606.96	5,725.76	5,843.88	5,960.81	6,076.11	6,189.32	6,300.03	6,407.86	6,512.48	6,613.60	6,710.98
1,965.7	2,077.3	2,195.8	2,321.3	2,453.5	2,592.2	2,736.9	2,887.1	3,042.1	3,201.1	3,363.4	3,527.9	3,693.6	3,859.5	4,024.5	4,187.4	4,347.2	4,502.9	4,653.4
			2292.0															
3.81	4.03	4.26	4.50	4.76	5.03	5.31	5.60	5.90	6.21	6.52	6.84	7.16	7.49	7.81	8.12	8.43	8.73	9.03
																	4,502.9	4,653.4
2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.16	2.16	2.16	2.16	2.16	2.15	2.15	2.15	2.14	2.14
5.6%	5.7%	5.7%	5.7%	5.7%	5.7%	5.6%	5.5%	5.4%	5.2%	5.1%	4.9%	4.7%	4.5%	4.3%	4.0%	3.8%	3.6%	3.3%
0.78%	0.79%	0.79%	0.79%	0.79%	0.79%	0.78%	0.76%	0.75%	0.73%	0.71%	0.68%	0.66%	0.63%	0.60%	0.57%	0.54%	0.50%	0.47%
			1.6%															
0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%	0.09%
94.01%	93.93%	93.84%	93.75%	93.67%	93.58%	93.49%	93.41%	93.32%	93.24%	93.15%	93.06%	92.98%	92.89%	92.81%	92.72%	92.63%	92.55%	92.50%
112,815	112,711	112,607	112,503	112,399	112,295	112,191	112,088	111,985	111,882	111,779	111,676	111,573	111,470	111,367	111,264	111,161	63,058	15,000
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	48,000	48,000
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	419,204	433,218
221,766	234,130	247,264	261,154	275,775	291,092	307,055	323,605	340,664	358,146	375,953	393,979	412,108	430,221	448,196	465,909	483,242	283,942	69,801
199	210	222	235	248	262	277	290	305	322	338	355	372	389	406	423	440	456	266
18.48	19.51	20.61	21.76	22.98	24.26	25.59	26.97	28.39	29.85	31.33	32.83	34.34	35.85	37.35	38.83	40.27	23.66	5.82
3	3	4	4	4	4	4	5	5	5	5	5	6	6	6	6	7	4	1
0.96%	0.97%	0.98%	0.98%	0.98%	0.98%	0.97%	0.96%	0.94%	0.92%	0.90%	0.88%	0.85%	0.82%	0.79%	0.76%	0.73%	0.69%	0.66%
0.42%	0.43%	0.43%	0.44%	0.44%	0.44%	0.44%	0.43%	0.43%	0.42%	0.42%	0.41%	0.40%	0.39%	0.38%	0.37%	0.36%	0.35%	0.34%
14,084	15,037	15,997	16,956	17,902	18,823	19,706	20,538	21,305	21,995	22,593	23,088	23,469	23,726	23,853	23,845	23,699	23,419	13,064
1.85	1.95	2.06	2.18	2.30	2.43	2.56	2.70	2.84	2.98	3.13	3.28	3.43	3.59	3.73	3.88	4.03	4.17	4.24
1.17	1.17	1.18	1.18	1.18	1.18	1.19	1.19	1.19	1.19	1.20	1.20	1.21	1.21	1.22	1.22	1.23	1.23	1.23
1.15	1.15	1.16	1.16	1.16	1.16	1.17	1.17	1.17	1.17	1.18	1.18	1.19	1.19	1.19	1.20	1.20	1.21	1.21
-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	1.00	1.00	1.00	1.00	-
$ 18,310	$ 19,548	$ 20,796	$ 22,043	$ 23,272	$ 24,470	$ 25,618	$ 26,699	$ 27,697	$ 28,593	$ 29,371	$ 30,015	$ 30,510	$ 30,844	$ 31,009	$ 30,998	$ 30,809	$ 30,444	$ 16,983
$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,064	$ 2,695	$ 2,695	$ 2,695	$ 2,695	$ 2,695	$ 2,064
$ 2,652	$ 3,462	$ 3,729	$ 4,483	$ 4,703	$ 4,893	$ 5,049	$ 5,166	$ 5,241	$ 5,273	$ 5,262	$ 5,206	$ 5,108	$ 4,971	$ 4,289	$ 4,083	$ 3,321	$ 549	$ -
$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489	$ 489
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 3,527	$ 3,834	$ 4,062	$ 4,362	$ 4,579	$ 4,787	$ 4,983	$ 5,163	$ 5,324	$ 5,463	$ 5,578	$ 5,666	$ 5,726	$ 5,850	$ 5,772	$ 5,740	$ 5,597	$ 5,127	$ 2,930
$ 764	$ 796	$ 831	$ 869	$ 908	$ 950	$ 993	$ 1,038	$ 1,084	$ 1,132	$ 1,181	$ 1,230	$ 1,281	$ 1,332	$ 1,383	$ 1,434	$ 1,484	$ 1,206	$ 976
$ 27,805	$ 30,193	$ 31,971	$ 34,308	$ 36,015	$ 37,652	$ 39,194	$ 40,617	$ 41,898	$ 43,014	$ 43,944	$ 44,670	$ 45,177	$ 46,180	$ 45,637	$ 45,439	$ 44,395	$ 40,509	$ 23,441
$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610	$ 2,610
$ 1,223	$ 1,276	$ 1,332	$ 1,392	$ 1,455	$ 1,521	$ 1,590	$ 1,661	$ 1,734	$ 1,810	$ 1,887	$ 1,965	$ 2,044	$ 2,126	$ 2,206	$ 2,286	$ 2,364	$ 2,435	$ 2,478
$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7	$ 1,017.7
$ 4,851	$ 4,904	$ 4,960	$ 5,020	$ 5,083	$ 5,149	$ 5,218	$ 5,289	$ 5,362	$ 5,438	$ 5,515	$ 5,593	$ 5,672	$ 5,753	$ 5,834	$ 5,914	$ 5,992	$ 6,063	$ 6,106
$ 32,655	$ 35,097	$ 36,931	$ 39,328	$ 41,098	$ 42,801	$ 44,412	$ 45,906	$ 47,260	$ 48,451	$ 49,458	$ 50,263	$ 50,849	$ 51,934	$ 51,471	$ 51,352	$ 50,387	$ 46,573	$ 29,547
$ 927,897	$ 962,993	$ 999,924	$ 1,039,252	$ 1,080,350	$ 1,123,151	$ 1,167,563	$ 1,213,469	$ 1,260,730	$ 1,309,181	$ 1,358,639	$ 1,408,902	$ 1,459,751	$ 1,511,685	$ 1,563,156	$ 1,614,508	$ 1,664,895	$ 1,711,468	$ 1,741,015
$ 8.22	$ 8.54	$ 8.88	$ 9.24	$ 9.61	$ 10.00	$ 10.41	$ 10.83	$ 11.26	$ 11.70	$ 12.15	$ 12.62	$ 13.08	$ 13.56	$ 14.04	$ 14.51	$ 14.98	$ 15.41	$ 15.68
$ 4.18	$ 4.11	$ 4.04	$ 3.98	$ 3.92	$ 3.86	$ 3.80	$ 3.75	$ 3.70	$ 3.66	$ 3.61	$ 3.58	$ 3.54	$ 3.51	$ 3.49	$ 3.47	$ 3.45	$ 3.79	$ 4.24
$ 1.75	$ 1.72	$ 1.70	$ 1.68	$ 1.66	$ 1.64	$ 1.62	$ 1.61	$ 1.59	$ 1.58	$ 1.56	$ 1.55	$ 1.54	$ 1.53	$ 1.53	$ 1.52	$ 1.51	$ 1.51	$ 1.50

17.0	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
31-Oct-98	**7-Nov-98**	**14-Nov-98**	**21-Nov-98**	**28-Nov-98**	**5-Dec-98**	**12-Dec-98**	**19-Dec-98**	**26-Dec-98**	**2-Jan-99**	**9-Jan-99**	**16-Jan-99**	**23-Jan-99**	**30-Jan-99**	**6-Feb-99**	**13-Feb-99**	**20-Feb-99**	**27-Feb-99**	**6-Mar-99**
13.35	**12.77**	**12.18**	**11.59**	**11.01**	**10.45**	**9.90**	**9.39**	**8.92**	**8.50**	**8.12**	**7.81**	**7.56**	**7.37**	**7.25**	**7.20**	**7.22**	**7.32**	**7.48**
13.35	12.77	12.18	11.59	11.01	10.45	9.90	9.39	8.92	8.50	8.12	7.81	7.56	7.37	7.25	7.20	7.22	7.32	7.48
12.72	12.20	11.68	11.15	10.62	10.11	9.63	9.17	8.75	8.36	8.03	7.75	7.52	7.35	7.24	7.20	7.22	7.31	7.45
30	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**
6,804.44	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
4,798.0	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
9.31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4,798.0																		
2.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.1%																		
0.44%																		
0.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
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13-Mar-99	**20-Mar-99**	**27-Mar-99**	**3-Apr-99**	**10-Apr-99**	**17-Apr-99**	**24-Apr-99**	**1-May-99**	**8-May-99**	**15-May-99**	**22-May-99**	**29-May-99**	**5-Jun-99**	**12-Jun-99**	**19-Jun-99**	**26-Jun-99**	**3-Jul-99**	**10-Jul-99**	**17-Jul-99**
7.71	**8.00**	**8.36**	**8.76**	**9.22**	**9.72**	**10.25**	**10.81**	**11.39**	**11.97**	**12.56**	**13.15**	**13.71**	**14.26**	**14.77**	**15.25**	**15.67**	**16.05**	**16.37**
7.71	8.00	8.36	8.76	9.22	9.72	10.25	10.81	11.39	11.97	12.56	13.15	13.71	14.26	14.77	15.25	15.67	16.05	16.37
7.66	7.92	8.24	8.60	9.01	9.46	9.94	10.44	10.96	11.49	12.02	12.54	13.05	13.54	14.00	14.43	14.81	15.15	15.44
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24-Jul-99	**31-Jul-99**	**7-Aug-99**	**14-Aug-99**	**21-Aug-99**	**28-Aug-99**	**4-Sep-99**	**11-Sep-99**	**18-Sep-99**	**25-Sep-99**	**2-Oct-99**	**9-Oct-99**	**16-Oct-99**	**23-Oct-99**	**30-Oct-99**	**6-Nov-99**	**13-Nov-99**	**20-Nov-99**	**27-Nov-99**
16.63	**16.82**	**16.94**	**17.00**	**16.98**	**16.89**	**16.73**	**16.51**	**16.22**	**15.87**	**15.47**	**15.01**	**14.52**	**13.99**	**13.43**	**12.86**	**12.27**	**11.68**	**11.09**
16.63	16.82	16.94	17.00	16.98	16.89	16.73	16.51	16.22	15.87	15.47	15.01	14.52	13.99	13.43	12.86	12.27	11.68	11.09
15.67	15.84	15.95	16.00	15.98	15.90	15.76	15.56	15.30	14.99	14.62	14.22	13.77	13.30	12.80	12.28	11.75	11.22	10.70
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4-Dec-99	11-Dec-99	18-Dec-99	25-Dec-99	31-Oct-98
10.53	**9.98**	**9.46**	**8.99**	**13.16**
10.53	9.98	9.46	8.99	
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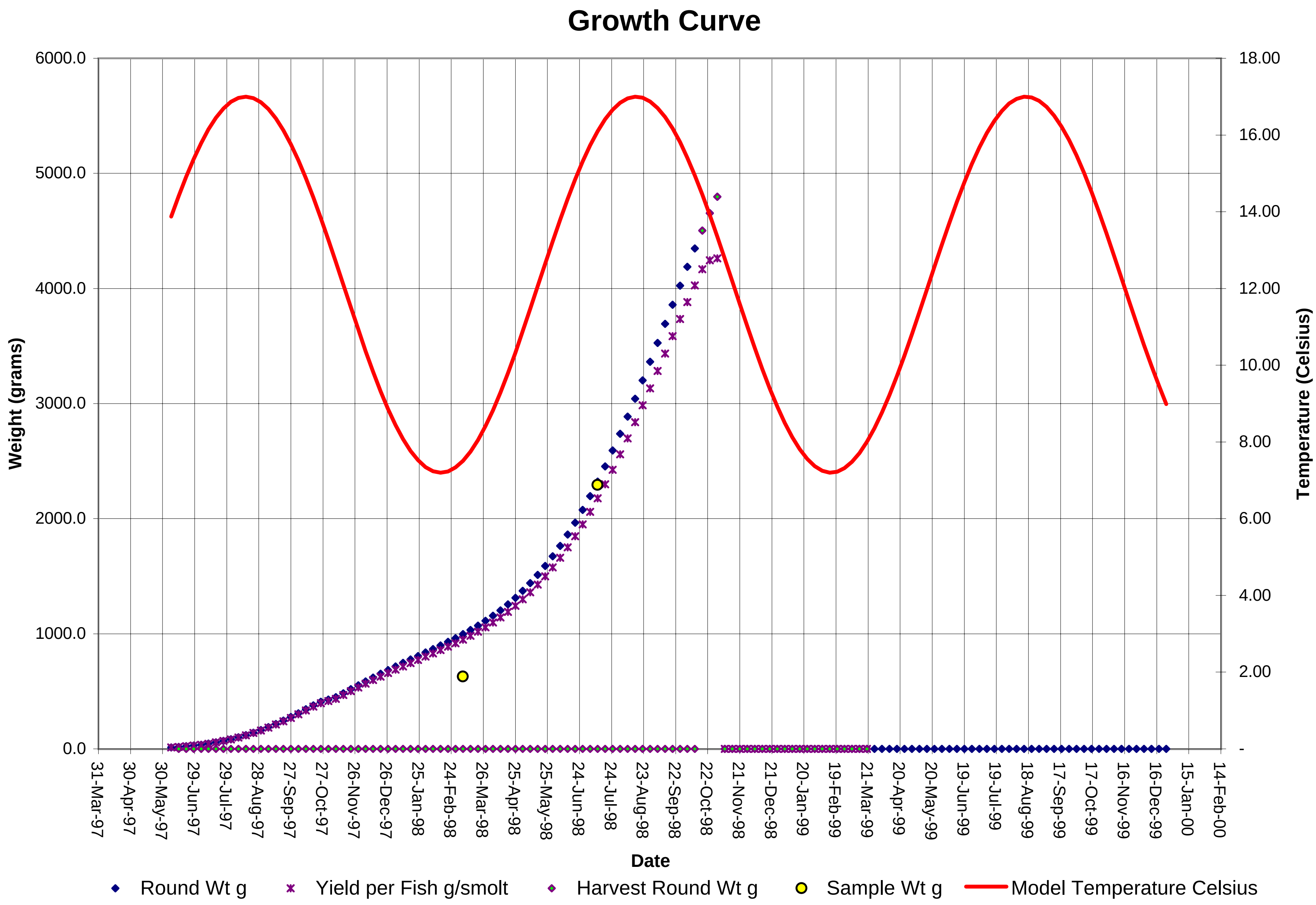
-	-	-	-	1
				$ 120,000
$ -	$ -	$ -	$ -	$ 819,100
$ -	$ -	$ -	$ -	$ 155,881
$ -	$ -	$ -	$ -	$ 82,970
$ -	$ -	$ -	$ -	$ 34,961
$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ 163,937
$ -	$ -	$ -	$ -	$ 41,049
$ -	**$ -**	**$ -**	**$ -**	**$ 1,417,897**
$ -	$ -	$ -	$ -	$ 193,157
$ -	$ -	$ -	$ -	$ 68,720
$ -	$ -	$ -	$ -	$ 75,308
$ -	$ -	$ -	$ -	$ 337,185
$ -	**$ -**	**$ -**	**$ -**	**$ 1,755,082**
$ -	$ -	$ -	$ -	$ 1,755,082
$ -	**$ -**	**$ -**	**$ -**	**$ 15.81**
$ -	**$ -**	**$ -**	**$ -**	**3.43**
$ -	**$ -**	**$ -**	**$ -**	**$ 1.77**



Growth Curve
Weight (grams)
Temperature (Celsius)
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
-
31-Mar-97
30-Apr-97
30-May-97
29-Jun-97
29-Jul-97
28-Aug-97
27-Sep-97
27-Oct-97
26-Nov-97
26-Dec-97
25-Jan-98
24-Feb-98
26-Mar-98
25-Apr-98
25-May-98
24-Jun-98
24-Jul-98
23-Aug-98
22-Sep-98
22-Oct-98
21-Nov-98
21-Dec-98
20-Jan-99
19-Feb-99
21-Mar-99
20-Apr-99
20-May-99
19-Jun-99
19-Jul-99
18-Aug-99
17-Sep-99
17-Oct-99
16-Nov-99
16-Dec-99
15-Jan-00
14-Feb-00
Date
Round Wt g
Yield per Fish g/smolt
Harvest Round Wt g
Sample Wt g
Model Temperature Celsius

Future SEA Kisutch Inlet : Seawater Growout

Coho 2000YC Reared in 12 Steel 15x15x15 - Quote# 003-01

(All Values in CDN Dollars)

Physical System				
Type		Steel 15x15x15		
Number of Units		12		
Volume	*m3*	40,500		
Initial Production Values				
Start Date		1-Jun-97		
Start Population		120,000		
Start Weight	*g*	10		
Stocking Density	*kg/m3*	0.03		
Ending Production Values				
End Date		26-Dec-98		
ATU	*celsius*	7,408		
Production Cycle	*month*	18.8	*573*	*days*
Harvest Time	*week*	3		
Harvest Number	*pieces*	103,604		
Survival	*%*	86.3%		
Feed	*kg*	764,297		
SDE	*days*	17		
End Weight	*kg*	4,713.1		
Harvest Biomass	*rnd kg*	476,660		
Mean Harvest Weight	*rnd g*	4,600.8		
Harvest Biomass	*dr lbs*	924,492		
Mean Harvest Weight	*dr lbs*	8.9		
Mort Biomass	*kg*	21,444		
Max Density	*kg/m3*	11.4		
Environmental				
Mean Temperature	*celsius*	12.93		
Mean Salinity	*ppt*	30.00		
Mean Oxygen (Ambient)	*mg/l*	7.56		
Supplemental O2	*m3*	-		
Oxygen need	*kgO2/rnd kg produced*	-		
Biological Performance				
Mortality Rate		13.7%		
Yield	*Kg/Smolt*	3.97		
EFCR		1.61		
BFCR		1.54		
SGR		1.07%		
Gc (TGC, GF3)		1.95		

Economic Performance - Cost of Production ($CDN)		Total	% of DFC	DFC /dr lb	% of COP	COP /rnd kg
Seed stock - Smolt/fry	$	120,000	8%	$ 0.13	7%	$ 0.25
Feed	$	993,586	65%	$ 1.07	57%	$ 2.08
Labour	$	167,759	11%	$ 0.18	10%	$ 0.35
Oxygen	$	-	0%	$ -	0%	$ -
Pumping	$	-	0%	$ -	0%	$ -
Health/Vaccine	$	4,767	0%	$ 0.01	0%	$ 0.01
Other Direct Costs	$	174,202	11%	$ 0.19	10%	$ 0.37
Insurance	$	59,079	4%	$ 0.06	3%	$ 0.12
Direct Farm Costs (DFC)	**$**	**1,519,392**	**100%**	**$ 1.64**	**88%**	**$ 3.19**
Depreciation	$	100,608			6%	$ 0.21
Interest - Operating Cost	$	84,402			5%	$ 0.18
Interest - Capital Investments	$	28,970			2%	$ 0.06
Total Cost of Production (COP)	**$**	**1,733,372**			**100%**	**$ 3.64**
COP per fish	**$**	**16.73**				
COP per Rnd Kg	**$**	**3.64**				
COP per Dr Lb	**$**	**1.87**				

Future SEA Kisutch Inlet : Seawater Growout
Coho 2000YC Reared in 12 Steel 15x15x15 - Quote# 003-01
(All Values in CDN Dollars)

Production Characteristics

Company/Site	**Future SEA**	Quote# 003-01
Location	**Kisutch Inlet**	
Type		
Site		

Stocking Parameters

Species			
Strain *			
BY / YC	**2000**		
Start Date	**1-Jun-97**		t_0
Start Weight	**10.0**	Grams	W_0
Start Population	**120,000**	Pieces	N_0
Target Weight	**4,500**	Grams	Wt
Min Harvest Pieces	**24,000**	Pieces	
Max Harvest Pieces	**48,000**	Pieces	

System Characteristics and Management Parameters

SEA System^{TM} Model				
Volume	3,375	m3		
Number of Units	**12**			
Rearing Volume	40,500	m3		
Max Rearing Density	**12**	kg/m3		
Max Flow per Unit	67,500	l/min		
Min Flow per Unit	33,750	l/min		
Desirable Oxygen at the Outlet	**6.5**	mg/l		
O2 Transfer Efficiency	**80%**			
O2 Saturation	**85%**			
Max[TAN]	0.50	mg/l		
Early Monthly Mortality Rate	**2.00%**	for the first	**1**	month(s)
Later Monthly Mortality Rate	**0.75%**	thereafter		

Water Temperature

Set for Northern Hemisphere

	Date	*Surface (Upper Layer/Above Thermocline)* Degree Celsius		*Depth (Bottom Layer/Below Thermocline)* Degree Celsius	
High	**15-Aug-98**	**17**	deg C	**16**	deg C
Mid	16-May-98	12.1	deg C	11.6	deg C
Low	**15-Feb-98**	**7.2**	deg C	**7.2**	deg C

Financial Assumptions

	$US/$CDN	
All Numbers in Canadian $	**$ 0.6967**	☐ Use US Currency

Variable Costs

Feed Cost	**$ 1.30**	per kg
Oxygen Cost	**$ 0.80**	per m3
Pumping Cost	**$ 0.07**	per kWhr
Insurance Premium	3.5%	

Fixed Costs

Site Manager	**$ 3,000**	per month	$ 36,000	per year
Technician	**$ 2,250**		$ 27,000	per year
Minimum Number of Technicians (F/T)	**2.0**			
Additional Technician	**100.0**	tons of production		
Benefits (%Wages)	**10%**			
Direct Costs as % of other Op. Cost	**15%**			
Smolt Unit Cost	**$ 1.00**			

	Years	Annual Depreciation Rate
Depreciation - Bag	3	33%
Depreciation - Other	7	14%

Capital Cost

Cage System	**$ 264,600**
Treated Net	**$ 60,000**
Mooring	**$ 42,000**
Walkway	**$ -**
Feed System	**$ -**
Feed Boat	**$ -**
Barge with Building	**$ -**
Barge	**$ -**
Building	**$ -**
	$ 366,600

Replacement Net	$ 60,000

Interest Rate

Operating Expenses	**9%**
Capital Investments	**8%**

Future SEA Kisutch Inlet : Seawater Growout
Coho 2000YC Reared in 12 Steel 15x15x15 - Quote# 003-01

Feeding Efficiency

	Externalities				
FCR Level	**Causes**	**Base Units**	**Deviation**	**Conversion Ratio**	**Improvement Factor Over Reference (%)**
TFCR				**0.85**	
	Feeding	0.35	41%		- 80 0
	Disease	0.15	18%		- 50 0
	Site	0.06	7%		- 40 0
	Lice	0.00	0%		0
	Other	0.09	11%		- 15 6
	Dust	0.01	1%		1
	Total	0.66	78%		
BFCR				**1.509**	
Extrinsic Factor (EF - Deviation of BFCR from TFCR)			78%		

Growth Cycle	Month	0.2	0.4	0.7	0.9	1.1	1.3	1.6	1.8	2.0	2.3	2.5	2.7	3.0	3.2	3.4	3.6	3.9	4.1	4.3	4.6	4.8
Week	StartDate is 1/6/1997	7-Jun-97	14-Jun-97	21-Jun-97	28-Jun-97	5-Jul-97	12-Jul-97	19-Jul-97	26-Jul-97	2-Aug-97	9-Aug-97	16-Aug-97	23-Aug-97	30-Aug-97	6-Sep-97	13-Sep-97	20-Sep-97	27-Sep-97	4-Oct-97	11-Oct-97	18-Oct-97	25-Oct-97
Environmental																						
Model Temperature	Celsius	13.87	14.41	14.91	15.37	15.79	16.15	16.45	16.69	16.86	16.97	17.00	16.96	16.85	16.68	16.43	16.13	15.76	15.34	14.88	14.37	13.83
Upper Layer Temperature	Celsius	13.87	14.41	14.91	15.37	15.79	16.15	16.45	16.69	16.86	16.97	17.00	16.96	16.85	16.68	16.43	16.13	15.76	15.34	14.88	14.37	13.83
Bottom Layer Temperature	Celsius	13.19	13.67	14.12	14.54	14.91	15.24	15.51	15.72	15.88	15.97	16.00	15.97	15.87	15.71	15.49	15.21	14.89	14.51	14.09	13.64	13.16
Salinity	ppt	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
ATU	Celsius	83	184.10	288.48	396.09	506.61	619.65	734.81	851.65	969.69	1,088.46	1,207.46	1,326.19	1,444.16	1,560.90	1,675.92	1,788.80	1,899.12	2,006.51	2,110.65	2,211.25	2,308.08
Growth																						
Round Wt	g	12.8	16.9	21.9	28.0	35.4	44.2	54.6	66.6	80.4	96.1	113.8	133.5	155.1	178.7	204.2	231.4	260.3	290.6	322.0	354.5	382.8
Sample Wt	g																					
Dr. Wt	lbs	0.02	0.03	0.04	0.05	0.07	0.09	0.11	0.13	0.16	0.19	0.22	0.26	0.30	0.35	0.40	0.45	0.50	0.56	0.62	0.69	0.74
Harvest Round Wt	g																					
Month Gc	1		1.22	1.59	1.76	1.86	1.93	1.98	2.01	2.04	2.06	2.08	2.09	2.10	2.11	2.12	2.12	2.13	2.13	2.14	2.14	2.13
Gc Factor	%																					
Growth	% per Week		31.7%	29.8%	28.0%	26.4%	24.8%	23.4%	22.0%	20.8%	19.5%	18.4%	17.3%	16.2%	15.2%	14.3%	13.3%	12.5%	11.6%	10.8%	10.1%	8.0%
Sgr		4.13%	3.93%	3.72%	3.53%	3.34%	3.17%	3.00%	2.85%	2.70%	2.55%	2.41%	2.28%	2.15%	2.02%	1.90%	1.79%	1.68%	1.57%	1.47%	1.37%	1.10%
Inventory																						
Mort Rate	% per Week	0.46%	0.46%	0.46%	0.46%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%
Survival	%	99.91%	99.45%	99.00%	98.54%	98.37%	98.20%	98.03%	97.86%	97.69%	97.53%	97.36%	97.19%	97.02%	96.86%	96.69%	96.52%	96.36%	96.19%	96.02%	95.86%	95.69%
Close Inventory		119,891	119,341	118,794	118,249	118,045	117,841	117,638	117,435	117,233	117,031	116,829	116,628	116,427	116,226	116,026	115,826	115,626	115,427	115,228	115,029	114,831
Harvest	#		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass																						
Harvest Biomass	Dr Lb		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	kg	1,536	2,014	2,601	3,314	4,181	5,210	6,418	7,819	9,427	11,250	13,295	15,566	18,060	20,773	23,693	26,808	30,097	33,539	37,109	40,780	43,961
Mort Biomass	Kg		8	11	14	6	8	10	12	15	18	21	25	29	34	38	44	49	55	61	67	73
Density																						
Density	kg/m3	0.04	0.05	0.06	0.08	0.10	0.13	0.16	0.19	0.23	0.28	0.33	0.38	0.45	0.51	0.59	0.66	0.74	0.83	0.92	1.01	1.09
Number of Bags Required	#	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
Feed																						
Feed Rate	%Bwt/day	5.10%	4.98%	4.72%	4.47%	4.24%	4.02%	3.82%	3.62%	3.44%	3.26%	3.09%	2.93%	2.77%	2.62%	2.47%	2.33%	2.20%	2.07%	1.94%	1.82%	1.55%
Feed Rate (maintenance)	%Bwt/day	1.40%	1.41%	1.36%	1.31%	1.27%	1.22%	1.18%	1.14%	1.10%	1.06%	1.02%	0.98%	0.94%	0.90%	0.87%	0.83%	0.79%	0.76%	0.72%	0.69%	0.65%
Starve days	day																					1
Feed	Kg	367	536	665	814	984	1,177	1,393	1,628	1,882	2,151	2,433	2,724	3,018	3,310	3,596	3,870	4,126	4,359	4,565	4,741	4,418
Performance																						
Yield per Fish	kg/smolt	0.01	0.02	0.02	0.03	0.03	0.04	0.05	0.07	0.08	0.09	0.11	0.13	0.15	0.17	0.20	0.22	0.25	0.28	0.31	0.34	0.37
EFCR			1.12	1.13	1.13	1.13	1.14	1.14	1.15	1.15	1.16	1.16	1.17	1.17	1.18	1.19	1.19	1.20	1.21	1.22	1.22	1.23
BFCR			1.12	1.12	1.12	1.12	1.12	1.13	1.14	1.14	1.15	1.15	1.16	1.16	1.17	1.18	1.18	1.19	1.20	1.20	1.21	1.22
Metabolism																						
Metabolism	mg/kg/hr	752.32	749.10	743.60	735.74	725.50	712.92	698.10	681.18	662.32	641.72	619.60	596.20	571.75	546.49	520.66	494.50	468.24	442.07	416.20	390.82	325.52
Oxygen Available																						
Inlet O2	mg/l	7.42	7.27	7.27	7.12	7.12	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98	7.12	7.12	7.27	7.27	7.42
outlet O2	mg/l	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Available O2	mg/l	0.92	0.77	0.77	0.62	0.62	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.62	0.62	0.77	0.77	0.92
Required flow rate	l/min	20,829	32,578	41,773	65,146	81,034	128,463	154,959	184,216	215,933	249,678	284,903	320,961	357,123	392,615	426,656	458,480	376,489	396,102	333,546	344,186	257,910
Required O2	mg/hr	1,155,724	1,508,544	1,934,310	2,438,484	3,033,183	3,714,368	4,480,485	5,326,430	6,243,491	7,219,196	8,237,691	9,280,268	10,325,850	11,352,070	12,336,318	13,256,500	14,092,365	14,826,512	15,444,841	15,937,548	14,310,120
Feasible Flow Rate per Unit	l/min	33,750	33,750	41,773	65,146	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500
Total Available O2 for 12 Units	mg/hr	22,471,425	18,753,525	23,211,725	29,261,805	30,319,110	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	30,319,110	30,319,110	37,507,050	37,507,050	44,942,850
Theoretical Oxygen Consumption																						
Metabolic Rate	mgO2/kg/hr	752.32	749.10	743.60	735.74	725.50	712.92	698.10	681.18	662.32	641.72	619.60	596.20	571.75	546.49	520.66	494.50	468.24	442.07	416.20	390.82	325.52
Biomass	kg	1,536	2,014	2,601	3,314	4,181	5,210	6,418	7,819	9,427	11,250	13,295	15,566	18,060	20,773	23,693	26,808	30,097	33,539	37,109	40,780	43,961
Theoretical O2 consumption	mg/hr	1,155,724	1,508,544	1,934,310	2,438,484	3,033,183	3,714,368	4,480,485	5,326,430	6,243,491	7,219,196	8,237,691	9,280,268	10,325,850	11,352,070	12,336,318	13,256,500	14,092,365	14,826,512	15,444,841	15,937,548	14,310,120
Pumping & Supplemental Oxygen																						
Total O2 Deficit	mg/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total O2 Supplemental Required	L/hr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	L/Month	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumping Requirement	KWhr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labour																						
Additional Labour Requirement		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cost of Production																						
Smolt Cost		$ 120,000																				
Feed Cost		$ 477	$ 697	$ 864	$ 1,058	$ 1,279	$ 1,531	$ 1,810	$ 2,116	$ 2,446	$ 2,797	$ 3,163	$ 3,541	$ 3,923	$ 4,304	$ 4,675	$ 5,031	$ 5,363	$ 5,667	$ 5,935	$ 6,163	$ 5,744
Labour Cost		$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893
Cost of Oxygen		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Pumping Cost		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Health/Vaccine		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Other Direct Costs		$ 356	$ 389	$ 414	$ 443	$ 476	$ 514	$ 556	$ 601	$ 651	$ 704	$ 759	$ 815	$ 872	$ 930	$ 985	$ 1,039	$ 1,089	$ 1,134	$ 1,174	$ 1,208	$ 1,146
Insurance		$ 83	$ 85	$ 87	$ 89	$ 91	$ 94	$ 97	$ 100	$ 204	$ 211	$ 218	$ 226	$ 235	$ 244	$ 254	$ 265	$ 276	$ 287	$ 299	$ 311	$ 323
Total Operating Cost		**$ 122,809**	**$ 3,063**	**$ 3,258**	**$ 3,483**	**$ 3,740**	**$ 4,032**	**$ 4,356**	**$ 4,711**	**$ 5,194**	**$ 5,604**	**$ 6,033**	**$ 6,476**	**$ 6,924**	**$ 7,371**	**$ 7,808**	**$ 8,227**	**$ 8,621**	**$ 8,981**	**$ 9,301**	**$ 9,576**	**$ 9,106**
(All Values in CDN Dollars)																						
Depreciation		*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*
Depreciation (over rearing period)		$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227
Interest - ShortTerm Loans		$ 182	$ 218	$ 223	$ 230	$ 236	$ 244	$ 251	$ 260	$ 269	$ 279	$ 289	$ 301	$ 313	$ 326	$ 339	$ 354	$ 369	$ 384	$ 401	$ 417	$ 433
Interest - Long Term Loans		$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3
Total Financial Costs		$ 1,762	$ 1,798	$ 1,804	$ 1,810	$ 1,817	$ 1,824	$ 1,832	$ 1,840	$ 1,849	$ 1,859	$ 1,870	$ 1,881	$ 1,893	$ 1,906	$ 1,920	$ 1,934	$ 1,949	$ 1,965	$ 1,981	$ 1,998	$ 2,013
			-$ 105,626																			
Monthly Cost of Production		**$ 124,571**	**$ 4,861**	**$ 5,062**	**$ 5,293**	**$ 5,556**	**$ 5,856**	**$ 6,188**	**$ 6,552**	**$ 7,044**	**$ 7,463**	**$ 7,903**	**$ 8,357**	**$ 8,817**	**$ 9,277**	**$ 9,727**	**$ 10,161**	**$ 10,570**	**$ 10,946**	**$ 11,282**	**$ 11,573**	**$ 11,120**
Cumulative COP		$ 124,571	$ 129,432	$ 134,494	$ 139,787	$ 145,343	$ 151,199	$ 157,387	$ 163,939	$ 170,982	$ 178,446	$ 186,349	$ 194,706	$ 203,523	$ 212,799	$ 222,527	$ 232,688	$ 243,258	$ 254,204	$ 265,486	$ 277,059	$ 288,179
COP per fish		**$ 1.04**	**$ 1.08**	**$ 1.13**	**$ 1.18**	**$ 1.23**	**$ 1.28**	**$ 1.34**	**$ 1.40**	**$ 1.46**	**$ 1.52**	**$ 1.60**	**$ 1.67**	**$ 1.75**	**$ 1.83**	**$ 1.92**	**$ 2.01**	**$ 2.10**	**$ 2.20**	**$ 2.30**	**$ 2.41**	**$ 2.51**
COP per Kg (rnd wt)		**$ 81.09**	**$ 64.27**	**$ 51.70**	**$ 42.18**	**$ 34.76**	**$ 29.02**	**$ 24.52**	**$ 20.97**	**$ 18.14**	**$ 15.86**	**$ 14.02**	**$ 12.51**	**$ 11.27**	**$ 10.24**	**$ 9.39**	**$ 8.68**	**$ 8.08**	**$ 7.58**	**$ 7.15**	**$ 6.79**	**$ 6.56**
COP per lb (HOG dr wt)		**$ 41.34**	**$ 32.41**	**$ 25.80**	**$ 20.85**	**$ 17.03**	**$ 14.10**	**$ 11.83**	**$ 10.04**	**$ 8.63**	**$ 7.51**	**$ 6.60**	**$ 5.86**	**$ 5.26**	**$ 4.77**	**$ 4.36**	**$ 4.01**	**$ 3.73**	**$ 3.49**	**$ 3.29**	**$ 3.12**	**$ 3.00**

5.0	5.2	5.5	5.7	5.9	6.2	6.4	6.6	6.9	7.1	7.3	7.5	7.8	8.0	8.2	8.5	8.7	8.9	9.1	9.4	9.6	9.8	10.1	10.3	10.5
1-Nov-97	8-Nov-97	15-Nov-97	22-Nov-97	29-Nov-97	6-Dec-97	13-Dec-97	20-Dec-97	27-Dec-97	3-Jan-98	10-Jan-98	17-Jan-98	24-Jan-98	31-Jan-98	7-Feb-98	14-Feb-98	21-Feb-98	28-Feb-98	7-Mar-98	14-Mar-98	21-Mar-98	28-Mar-98	4-Apr-98	11-Apr-98	18-Apr-98
13.27	**12.69**	**12.10**	**11.51**	**10.93**	**10.37**	**9.83**	**9.32**	**8.86**	**8.44**	**8.07**	**7.77**	**7.52**	**7.35**	**7.24**	**7.20**	**7.23**	**7.34**	**7.51**	**7.75**	**8.05**	**8.41**	**8.83**	**9.29**	**9.79**
13.27	12.69	12.10	11.51	10.93	10.37	9.83	9.32	8.86	8.44	8.07	7.77	7.52	7.35	7.24	7.20	7.23	7.34	7.51	7.75	8.05	8.41	8.83	9.29	9.79
12.65	12.13	11.60	11.07	10.55	10.04	9.56	9.11	8.69	8.31	7.99	7.71	7.49	7.33	7.23	7.20	7.23	7.32	7.48	7.69	7.96	8.29	8.66	9.08	9.53
30	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**
2,400.97	**2,489.79**	**2,574.49**	**2,655.07**	**2,731.58**	**2,804.15**	**2,872.95**	**2,938.21**	**3,000.22**	**3,059.30**	**3,115.82**	**3,170.20**	**3,222.86**	**3,274.29**	**3,324.96**	**3,375.36**	**3,425.99**	**3,477.35**	**3,529.91**	**3,584.15**	**3,640.51**	**3,699.39**	**3,761.18**	**3,826.20**	**3,894.73**
401.6	**420.1**	**452.3**	**484.5**	**516.3**	**547.7**	**578.5**	**608.7**	**638.4**	**667.4**	**695.9**	**723.9**	**751.8**	**779.6**	**807.5**	**835.9**	**865.1**	**895.3**	**926.9**	**960.3**	**995.8**	**1,033.8**	**1,074.7**	**1,118.9**	**1,166.8**
																	627.0							
0.78	0.81	0.88	0.94	1.00	1.06	1.12	1.18	1.24	1.29	1.35	1.40	1.46	1.51	1.57	1.62	1.68	1.74	1.80	1.86	1.93	2.01	2.08	2.17	2.26
2.10	2.07	2.07	2.08	2.08	2.08	2.09	2.09	2.09	2.09	2.09	2.09	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
4.9%	4.6%	7.7%	7.1%	6.6%	6.1%	5.6%	5.2%	4.9%	4.5%	4.3%	4.0%	3.8%	3.7%	3.6%	3.5%	3.5%	3.5%	3.5%	3.6%	3.7%	3.8%	4.0%	4.1%	4.3%
0.68%	0.64%	1.06%	0.98%	0.91%	0.84%	0.78%	0.73%	0.68%	0.63%	0.60%	0.57%	0.54%	0.52%	0.50%	0.49%	0.49%	0.49%	0.50%	0.51%	0.52%	0.54%	0.55%	0.58%	0.60%
0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%
95.53%	95.36%	95.20%	95.03%	94.87%	94.71%	94.54%	94.38%	94.22%	94.06%	93.89%	93.73%	93.57%	93.41%	93.25%	93.09%	92.93%	92.77%	92.61%	92.45%	92.29%	92.13%	91.97%	91.81%	91.65%
114,633	114,435	114,238	114,041	113,844	113,648	113,452	113,256	113,061	112,866	112,671	112,477	112,283	112,089	111,896	111,703	111,510	111,318	111,126	110,934	110,743	110,552	110,361	110,171	109,981
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-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46,035	48,070	51,672	55,248	58,776	62,242	65,633	68,944	72,173	75,323	78,402	81,426	84,411	87,379	90,358	93,377	96,467	99,665	103,007	106,531	110,280	114,291	118,608	123,273	128,325
78	81	86	92	99	104	110	116	122	127	133	138	143	149	153	159	164	169	175	181	187	194	201	208	217
1.14	**1.19**	**1.28**	**1.36**	**1.45**	**1.54**	**1.62**	**1.70**	**1.78**	**1.86**	**1.94**	**2.01**	**2.08**	**2.16**	**2.23**	**2.31**	**2.38**	**2.46**	**2.54**	**2.63**	**2.72**	**2.82**	**2.93**	**3.04**	**3.17**
2	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**4**	**4**
1.16%	1.10%	1.43%	1.33%	1.24%	1.16%	1.08%	1.01%	0.95%	0.89%	0.84%	0.80%	0.76%	0.74%	0.72%	0.71%	0.70%	0.71%	0.72%	0.73%	0.75%	0.78%	0.81%	0.84%	0.87%
0.60%	0.58%	0.57%	0.53%	0.50%	0.47%	0.45%	0.42%	0.40%	0.38%	0.36%	0.34%	0.33%	0.32%	0.31%	0.31%	0.31%	0.31%	0.32%	0.33%	0.33%	0.35%	0.36%	0.37%	0.39%
3	**3**																							
3,560	3,532	4,815	4,826	4,810	4,771	4,713	4,644	4,569	4,496	4,432	4,384	4,359	4,362	4,400	4,478	4,601	4,772	4,994	5,271	5,604	5,994	6,443	6,951	7,517
0.38	0.40	0.43	0.46	0.49	0.52	0.55	0.57	0.60	0.63	0.65	0.68	0.70	0.73	0.75	0.78	0.80	0.83	0.86	0.89	0.92	0.95	0.99	1.03	1.07
1.26	1.28	1.28	1.29	1.29	1.30	1.30	1.31	1.31	1.32	1.32	1.33	1.33	1.34	1.34	1.35	1.35	1.35	1.36	1.36	1.37	1.37	1.38	1.38	1.39
1.24	1.26	1.26	1.27	1.27	1.27	1.28	1.28	1.29	1.29	1.29	1.30	1.30	1.30	1.31	1.31	1.32	1.32	1.32	1.33	1.33	1.33	1.34	1.34	1.34
228.28	215.24	305.05	283.76	263.79	245.21	228.09	212.49	198.46	186.04	175.25	166.09	158.56	152.65	148.32	145.51	144.15	144.17	145.44	147.84	151.23	155.45	160.32	165.66	171.29
7.42	7.58	7.58	7.75	7.92	7.92	8.10	8.10	8.29	8.29	8.29	8.48	8.48	8.48	8.48	8.48	8.48	8.48	8.48	8.48	8.29	8.29	8.29	8.10	8.10
6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
0.92	1.08	1.08	1.25	1.42	1.42	1.60	1.60	1.79	1.79	1.79	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.79	1.79	1.79	1.60	1.60
189,402	159,000	242,227	208,980	181,613	178,775	155,726	152,395	133,427	130,534	127,986	113,615	112,443	112,057	112,588	114,147	116,828	120,712	125,859	132,315	155,353	165,493	177,126	212,431	228,650
10,508,971	10,346,591	15,762,437	15,677,259	15,504,468	15,262,162	14,970,230	14,650,036	14,323,706	14,013,093	13,739,603	13,523,706	13,384,201	13,338,311	13,401,495	13,587,000	13,906,171	14,368,473	14,981,144	15,749,589	16,677,426	17,766,025	19,014,861	20,421,435	21,980,573
67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500
44,942,850	52,709,130	52,709,130	60,764,580	69,150,510	69,150,510	77,866,920	77,866,920	86,955,120	86,955,120	86,955,120	96,415,110	96,415,110	96,415,110	96,415,110	96,415,110	96,415,110	96,415,110	96,415,110	96,415,110	86,955,120	86,955,120	86,955,120	77,866,920	77,866,920
228.28	215.24	305.05	283.76	263.79	245.21	228.09	212.49	198.46	186.04	175.25	166.09	158.56	152.65	148.32	145.51	144.15	144.17	145.44	147.84	151.23	155.45	160.32	165.66	171.29
46,035	48,070	51,672	55,248	58,776	62,242	65,633	68,944	72,173	75,323	78,402	81,426	84,411	87,379	90,358	93,377	96,467	99,665	103,007	106,531	110,280	114,291	118,608	123,273	128,325
10,508,971	10,346,591	15,762,437	15,677,259	15,504,468	15,262,162	14,970,230	14,650,036	14,323,706	14,013,093	13,739,603	13,523,706	13,384,201	13,338,311	13,401,495	13,587,000	13,906,171	14,368,473	14,981,144	15,749,589	16,677,426	17,766,025	19,014,861	20,421,435	21,980,573
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$ 4,628	$ 4,592	$ 6,259	$ 6,274	$ 6,253	$ 6,202	$ 6,127	$ 6,037	$ 5,940	$ 5,845	$ 5,762	$ 5,699	$ 5,666	$ 5,670	$ 5,720	$ 5,821	$ 5,981	$ 6,203	$ 6,492	$ 6,852	$ 7,285	$ 7,793	$ 8,376	$ 9,036	$ 9,772
$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*	*$ -*
$ 978	$ 973	$ 1,223	$ 1,225	$ 1,222	$ 1,214	$ 1,203	$ 1,190	$ 1,175	$ 1,161	$ 1,148	$ 1,139	$ 1,134	$ 1,135	$ 1,142	$ 1,157	$ 1,181	$ 1,214	$ 1,258	$ 1,312	$ 1,377	$ 1,453	$ 1,540	$ 1,639	$ 1,750
$ 334	$ 344	$ 356	$ 368	$ 381	$ 394	$ 406	$ 418	$ 431	$ 443	$ 455	$ 466	$ 478	$ 490	$ 502	$ 513	$ 525	$ 538	$ 551	$ 564	$ 578	$ 592	$ 608	$ 624	$ 642
$ 7,834	**$ 7,803**	**$ 9,731**	**$ 9,761**	**$ 9,750**	**$ 9,703**	**$ 9,630**	**$ 9,539**	**$ 9,439**	**$ 9,342**	**$ 9,258**	**$ 9,198**	**$ 9,171**	**$ 9,188**	**$ 9,257**	**$ 9,385**	**$ 9,581**	**$ 9,849**	**$ 10,194**	**$ 10,621**	**$ 11,133**	**$ 11,731**	**$ 12,418**	**$ 13,193**	**$ 14,057**
$ 1,227	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*
$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227
$ 447	$ 461	$ 478	$ 495	$ 512	$ 529	$ 546	$ 562	$ 579	$ 595	$ 612	$ 628	$ 644	$ 660	$ 676	$ 693	$ 710	$ 727	$ 745	$ 764	$ 783	$ 804	$ 826	$ 849	$ 874
$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3
$ 2,027	$ 2,041	$ 2,058	$ 2,075	$ 2,092	$ 2,109	$ 2,126	$ 2,143	$ 2,159	$ 2,176	$ 2,192	$ 2,208	$ 2,224	$ 2,240	$ 2,257	$ 2,273	$ 2,290	$ 2,307	$ 2,325	$ 2,344	$ 2,363	$ 2,384	$ 2,406	$ 2,429	$ 2,454
$ 9,861	**$ 9,844**	**$ 11,789**	**$ 11,836**	**$ 11,842**	**$ 11,812**	**$ 11,756**	**$ 11,681**	**$ 11,598**	**$ 11,518**	**$ 11,450**	**$ 11,406**	**$ 11,396**	**$ 11,428**	**$ 11,513**	**$ 11,659**	**$ 11,871**	**$ 12,156**	**$ 12,520**	**$ 12,965**	**$ 13,496**	**$ 14,115**	**$ 14,824**	**$ 15,622**	**$ 16,511**
$ 298,040	$ 307,884	$ 319,673	$ 331,509	$ 343,351	$ 355,163	$ 366,919	$ 378,600	$ 390,198	$ 401,716	$ 413,166	$ 424,573	$ 435,968	$ 447,397	$ 458,910	$ 470,568	$ 482,439	$ 494,595	$ 507,115	$ 520,080	$ 533,576	$ 547,692	$ 562,515	$ 578,138	$ 594,648
$ 2.60	**$ 2.69**	**$ 2.80**	**$ 2.91**	**$ 3.02**	**$ 3.13**	**$ 3.23**	**$ 3.34**	**$ 3.45**	**$ 3.56**	**$ 3.67**	**$ 3.77**	**$ 3.88**	**$ 3.99**	**$ 4.10**	**$ 4.21**	**$ 4.33**	**$ 4.44**	**$ 4.56**	**$ 4.69**	**$ 4.82**	**$ 4.95**	**$ 5.10**	**$ 5.25**	**$ 5.41**
$ 6.47	**$ 6.40**	**$ 6.19**	**$ 6.00**	**$ 5.84**	**$ 5.71**	**$ 5.59**	**$ 5.49**	**$ 5.41**	**$ 5.33**	**$ 5.27**	**$ 5.21**	**$ 5.16**	**$ 5.12**	**$ 5.08**	**$ 5.04**	**$ 5.00**	**$ 4.96**	**$ 4.92**	**$ 4.88**	**$ 4.84**	**$ 4.79**	**$ 4.74**	**$ 4.69**	**$ 4.63**
$ 2.96	**$ 2.92**	**$ 2.82**	**$ 2.73**	**$ 2.66**	**$ 2.59**	**$ 2.54**	**$ 2.49**	**$ 2.45**	**$ 2.41**	**$ 2.38**	**$ 2.35**	**$ 2.33**	**$ 2.30**	**$ 2.28**	**$ 2.26**	**$ 2.24**	**$ 2.22**	**$ 2.20**	**$ 2.18**	**$ 2.16**	**$ 2.14**	**$ 2.12**	**$ 2.10**	**$ 2.07**

10.8	11.0	11.2	11.4	11.7	11.9	12.1	12.4	12.6	12.8	13.0	13.3	13.5	13.7	14.0	14.2	14.4	14.7	14.9	15.1	15.3	15.6	15.8	16.0	16.3
25-Apr-98	2-May-98	9-May-98	16-May-98	23-May-98	30-May-98	6-Jun-98	13-Jun-98	20-Jun-98	27-Jun-98	4-Jul-98	11-Jul-98	18-Jul-98	25-Jul-98	1-Aug-98	8-Aug-98	15-Aug-98	22-Aug-98	29-Aug-98	5-Sep-98	12-Sep-98	19-Sep-98	26-Sep-98	3-Oct-98	10-Oct-98
10.33	10.89	11.47	12.06	12.65	13.23	13.79	14.33	14.84	15.31	15.73	16.10	16.41	16.66	16.84	16.96	17.00	16.97	16.87	16.71	16.47	16.17	15.82	15.40	14.95
10.33	10.89	11.47	12.06	12.65	13.23	13.79	14.33	14.84	15.31	15.73	16.10	16.41	16.66	16.84	16.96	17.00	16.97	16.87	16.71	16.47	16.17	15.82	15.40	14.95
10.01	10.51	11.03	11.56	12.09	12.61	13.12	13.61	14.06	14.48	14.86	15.19	15.47	15.70	15.86	15.96	16.00	15.97	15.89	15.74	15.52	15.26	14.94	14.57	14.16
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
3,967.03	4,043.25	4,123.54	4,207.94	4,296.47	4,389.07	4,485.63	4,585.96	4,689.86	4,797.03	4,907.15	5,019.86	5,134.75	5,251.37	5,369.27	5,487.97	5,606.96	5,725.76	5,843.88	5,960.81	6,076.11	6,189.32	6,300.03	6,407.86	6,512.48
1,218.7	1,275.2	1,336.4	1,402.8	1,474.7	1,552.5	1,636.3	1,726.3	1,822.8	1,910.0	2,002.2	2,090.5	2,182.8	2,278.9	2,378.5	2,481.1	2,586.3	2,693.5	2,802.3	2,912.0	3,022.0	3,131.6	3,251.6	3,370.1	3,509.2
												1750.0												
2.36	2.47	2.59	2.72	2.86	3.01	3.17	3.35	3.54	3.70	3.88	4.05	4.23	4.42	4.61	4.81	5.02	5.22	5.44	5.65	5.86	6.07	6.31	6.54	6.81
2.10	2.10	2.10	2.10	2.10	2.11	2.11	2.11	2.11	2.10	2.09	2.08	2.07	2.06	2.05	2.04	2.03	2.02	2.01	2.00	1.99	1.99	1.98	1.97	1.97
4.5%	4.6%	4.8%	5.0%	5.1%	5.3%	5.4%	5.5%	5.6%	4.8%	4.8%	4.4%	4.4%	4.4%	4.4%	4.3%	4.2%	4.1%	4.0%	3.9%	3.8%	3.6%	3.8%	3.6%	4.1%
0.62%	0.65%	0.67%	0.69%	0.71%	0.73%	0.75%	0.77%	0.78%	0.67%	0.67%	0.62%	0.62%	0.62%	0.61%	0.60%	0.59%	0.58%	0.57%	0.55%	0.53%	0.51%	0.54%	0.51%	0.58%
0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%
91.49%	91.34%	91.18%	91.02%	90.86%	90.71%	90.55%	90.39%	90.24%	90.08%	89.93%	89.77%	89.62%	89.46%	89.31%	89.16%	89.00%	88.85%	88.70%	88.54%	88.39%	88.24%	88.08%	87.93%	87.78%
109,791	109,602	109,413	109,224	109,036	108,848	108,660	108,473	108,286	108,099	107,913	107,727	107,541	107,356	107,171	106,986	106,802	106,618	106,434	106,250	106,067	105,884	105,701	105,519	105,337
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
133,807	139,759	146,218	153,220	160,799	168,983	177,797	187,260	197,385	206,468	216,062	225,200	234,741	244,654	254,901	265,439	276,218	287,181	298,265	309,405	320,535	331,582	343,699	355,605	369,644
227	236	247	259	270	285	300	314	332	349	364	381	397	413	431	450	466	486	506	526	543	563	584	603	626
3.30	3.45	3.61	3.78	3.97	4.17	4.39	4.62	4.87	5.10	5.33	5.56	5.80	6.04	6.29	6.55	6.82	7.09	7.36	7.64	7.91	8.19	8.49	8.78	9.13
4	4	4	4	4	5	5	5	5	6	6	6	6	7	7	7	7	8	8	8	8	9	9	9	10
0.91%	0.94%	0.98%	1.01%	1.04%	1.07%	1.10%	1.12%	1.14%	1.05%	1.06%	1.02%	1.02%	1.02%	1.01%	1.01%	1.00%	0.98%	0.96%	0.94%	0.92%	0.89%	0.90%	0.87%	0.91%
0.40%	0.42%	0.44%	0.45%	0.46%	0.48%	0.49%	0.50%	0.51%	0.51%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.51%	0.51%	0.50%	0.49%	0.48%	0.47%	0.46%	0.45%
									1	1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1	1	
8,141	8,821	9,556	10,342	11,178	12,057	12,975	13,926	14,902	14,498	15,321	15,357	16,065	16,741	17,377	17,963	18,490	18,949	19,332	19,632	19,840	19,952	20,963	20,913	22,726
1.12	1.16	1.22	1.28	1.34	1.41	1.48	1.56	1.64	1.72	1.80	1.88	1.96	2.04	2.12	2.21	2.30	2.39	2.49	2.58	2.67	2.76	2.86	2.96	3.08
1.39	1.39	1.40	1.40	1.40	1.41	1.41	1.41	1.42	1.43	1.43	1.44	1.45	1.46	1.47	1.48	1.49	1.50	1.51	1.52	1.53	1.54	1.54	1.55	1.55
1.35	1.35	1.35	1.36	1.36	1.36	1.37	1.37	1.37	1.38	1.39	1.40	1.41	1.42	1.42	1.43	1.44	1.45	1.46	1.47	1.47	1.48	1.49	1.50	1.50
177.01	182.63	187.96	192.85	197.13	200.65	203.32	205.03	205.73	182.81	182.49	170.03	168.53	166.24	163.20	159.47	155.11	150.20	144.82	139.06	132.98	126.69	128.15	120.84	127.45
7.92	7.92	7.75	7.58	7.58	7.42	7.42	7.27	7.27	7.12	7.12	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98	7.12	7.12	7.27
6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
1.42	1.42	1.25	1.08	1.08	0.92	0.92	0.77	0.77	0.62	0.62	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.62	0.62	0.77
277,433	298,974	366,364	454,083	487,110	611,105	651,519	829,161	876,951	1,008,344	1,053,389	1,324,337	1,368,253	1,406,647	1,438,770	1,463,990	1,481,814	1,491,867	1,493,946	1,488,019	1,474,238	1,452,895	1,176,689	1,148,054	1,017,414
23,684,710	25,523,704	27,483,911	29,548,571	31,697,706	33,907,188	36,149,552	38,394,296	40,607,237	37,743,330	39,429,395	38,291,894	39,561,672	40,671,777	41,600,590	42,329,812	42,845,182	43,135,846	43,195,961	43,024,576	42,626,105	42,009,005	44,044,639	42,972,816	47,111,345
67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500
69,150,510	69,150,510	60,764,580	52,709,130	52,709,130	44,942,850	44,942,850	37,507,050	37,507,050	30,319,110	30,319,110	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	23,420,340	30,319,110	30,319,110	37,507,050
177.01	182.63	187.96	192.85	197.13	200.65	203.32	205.03	205.73	182.81	182.49	170.03	168.53	166.24	163.20	159.47	155.11	150.20	144.82	139.06	132.98	126.69	128.15	120.84	127.45
133,807	139,759	146,218	153,220	160,799	168,983	177,797	187,260	197,385	206,468	216,062	225,200	234,741	244,654	254,901	265,439	276,218	287,181	298,265	309,405	320,535	331,582	343,699	355,605	369,644
23,684,710	25,523,704	27,483,911	29,548,571	31,697,706	33,907,188	36,149,552	38,394,296	40,607,237	37,743,330	39,429,395	38,291,894	39,561,672	40,671,777	41,600,590	42,329,812	42,845,182	43,135,846	43,195,961	43,024,576	42,626,105	42,009,005	44,044,639	42,972,816	47,111,345
-	-	-	-	-	-	-	887,246	3,100,187	7,424,220	9,110,285	14,871,554	16,141,332	17,251,437	18,180,250	18,909,472	19,424,842	19,715,506	19,775,621	19,604,236	19,205,765	18,588,665	13,725,529	12,653,706	9,604,295
-	-	-	-	-	-	-	819.10	2,862.06	6,853.97	8,410.53	13,729.28	14,901.52	15,926.36	16,783.83	17,457.05	17,932.83	18,201.17	18,256.67	18,098.45	17,730.58	17,160.88	12,671.28	11,681.78	8,866.59
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	1.00	1.00	1.00	1.00	1.00
$ 10,583	$ 11,467	$ 12,423	$ 13,445	$ 14,531	$ 15,674	$ 16,867	$ 18,103	$ 19,373	$ 18,847	$ 19,918	$ 19,964	$ 20,884	$ 21,763	$ 22,590	$ 23,352	$ 24,037	$ 24,634	$ 25,132	$ 25,521	$ 25,792	$ 25,938	$ 27,252	$ 27,187	$ 29,544
$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 1,893	$ 2,461	$ 2,461	$ 2,461	$ 2,461	$ 2,461	$ 2,461
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 1,871	$ 2,004	$ 2,147	$ 2,301	$ 2,464	$ 2,635	$ 2,814	$ 3,000	$ 3,190	$ 3,111	$ 3,272	$ 3,279	$ 3,417	$ 3,549	$ 3,672	$ 3,787	$ 3,890	$ 3,979	$ 4,054	$ 4,197	$ 4,238	$ 4,260	$ 4,457	$ 4,447	$ 4,801
$ 660	$ 680	$ 702	$ 725	$ 749	$ 776	$ 804	$ 834	$ 866	$ 898	$ 931	$ 965	$ 999	$ 1,035	$ 1,073	$ 1,111	$ 1,151	$ 1,191	$ 1,233	$ 1,275	$ 1,319	$ 1,363	$ 1,408	$ 1,454	$ 1,501
$ 15,008	$ 16,045	$ 17,165	$ 18,364	$ 19,637	$ 20,978	$ 22,379	$ 23,830	$ 25,322	$ 24,750	$ 26,014	$ 26,101	$ 27,194	$ 28,241	$ 29,228	$ 30,143	$ 30,971	$ 31,698	$ 32,312	$ 33,455	$ 33,810	$ 34,022	$ 35,579	$ 35,550	$ 38,307
$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227
$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227
$ 900	$ 928	$ 958	$ 990	$ 1,025	$ 1,061	$ 1,100	$ 1,142	$ 1,186	$ 1,230	$ 1,275	$ 1,321	$ 1,369	$ 1,418	$ 1,469	$ 1,522	$ 1,576	$ 1,632	$ 1,688	$ 1,747	$ 1,806	$ 1,866	$ 1,928	$ 1,990	$ 2,057
$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3
$ 2,480	$ 2,508	$ 2,538	$ 2,570	$ 2,605	$ 2,642	$ 2,681	$ 2,722	$ 2,767	$ 2,810	$ 2,855	$ 2,901	$ 2,949	$ 2,998	$ 3,049	$ 3,102	$ 3,156	$ 3,212	$ 3,268	$ 3,327	$ 3,386	$ 3,446	$ 3,508	$ 3,570	$ 3,638
$ 17,488	$ 18,553	$ 19,703	$ 20,935	$ 22,242	$ 23,620	$ 25,059	$ 26,553	$ 28,088	$ 27,560	$ 28,869	$ 29,003	$ 30,143	$ 31,239	$ 32,278	$ 33,245	$ 34,127	$ 34,910	$ 35,581	$ 36,782	$ 37,196	$ 37,468	$ 39,087	$ 39,120	$ 41,945
$ 612,136	$ 630,690	$ 650,393	$ 671,328	$ 693,570	$ 717,189	$ 742,249	$ 768,801	$ 796,889	$ 824,449	$ 853,318	$ 882,321	$ 912,464	$ 943,702	$ 975,980	$ 1,009,225	$ 1,043,352	$ 1,078,262	$ 1,113,843	$ 1,150,625	$ 1,187,821	$ 1,225,289	$ 1,264,376	$ 1,303,496	$ 1,345,441
$ 5.58	$ 5.75	$ 5.94	$ 6.15	$ 6.36	$ 6.59	$ 6.83	$ 7.09	$ 7.36	$ 7.63	$ 7.91	$ 8.19	$ 8.48	$ 8.79	$ 9.11	$ 9.43	$ 9.77	$ 10.11	$ 10.47	$ 10.83	$ 11.20	$ 11.57	$ 11.96	$ 12.35	$ 12.77
$ 4.57	$ 4.51	$ 4.45	$ 4.38	$ 4.31	$ 4.24	$ 4.17	$ 4.11	$ 4.04	$ 3.99	$ 3.95	$ 3.92	$ 3.89	$ 3.86	$ 3.83	$ 3.80	$ 3.78	$ 3.75	$ 3.73	$ 3.72	$ 3.71	$ 3.70	$ 3.68	$ 3.67	$ 3.64
$ 2.05	$ 2.02	$ 1.99	$ 1.96	$ 1.94	$ 1.91	$ 1.88	$ 1.85	$ 1.82	$ 1.80	$ 1.79	$ 1.78	$ 1.76	$ 1.75	$ 1.74	$ 1.73	$ 1.72	$ 1.71	$ 1.71	$ 1.70	$ 1.70	$ 1.70	$ 1.69	$ 1.68	$ 1.67

16.5	**16.7**	**17.0**	**17.2**	**17.4**	**17.6**	**17.9**	**18.1**	**18.3**	**18.6**	**18.8**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Oct-98	**24-Oct-98**	**31-Oct-98**	**7-Nov-98**	**14-Nov-98**	**21-Nov-98**	**28-Nov-98**	**5-Dec-98**	**12-Dec-98**	**19-Dec-98**	**26-Dec-98**	**2-Jan-99**	**9-Jan-99**	**16-Jan-99**	**23-Jan-99**	**30-Jan-99**	**6-Feb-99**	**13-Feb-99**	**20-Feb-99**	**27-Feb-99**	**6-Mar-99**	**13-Mar-99**	**20-Mar-99**	**27-Mar-99**	**3-Apr-99**
14.45	**13.91**	**13.35**	**12.77**	**12.18**	**11.59**	**11.01**	**10.45**	**9.90**	**9.39**	**8.92**	**8.50**	**8.12**	**7.81**	**7.56**	**7.37**	**7.25**	**7.20**	**7.22**	**7.32**	**7.48**	**7.71**	**8.00**	**8.36**	**8.76**
14.45	13.91	13.35	12.77	12.18	11.59	11.01	10.45	9.90	9.39	8.92	8.50	8.12	7.81	7.56	7.37	7.25	7.20	7.22	7.32	7.48	7.71	8.00	8.36	8.76
13.71	13.23	12.72	12.20	11.68	11.15	10.62	10.11	9.63	9.17	8.75	8.36	8.03	7.75	7.52	7.35	7.24	7.20	7.22	7.31	7.45	7.66	7.92	8.24	8.60
30	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**
6,613.60	**6,710.98**	**6,804.44**	**6,893.85**	**6,979.14**	**7,060.31**	**7,137.39**	**7,210.52**	**7,279.84**	**7,345.59**	**7,408.05**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3,645.3	**3,777.7**	**3,905.6**	**4,028.3**	**4,145.2**	**4,256.0**	**4,360.4**	**4,458.2**	**4,549.4**	**4,634.3**	**4,713.1**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.07	7.33	7.57	7.81	8.04	8.25	8.46	8.65	8.82	8.99	9.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-
								4,549.4	4,634.3	4,713.1														
1.97	1.97	1.97	1.97	1.97	1.96	1.96	1.96	1.95	1.95	1.95	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.9%	3.6%	3.4%	3.1%	2.9%	2.7%	2.5%	2.2%	2.0%	1.9%	1.7%														
0.54%	0.51%	0.48%	0.44%	0.41%	0.38%	0.35%	0.32%	0.29%	0.26%	0.24%														
0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
87.63%	87.48%	87.33%	87.18%	87.03%	86.88%	86.73%	86.58%	86.43%	86.35%	86.34%														
105,155	104,974	104,793	104,612	104,432	104,252	104,072	103,893	55,714	7,618	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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383,324	396,562	409,278	421,405	432,893	443,697	453,793	463,174	253,468	35,304	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
651	672	695	718	736	756	775	789	806	441	65	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9.46	**9.79**	**10.11**	**10.41**	**10.69**	**10.96**	**11.20**	**11.44**	**6.26**	**0.87**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	**10**	**11**	**11**	**11**	**11**	**12**	**12**	**7**	**1**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.87%	0.83%	0.78%	0.74%	0.70%	0.65%	0.61%	0.57%	0.53%	0.50%	0.47%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0.43%	0.42%	0.40%	0.38%	0.37%	0.35%	0.33%	0.32%	0.30%	0.29%	0.27%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
22,516	22,180	21,725	21,161	20,503	19,766	18,971	18,136	17,286	8,832	1,150	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.19	3.30	3.41	3.51	3.61	3.70	3.78	3.86	3.93	3.97	3.97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.56	1.56	1.57	1.57	1.58	1.58	1.59	1.60	1.60	1.61	1.61	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.50	1.50	1.51	1.51	1.52	1.52	1.53	1.53	1.54	1.54	1.54	-	-	-	-	-	-	-	-	-	-	-	-	-	-
118.71	110.28	102.22	94.57	87.37	80.66	74.43	68.72	63.52	58.83	54.65	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.27	7.42	7.42	7.58	7.58	7.75	7.75	7.92	8.10	8.10	8.29	8.29	8.29	8.48	8.48	8.48	8.48	8.48	8.48	8.48	8.48	8.48	8.29	8.29	8.29
6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
0.77	0.92	0.92	1.08	1.08	1.25	1.25	1.42	1.60	1.60	1.79	1.79	1.79	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.79	1.79	1.79
982,690	788,171	753,979	612,419	581,248	477,042	450,256	372,823	167,468	21,604	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45,503,465	43,731,648	41,834,552	39,851,958	37,823,542	35,786,771	33,777,294	31,828,265	16,099,017	2,076,826	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	67,500	33,750	33,750	-	-	-	-	-	-	-	-	-	-	-	-	-	-
37,507,050	44,942,850	44,942,850	52,709,130	52,709,130	60,764,580	60,764,580	69,150,510	77,866,920	38,933,460	33,477,560	-	-	-	-	-	-	-	-	-	-	-	-	-	-
118.71	110.28	102.22	94.57	87.37	80.66	74.43	68.72	63.52	58.83	54.65	-	-	-	-	-	-	-	-	-	-	-	-	-	-
383,324	396,562	409,278	421,405	432,893	443,697	453,793	463,174	253,468	35,304	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45,503,465	43,731,648	41,834,552	39,851,958	37,823,542	35,786,771	33,777,294	31,828,265	16,099,017	2,076,826	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7,996,415	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7,382.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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1.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$ 29,271	$ 28,833	$ 28,242	$ 27,510	$ 26,654	$ 25,696	$ 24,662	$ 23,577	$ 22,471	$ 11,482	$ 1,495	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 2,461	$ 2,461	$ 3,030	$ 3,030	$ 3,030	$ 3,030	$ 3,030	$ 3,030	$ 3,030	$ 1,893	$ 1,893	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
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$ 4,760	$ 4,694	$ 4,691	$ 4,581	$ 4,452	$ 4,309	$ 4,154	$ 3,991	$ 3,825	$ 2,006	$ 508	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 1,551	$ 1,600	$ 1,648	$ 1,696	$ 1,742	$ 1,788	$ 1,831	$ 1,873	$ 1,476	$ 1,111	$ 981	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 38,043	**$ 37,589**	**$ 37,610**	**$ 36,816**	**$ 35,878**	**$ 34,822**	**$ 33,676**	**$ 32,471**	**$ 30,802**	**$ 16,493**	**$ 4,878**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
$ 1,227	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*	*$ 1,227*
$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ 1,227	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 2,124	$ 2,190	$ 2,256	$ 2,321	$ 2,384	$ 2,445	$ 2,504	$ 2,561	$ 2,616	$ 2,646	$ 2,657	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ 353.3	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 3,704	$ 3,770	$ 3,836	$ 3,901	$ 3,964	$ 4,025	$ 4,084	$ 4,142	$ 4,196	$ 4,227	$ 4,238	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 41,747	**$ 41,359**	**$ 41,446**	**$ 40,717**	**$ 39,842**	**$ 38,848**	**$ 37,761**	**$ 36,613**	**$ 34,998**	**$ 20,719**	**$ 9,116**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
$ 1,387,188	$ 1,428,546	$ 1,469,993	$ 1,510,709	$ 1,550,551	$ 1,589,399	$ 1,627,160	$ 1,663,772	$ 1,698,770	$ 1,719,490	$ 1,728,606	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 13.19	**$ 13.61**	**$ 14.03**	**$ 14.44**	**$ 14.85**	**$ 15.25**	**$ 15.63**	**$ 16.01**	**$ 16.38**	**$ 16.59**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
$ 3.62	**$ 3.60**	**$ 3.59**	**$ 3.58**	**$ 3.58**	**$ 3.58**	**$ 3.59**	**$ 3.59**	**$ 4.02**	**$ 4.56**	**$ 4.68**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
$ 1.67	**$ 1.66**	**$ 1.66**	**$ 1.65**	**$ 1.65**	**$ 1.65**	**$ 1.66**	**$ 1.66**	**$ 1.66**	**$ 1.67**	**$ 1.67**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**

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10-Apr-99	**17-Apr-99**	**24-Apr-99**	**1-May-99**	**8-May-99**	**15-May-99**	**22-May-99**	**29-May-99**	**5-Jun-99**	**12-Jun-99**	**19-Jun-99**	**26-Jun-99**	**3-Jul-99**	**10-Jul-99**	**17-Jul-99**	**24-Jul-99**	**31-Jul-99**	**7-Aug-99**	**14-Aug-99**	**21-Aug-99**	**28-Aug-99**	**4-Sep-99**	**11-Sep-99**	**18-Sep-99**	**25-Sep-99**
9.22	**9.72**	**10.25**	**10.81**	**11.39**	**11.97**	**12.56**	**13.15**	**13.71**	**14.26**	**14.77**	**15.25**	**15.67**	**16.05**	**16.37**	**16.63**	**16.82**	**16.94**	**17.00**	**16.98**	**16.89**	**16.73**	**16.51**	**16.22**	**15.87**
9.22	9.72	10.25	10.81	11.39	11.97	12.56	13.15	13.71	14.26	14.77	15.25	15.67	16.05	16.37	16.63	16.82	16.94	17.00	16.98	16.89	16.73	16.51	16.22	15.87
9.01	9.46	9.94	10.44	10.96	11.49	12.02	12.54	13.05	13.54	14.00	14.43	14.81	15.15	15.44	15.67	15.84	15.95	16.00	15.98	15.90	15.76	15.56	15.30	14.99
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0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
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8.10	8.10	7.92	7.92	7.75	7.75	7.58	7.42	7.42	7.27	7.27	7.12	7.12	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98	6.98	7.12
6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
1.60	1.60	1.42	1.42	1.25	1.25	1.08	0.92	0.92	0.77	0.77	0.62	0.62	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.62
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15.47	15.01	14.52	13.99	13.43	12.86	12.27	11.68	11.09	10.53	9.98	9.46	8.99	12.93
15.47	15.01	14.52	13.99	13.43	12.86	12.27	11.68	11.09	10.53	9.98	9.46	8.99	
14.62	14.22	13.77	13.30	12.80	12.28	11.75	11.22	10.70	10.19	9.70	9.23	8.80	
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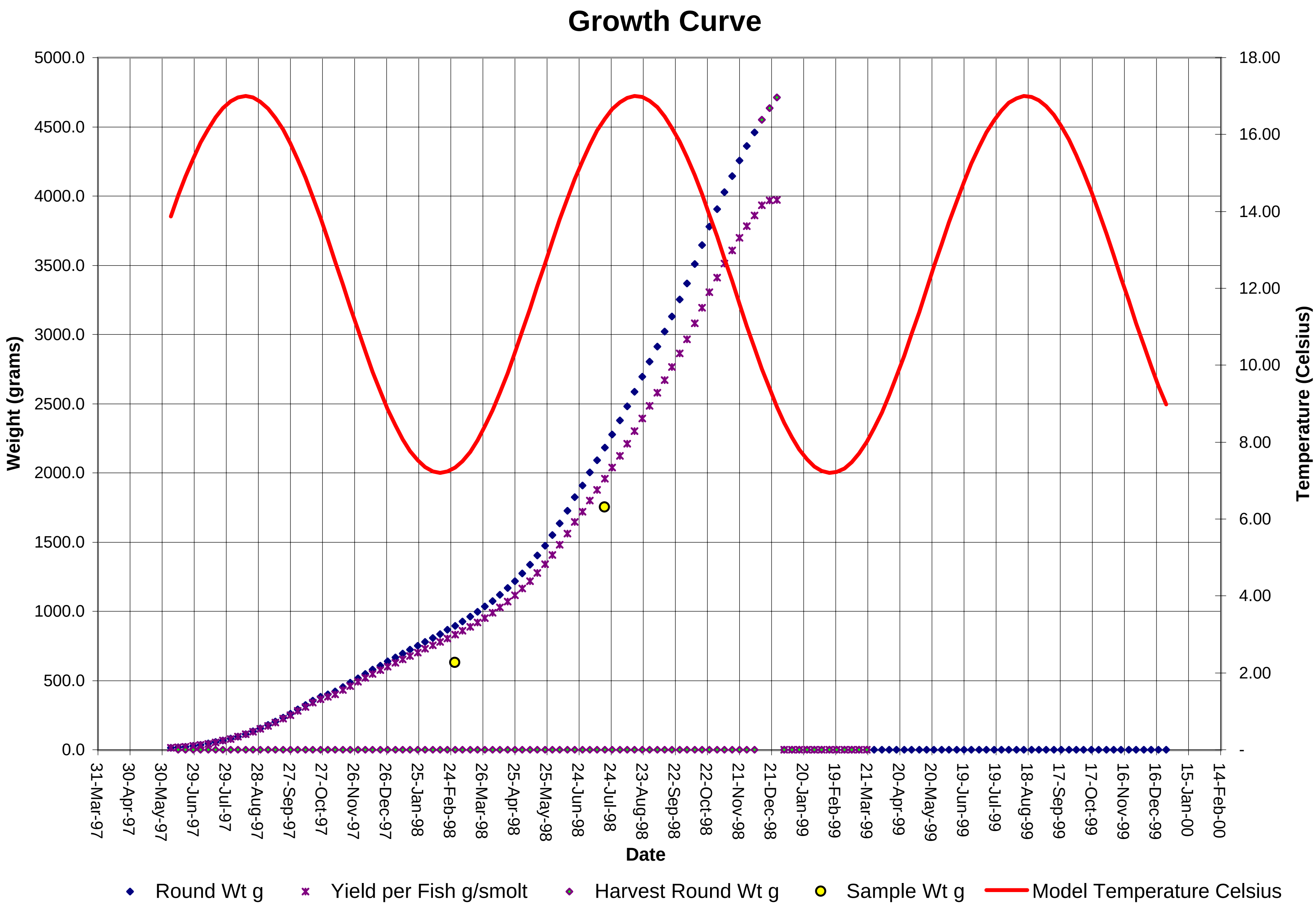

Growth Curve
Weight (grams)
5000.0
4500.0
4000.0
3500.0
3000.0
2500.0
2000.0
1500.0
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500.0
0.0
Temperature (Celsius)
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
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31-Mar-97
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16-Dec-99
15-Jan-00
14-Feb-00
Date
Round Wt g
Yield per Fish g/smolt
Harvest Round Wt g
Sample Wt g
Model Temperature Celsius

Appendix 3:

Costs of Freshwater Aquaculture Industry
(Alberta Ministry of Agriculture, Food and Rural Development)

Fresh Water Aquaculture Industry

Adapted from Agdex 485/830-1 June 1996

Aquaculture Enterprise No. 1: Rainbow Trout Grow Out Operation

Production Process

- Dugout or pond - extensive - seasonal
- Stocking rate of 300 fingerlings per year.
- Secondary use for pond for livestock watering
- Market 1 pound trout
- Assume 90% recovery rate

Capital Investment Required

Item	Purchase Price	Useful Life	Depreciation $ Per Year	Interest Cost $ Per Year
Dugout (2.000 cubic meters)	$3,000.00	20	$150.00	$150.00
Share of Power Service	$1,800.00	10	$180.00	$90.00
Aeration System Including Building	$500.00	10	$50.00	$25.00
Water Testing Equipment	$300.00	5	$60.00	$15.00
Planting Aquatic Vegetation	$200.00	10	$20.00	$10.00
Net	$55.00	20	$2.75	$2.75
Jigger	$90.00	2	$45.00	$4.50
Livestock Fencing	$500.00	5	$100.00	$25.00
Total Costs	**$6,445.00**		**$607.75**	**$322.25**

Revenue and Expense Estimates for Rainbow Trout Grow-Out Operation

Revenues

	Weight	Number	Price/ Pound	Price/Head	Revenue
Market Trout	1	270	$3.10	$3.10	$837.00
Total Revenues					$837.00

Variable Costs

	Number	Price/Head	Cost
Fingerling Costs	300	$0.75	$225.00
Feed Costs			$200.00
Labour			$600.00
Total Variable Costs			**$600.00**
Gross Margin			**$237.00**

Fixed Costs

Depreciation		$607.75
Total Fixed Costs		**$607.75**
Gross Operating Profit		**($370.75)**
Interest Cost		$322.25
Total Returns to Management and Labour		**($693.00)**

Note: Purchase prices are only guidelines and will vary according to dugout size, location, etc.

Aquaculture Enterprise No. 2: Commercial Trout Hatchery/Fingerling Operation

Production Process

Intensive year round operation

Produce 70,000 fingerlings per year

Capital Investment Required

Item	Purchase Price	Useful Life	Depreciation $ Per Year	Interest Cost $ Per Year
Building	$25,000.00	15	$1,666.67	$1,250.00
Tanks	$22,500.00	10	$2,250.00	$1,125.00
Pumps and Miscellaneous Equipment	$20,000.00	10	$2,000.00	$1,000.00
3/4 Ton, 4WD Truck	$20,000.00	5	$4,000.00	$1,000.00
Hatchery System	$3,000.00	10	$300.00	$150.00
Well	$6,000.00	15	$400.00	$300.00
Power	$1,800.00	20	$90.00	$90.00
Total Costs	**$98,300.00**		**$10,706.67**	**$4,915.00**

Revenue and Expense Estimates for Rainbow Trout Hatchery Operation

Revenues

	Number	Price/Fingerling	Revenue
Market Fingerlings	70,000	$0.80	$56,000.00
Total Revenues			**$56,000.00**

Variable Costs

	Number	Price/Head	Cost
Eggs	100,000	$0.025	$2,500.00
Feed Costs			$10,000.00
Feed Freight			$1,000.00
Power			$4,000.00
Gas			$1,200.00
Phone			$4,000.00
Labour			$6,300.00
Marketing Expense			$1,000.00
Travel			$10,000.00
Total Variable Costs			**$40,000.00**
Gross Margin			**$16,000.00**
Fixed Costs			
Depreciation			$10,706.67
Total Fixed Costs			**$10,706.67**
Gross Operating Profit			**$5,293.33**
Interest Cost			$4,915.00
Total Returns to Management and Labour			**$378.33**

Note: Purchase prices are rough guidelines and vary according to location, species, etc.

Appendix 4:

Cost-Benefit of Recirculating Systems

Comparison of Economic Feasibility

(from: Minnesota Department of Agriculture and University of Minnesota, 1997)

Capital costs are summarized in Table 3. Variable cost data were collected on labor, energy consumption, feed expense and other inputs and presented through the following assumptions or as otherwise noted.

Table 3. Capital Cost of Recirculating Aquaculture Systems

Components	Costs ($)
Common Costs to all Systems	
• Culture tank	1424.00
• Screen filter	4261.00
• Immersion heater and control	230.00
• Airstones (10 @ $9.00 each)	90.00
• Piping and valves	300.00
• Automatic feeder	399.50
• Aeration (1/6 of blower cost)	112.67
Subtotal	6817.17
Additional costs of trickling filter system	
• Biofilter tank	450.00
• Biofilter media (49.5 ft3 @ $19.00/ft3)	940.50
• Pump	550.00
• Subtotal for additional costs for trickling filter system	1940.50
Total for trickling filter system	8757.67
Additional costs of fluidized bed system	
• Biofilter package cost (does not include media)	3022.10
• Biofilter media (filter sand)	75.00
• Subtotal for additional costs of fluidized bed system	3097.10
Total costs for fluidized bed system	9914.27
Additional costs of submerged thin film system	
• Biofilter cost	995.00
• Blower	498.00
• Airlift pumps (piping and airstones)	150.00
Subtotal for additional costs of submerged thin film system	1643.00
Total costs for submerged thin film system	**8460.17**

The economic evaluation only included data based on a 156 day period from July 24, 1995 to December 26, 1995. Before that period, time was spent on fine tuning the mechanical components of the systems and cultivation of bacteria in the biofilters for processing of fish waste.

Based on these data, the actual operation in the laboratory was analyzed and commercial scale projections were made to project income statements, supporting depreciation schedules, and break-even production and prices. The expanded commercial scale projection should be used only as a guide or a template for comparison. Actual system results may be different due to changing market conditions, site selection, and individual production techniques.

The analysis and projection were performed for each of the three systems. From the data and results of the laboratory analysis, model adjustments that were made in the scale-up projection included building costs, additional capital equipment and changing labor usage. A comparison of the two scenarios reveal some key differences between the three recirculating systems. These results are highlighted in the financial statement discussion.

Relevant information such as sales prices, fixed and variable costs, and production information are included in the List of Assumptions as shown below.

a. List of Assumptions

1. The analysis is based on the two 3000 gallon tanks per recirculating system or six tanks total used in this evaluation in the Aquaculture Laboratory. In the Commercial Scale-up Projection model, six 10,000 gallon tanks for each system are used.
2. Tilapia are stocked at a rate of 1500 fingerlings per tank in the Aquaculture Laboratory. In the Commercial Projection, maximum stocking capacity is set at 0.25 lb of fish per gallon of water; an average stocking rate at 0.21 lb per gallon is used and the feeding rate is assumed at 2% body weight per day which approximate the final maximum production capacity in the laboratory.
3. Tilapia are sold for $1.40 per pound (lb). Assuming feed conversion rate of 1.5:1, a production of 4784 lbs of fish is estimated to be sold per month in six 10,000 gallon tank systems.
4. The aquaculture Laboratory fingerling cost is $0.69 per fish at 8 inches in size or 0.41 lb (181 grams) on July 24, 1995 and $0.25 for 3-inch fish in the Commercial Projection.
5. Tilapia are fed five times per day for both the 156 day growing period in the aquaculture Laboratory and in Commercial Projection. Feed cost is 24.5 cents per lb.
6. The cost of Buildings and Capital Equipment requirements are amortized and Depreciation/Amortization is shown as operating expenses. The 2000 ft2 Aquaculture Lab facility rent is estimated at $10/ft2. New commercial construction is projected at $15/ft2 for a 6300 ft2 building.
7. The cost of fluidized bed systems in the Aquaculture Laboratory testing is based on the purchase of ready made equipment. New studies have been published that enables individuals to construct systems according to design, instead of purchase of whole system. The cost of fluidized bed in the Commercial Production Projection is based on the purchase of components.
8. Labor Expenses are shown as three types of tasks with various activities:

   Daily tasks: Feeding, Cleaning standpipes and screens, Water changes, Water quality monitoring
   Recurring periodic tasks: Clean screen filters, Clean airstones, Weigh fish
   System maintenance: Replace parts, Check and clean probes, airstones and airlifts, Clean and pack media
9. System Utilities are calculated for key equipment by kilowatt (kW) equivalent usage. The utility rate is $0.060/kW. There is a total of 3744 hours (24 hours x 156 days) for the Aquaculture Lab and a total of 8760 hours (24 hours x 365 days) for the Commercial Production model. Tables 4 and 5 show the rate of kW usage per hour for system equipment and length of time used.
10. Water and Sewage cost is estimated at $1.85 per 1000 gallons.
11. The Aquaculture Lab building utilities for the 5-month period are estimated at $200 per system or $600 total. Commercial Production model is projected at $250 per month.
12. The Aquaculture Lab building telephone for the 156 day period is estimated at $200 per system or $600 total. Commercial Production model is projected at $50 per month.
13. The Aquaculture Lab building rent for the 5 month period is estimated at $200 per system or $600 total. Commercial Production model is projected to build a 6300 sq. ft. facility at a cost of $15/sq.ft.
14. Equipment purchases included in the Commercial Projection are Test Kit for $200 with $600 of reagents replaced annually and a $76 Top Load Scale.
15. Chemical cost is quicklime at $0.17 per lb applied at 0.014/lb per lb of feed.
16. Marketing and Travel cost are zero for the Aquaculture Lab because of a special marketing arrangement for the grown tilapia. For the Commercial Production model marketing and travel are estimated at $0.02/lb of fish production.
17. License fees are zero for the Aquaculture Lab and $55 for the Commercial Production operation.
18. Commercial Production Insurance is projected at $0.01/lb. of fish production.
19. No Loan or Interest Expense are shown for the Aquaculture Lab. Building and equipment loans of $94,600 and $50,000, respectively, are projected for Commercial Production. The building loan is amortized at 9.0% over 30 years. The equipment loan is amortized at 10.5% over 10 years.
20. Property taxes are only estimated as $1200 for the Commercial Production scenario.

Straight-line depreciation method is used in all depreciation estimates for building and equipment. In only the Aquaculture Lab scenario shared or common equipment depreciation is split equally between the three systems.

Table 4. Utility consumption of major components of different recirculating aquaculture systems as evaluated in the Aquaculture Laboratory.

Equipment	Hourly kW Rate	Length of Use
Lab Trickling Filter		
• 1/2 hp centrifugal pump	0.703	Continuous
• 2 kW immersion heater	1.960	Continuous
• Hydrotech screen filter	1.080	79 minutes/day
• Main lab blower	0.390	Continuous
Lab Fluidized Bed Filter		
• 1/2 hp centrifugal pump	0.894	Continuous
• 2 kW immersion heater	1.960	Continuous
• Hydrotech screen filter	1.080	79 minutes/day
• Main lab blower	0.390	Continuous
Lab submerged Thin Film Filter		
• 1/2 hp centrifugal pump	0.794	Continuous
• 2 kW immersion heater	1.960	Continuous
• Hydrotech screen filter	1.080	79 minutes/day
• Main lab blower	0.390	Continuous

Table 5. Utility consumption of major components of different recirculating aquaculture systems as projected in a scale up Commercial Production System.

Equipment	Hourly kW Rate or Hourly Therm Rate	Length of Use
Projected Trickling Filter System		
• 1 hp centrifugal pump	1.000	Continuous
• 2 hp submersible pumps (3)	3.500	Continuous
• Hydrotech screen filter	2.000	4.8 hours/day
• 2.5 hp blowers (3)	2.400	Continuous
• Natural gas water heater, Controls and circulating pump	4.29	Continuous
Projected Fluidized Bed Filter System		
• 1 hp centrifugal pump	1.000	Continuous
• 2 hp submersible pumps (3)	3.500	Continuous
• Hydrotech screen filter	2.000	4.8 hours/day
• 2.5 hp blowers (3)	2.400	Continuous
• Natural gas water heater, Controls and circulating pump	4.29	Continuous
Projected Submerged Thin Film Filter System		
• Rotary lobe blower	5.000	Continuous
• 2.5 hp blowers (3)	2.400	Continuous
• Hydrotech screen filter	2.000	4.8 hours/day
• Natural gas water heater, Controls and circulating pump	4.29	Continuous

b. Income Statements

1. Aquaculture Laboratory Analysis

Table 6 is the income (profit or loss) statement for the three recirculating aquaculture systems in the Aquaculture Laboratory. The first point to be made about the income statement is profitability. None of the Aquaculture Lab systems are profitable. This is because the two tank systems are not taking advantage of economies of scale which lowers the per-tank cost of utilities and labor. But rank ordering each system by net income reveals that the Tricking Filter has the smallest loss (-$5480) with the Submerged Thin Film second (-$5679) and finally the Fluidized Bed (-$5790). But there is much more knowledge that can be gained from Table 6 than just bottom-line profitability.

Table 6. Aquaculture Laboratory Filter systems

Income Statement

	Trickling Filter	Fluidized Bed Filter	Submerged Thin Film
Revenues			
• Fish Production (lb.)	1743	1,800	1,946
• Price per lb.	1.40	1.40	1.4
• Total Revenues	2,440	2,521	2,724
Cost of Goods Sold			
• Purchased Stock	2,070	2,070	2,070
• Feed	744	738	738
Gross Profit	(374)	(287)	(85)
Operating Expenses			
Labor Expenses			
• Daily Tasks	2,761	2,761	2,761
• Recurring Periodic Tasks	708	708	708
• System Maintenance	61	400	539
System Utilities			
• Pump	158	201	0
• Heater	440	440	440
• Screen Filter	13	13	13
• Blower	88	88	266
• Water and Sewage	141	141	141
• Building Utilities	200	200	200
• Telephone	50	50	50
• Rent	200	200	200
• Equipment	0	0	0
• Chemicals	0	0	0
• Marketing and Travel	0	0	0
• Licenses & Fees	0	0	0
• Insurance	0	0	0
• Depreciation/Amortization	285	300	275
• Other	0	0	0
• Total Operating Expenses	5,106	5,503	5,594
• Operating Income	(5,480)	(5,790)	(5,679)
Other Expenses			
• Interest Expenses	0	0	0
• Property Taxes	0	0	0
Net Income Before Taxes	**(5,480)**	**(5,790)**	**(5,679)**

Tilapia production ranged from 1,743 to 1,946 lbs. between the systems. Fish production was not maximized in the Aquaculture Lab scenario, therefore these results (and profitability) could have been improved. Also, due to unforeseen delays in the project, Purchased Stock fingerlings size was 8 inches and reported value was 69 cents each. These are expensive fingerlings and normally this cost would be much lower.

Upon closer examination of Labor Expenses, System Maintenance is one key difference between the systems. The Trickling Filter system was very inexpensive ($69 for 5 months) to maintain. However, the Submerged Thin Film system needed $539 of labor maintenance over 5 months and the Fluidized Bed required $400 of labor over 5 months.

Another important comparison can be seen in System Utilities. The cost of running pumps and blowers varied between the systems. Again, the Trickling Filter system was the cheapest to operate with a total System Utilities cost of $699 over 5 months. The Submerged Thin Film was the second cheapest system at $719 over 5 months, while the Fluidized Bed was the most costly with $742 over the 5-month period. These differences would expand if the costs were annualized.

Depreciation/Amortization is another cost category that should be noted. Due to higher lab equipment requirements, the Fluidized Bed system had the highest Depreciation Expense of $300. The Trickling Filter had the second highest equipment needs and had a $285 Depreciation Expense. Finally the Submerged Thin Film was the lowest lab equipment cost system with $275 of Depreciation cost.

2. Commercial Production Projection

Table 7 is the income statement for the three projected recirculating Commercial Production systems. All of the commercial systems were profitable. The six-tank systems take advantage of economies of scale which lowers the per-tank cost of utilities and labor. Rank ordering each system by net income reveals that the Fluidized Bed had the highest profits ($1,946) with the Trickling Filter second ($1,813) and finally the Submerged Thin Film ($107).

Tilapia production is 57,408 lbs annually for all systems This is based on 0.25 lb stocking density and selling 4,784 lbs monthly. Purchased Stock fingerling size has changed to 3 inches and reported value is 25 cents each. These are less expensive fingerlings than the $0.69 Aquaculture Lab fingerlings and reflect a typical stocking cost.

Under Labor Expenses, System Maintenance was again one key difference between the systems. The Submerged Thin Film system was the most costly to maintain ($2,614 for 12 months). However, the Trickling Filter system needed only $147 of labor maintenance over 12 months and the Fluidized Bed required $1,389 of labor maintenance annually.

The cost of running pumps and blowers would vary between the systems. The Submerged Thin Film system was the most expensive to operate with a total System Utilities cost of $4,875 over 12 months. The Fluidized Bed and Trickling Filter had the same System Utilities Expense of $4,612 annually.

Due to lowest equipment requirements in the commercial scenario, the Fluidized Bed showed the lowest Depreciation Expense of $13,590. Although the tank for the biofilter in the Fluidized Bed system is a costly item, the filter media, sand, is a very abundant and very low cost item. The filter media in the Trickling Filter system, on the other hand, was rather expensive; resulting in the Trickling Filter having the highest equipment cost of a $14,965 Depreciation Expense. The Submerged Thin Film system was between the other systems at $13,941 for Depreciation cost.

The Return on Equity equipment investment (ROE) is the rate of return on equity that is realized from the profitability of each scenario. The Fluidized Bed System has the highest ROE of 4.2% based on a profit of $1,946 and an equity investment of $$46,890. Because the Submerged Thin Film System is close to break-even, its ROE is only 0.23%, while the Trickling Tower System is between the other two systems with a ROE of 3.4%.

c. Break-even Yields and Prices

Tables 8-10 and Tables 11-13 are break-even evaluations for the Aquaculture Lab and projected Commercial Production, respectively . The costs used are the same as those shown on the income statement but are broken down into fixed and variable costs. Fixed costs include equipment, licenses and fees, property taxes, and depreciation. All other costs are considered variable.

The Tables look at both break-even yields and break-even prices. The break-even yield is the pounds of production needed to cover either the variable or total costs when sold for $1.40 per pound. The break-even price is the market sales price required to cover variable and total costs at the production quantity shown on the total revenue line.

1. Aquaculture Laboratory Analysis

Due to relatively low tilapia production and only a two tank system, economies of scale were not seen so the break-even prices and break-even yields were extremely high. But just as in the income statement evaluation, comparisons between the systems is valuable.

The break-even yield ranged from 5,310 lbs for the Trickling Filter system to cover just variable costs to 6,001 lbs in the Submerged Thin Film system to cover all costs. The Variable Costs calculations reveal why the differences were found.

Trickling Filter system had the lowest variable cost of $7,434 and the Submerged Thin Film had the highest at $7,926.

The break-even price ranged from a low of $4.07 per lb in the Submerged Thin Film system to cover just variable costs to $4.62 per lb to cover all costs in the Fluidized Bed system. This result appears to be inconsistent with previous results. But it can be explained by the fact that fish production determines the break-even price. The relatively high production allowed the Submerged Thin Film system to overcome its variable cost disadvantage to have the lowest break-even price. If tilapia production were maximized, these break-even findings would change. However, since the market price was $1.40 per pound, the $4.07 break-even price still indicated this was an unprofitable situation. One observation should be made that in the Aquaculture Laboratory situation, only in the last week of the 5-month period, the systems were operating near their carrying capacity. The rest of time there was considerable waste of system space that was not fully utilized for maximum production due to various constraints of the laboratory setup.

Table 7. Projected Commercial Production Systems
Income Statement

	Trickling Filter	Fluidized Bed Filter	Submerged Thin Film
Revenues			
• Fish Production (lb.)	57,408	57,408	57,408
• Price per lb.	1.40	1.40	1.4
• Total Revenues	80,371	80,371	80,371
Cost of Goods Sold			
• Purchased Stock	11,482	11,482	11,482
• Feed	21,097	21,097	21,097
Gross Profit	47,792	47,792	47,792
Operating Expenses			
Labor Expenses			
• Daily Tasks	3,489	3,489	3,489
• Recurring Periodic Tasks	1,013	1,013	1,013
• System Maintenance	147	1,389	2,614
System Utilities			
• Pump	2,365	2,365	0
• Heater	1,879	1,879	1,879
• Screen Filter	210	210	210
• Blower	158	158	2,786
• Water and Sewage	3,150	3,150	3,150
• Building Utilities	3,000	3,000	3,000
• Telephone	600	600	600
• Rent	0	0	0
• Equipment	876	876	876
• Chemicals	2,049	2,049	2,049
• Marketing and Travel	1,148	1,148	1,148
• Licenses & Fees	55	55	55
• Insurance	574	574	574
• Depreciation/Amortization	14,965	14,965	14,965
• Other	0	0	0
Total Operating Expenses	35,679	35,545	37,385
Operating Income	12,113	12,246	10,407
Other Expenses			
• Interest Expenses	9,100	9,100	9,100
• Property Taxes	1,200	1,200	1.200
Net Income Before Taxes	**1,813**	**1,946**	**107**

Table 8. Aquaculture Laboratory Break-Even Analysis Trickling Filter System

Two 3000 gallon tanks stocked at 1500 fingerlings per tank
Total Gallons 6000
Total LBS of harvested fish is 1743

	Unit	Total value or cost	Value or cost per lb.	Value or cost per gal.	Value or cost per tank
Revenues					
• Net Sales	lbs	$2,440	$1.40	$0.41	$1,220
• Total Revenues		$2,440	$1.40	$0.41	$1,220
Variable Costs					
• Purchased Stock		$2,070	$1.19	$0.35	$1,035
• Feed	lbs	$744	$0.43	$0.12	$372
Labor Expenses					
• Daily Tasks	hrs	$2,761	$1.58	$0.46	$1,381
• Recurring Periodic Tasks	hrs	$708	$0.41	$0.12	$354
• System Maintenance	hrs	$61	$0.03	$0.01	$31
System Utilities					
• Pump	Tank	$158	$0.09	$0.03	$79
• Heater	Tank	$440	$0.25	$0.07	$220
• Screen Filter	Tank	$13	$0.01	$0.002	$7
• Blower	Tank	$88	$0.05	$0.01	$44
• Water and Sewage	Tank	$141	$0.08	$0.02	$71
• Building Utilities	Tank	$200	$0.11	$0.03	$100
• Telephone	Tank	$50	$0.03	$0.01	$25
• Chemicals	Gal	$0	$0.00	$0.00	$0
• Marketing and Travel	Tank	$0	$0.00	$0.00	$0
• Insurance	System	$0	$0.00	$0.00	$0
• Other	Tank	$0	$0.00	$0.00	$0
• Total variable costs	Tank	$7,434	$4.27	$1.24	$3,717
Fixed Costs					
• Rent		$200	$0.11	$0.03	$100
• Equipment		0	$0.00	$0.00	$0
• License & Fees		0	$0.00	$0.00	$0
• Interest Expenses		0	$0.00	$0.00	$0
• Property Taxes		0	$0.00	$0.00	$0
• Depreciation/Amortization		$285	$0.16	$0.05	$143
Total fixed costs		$485	$0.28	$0.08	$243
Total costs		$7,919	$4.54	$1.32	$3,960
Return after costs		($5,479)	($3.14)	($0.91)	($2,740)

Break-even yield - var. costs	5,310 (lbs)	Break-even price - var. costs	$4.27
Break-even yield - all costs	5,656 (lbs)	Break-even price - all costs	$4.45

Table 9. Aquaculture Laboratory Break-Even Analysis
Fluidized Bed Filter System

Two 3000 gallon tanks stocked at 1500 fingerlings per tank
Total Gallons 6000
Total LBS of harvested fish is 1800

	Unit	Total value or cost	Value or cost per lb.	Value or cost per gal.	Value or cost per tank
Revenues					
• Net Sales	lbs	$2,521	$1.40	$0.42	$1,261
• Total Revenues		$2,521	$1.40	$0.42	$1,261
Variable Costs					
• Purchased Stock		$2,070	$1.15	$0.35	$1,035
• Feed	lbs	$738	$0.41	$0.12	$369
Labor Expenses					
• Daily Tasks	hrs	$2,761	$1.53	$0.46	$1,381
• Recurring Periodic Tasks	hrs	$708	$0.39	$0.12	$354
• System Maintenance	hrs	$400	$0.22	$0.07	$200
System Utilities					
• Pump	Tank	$201	$011	$0.03	$101
• Heater	Tank	$440	$0.24	$0.07	$220
• Screen Filter	Tank	$13	$0.01	$0.002	$7
• Blower	Tank	$88	$0.05	$0.01	$44
• Water and Sewage	Tank	$141	$0.08	$0.02	$71
• Building Utilities	Tank	$200	$0.11	$0.03	$100
• Telephone	Tank	$50	$0.03	$0.01	$25
• Chemicals	Gal	$0	$0.00	$0.00	$0
• Marketing and Travel	Tank	$0	$0.00	$0.00	$0
• Insurance	System	$0	$0.00	$0.00	$0
• Other	Tank	$0	$0.00	$0.00	$0
• Total variable costs	Tank	$7,810	$4.34	$1.30	$3,905
Fixed Costs					
• Rent		$200	$0.11	$0.03	$100
• Equipment		0	$0.00	$0.00	$0
• License & Fees		0	$0.00	$0.00	$0
• Interest Expenses		0	$0.00	$0.00	$0
• Property Taxes		0	$0.00	$0.00	$0
• Depreciation/Amortization		$300	$0.17	$0.05	$150
Total fixed costs		$500	$0.28	$0.08	$250
Total costs		$8,310	$4.62	$1.39	$4,155
Return after costs		($5,789)	($3.22)	($0.96)	($2,895)

Break-even yield - var. costs	5,579 (lbs)	Break-even price - var. costs	$4.34
Break-even yield - all costs	5,936 (lbs)	Break-even price - all costs	$4.62

Table 10. Aquaculture Laboratory Break-Even Analysis
Submerged Thin Film System

Two 3000 gallon tanks stocked at 1500 fingerlings per tank
Total Gallons 6000
Total LBS of harvested fish is 1946

	Unit	Total value or cost	Value or cost per lb.	Value or cost per gal.	Value or cost per tank
Revenues					
Net Sales	lbs	$2,724	$1.40	$0.45	$1,362
Total Revenues		$2,724	$1.40	$0.45	$1,362
Variable Costs					
Purchased Stock		$2,070	$1.06	$0.35	$1,035
Feed	lbs	$738	$0.38	$0.12	$369
Labor Expenses					
Daily Tasks	hrs	$2,761	$1.42	$0.46	$1,381
Recurring Periodic Tasks	hrs	$708	$0.36	$0.12	$354
System Maintenance	hrs	$539	$0.28	$0.09	$270
System Utilities					
Pump	Tank	$0	$0.00	$0.00	$0
Heater	Tank	$440	$0.23	$0.07	$220
Screen Filter	Tank	$13	$0.01	$0.002	$7
Blower	Tank	$266	$0.14	$0.04	$133
Water and Sewage	Tank	$141	$0.07	$0.02	$71
Building Utilities	Tank	$200	$0.10	$0.03	$100
Telephone	Tank	$50	$0.03	$0.01	$25
Chemicals	Gal	$0	$0.00	$0.00	$0
Marketing and Travel	Tank	$0	$0.00	$0.00	$0
Insurance	System	$0	$0.00	$0.00	$0
Other	Tank	$0	$0.00	$0.00	$0
Total variable costs	Tank	$7,810	$4.34	$1.30	$3,905
Fixed Costs					
Rent		$200	$0.11	$0.03	$100
Equipment		0	$0.00	$0.00	$0
License & Fees		0	$0.00	$0.00	$0
Interest Expenses		0	$0.00	$0.00	$0
Property Taxes		0	$0.00	$0.00	$0
Depreciation/Amortization		$75	$0.14	$0.05	$138
Total fixed costs		$75	$0.24	$0.08	$238
Total costs		$8,401	$4.32	$1.40	$4,201
Return after costs		($5,677)	($2.92)	($0.95)	($2,839)

Break-even yield - var. costs	5,661 (lbs)	Break-even price - var. costs	$4.07
Break-even yield - all costs	6,001 (lbs)	Break-even price - all costs	$4.32

2. Projected Commercial Production

Tables 11, 12 and 13 are break-even evaluations for the Projected Commercial Production. These tables show that the six 10,000 gallon tanks scenarios were relatively close to the break-even yields and prices. The Submerged Thin Film was virtually at the break-even points based on the current $1.40 market price for tilapia.

Table 11. Projected Commercial Production Break-Even Analysis

Trickling Filter System

Six 10,000 gallon tanks stocked at 5500 fingerlings per tank
Total Gallons 60,000
Total LBS of harvested fish is 57,408

	Unit	Total value or cost	Value or cost per lb.	Value or cost per gal.	Value or cost per tank
Revenues					
• Net Sales	lbs	$80,371	$1.40	$1.34	$40,186
• Total Revenues		$80,371	$1.40	$1.34	$40,186
Variable Costs					
• Purchased Stock		$11,482	$0.20	$0.19	$5,741
• Feed	lbs	$21,097	$0.37	$0.35	$10,549
• Labor Expenses					
• Daily Tasks	hrs	$3,489	$0.06	$0.06	$1,745
• Recurring Periodic Tasks	hrs	$1,013	$0.02	$0.02	$507
• System Maintenance	hrs	$147	$0.00	$0.007	$74
System Utilities					
• Pump	Tank	$2,365	$0.04	$0.04	$1,183
• Heater	Tank	$1,879	$0.03	$0.03	$940
• Screen Filter	Tank	$210	$0.00	$0.01	$105
• Blower	Tank	$158	$0.00	$0.008	$79
• Water and Sewage	Tank	$3,150	$0.05	$0.05	$1,575
• Building Utilities	Tank	$3,000	$0.05	$0.05	$1,500
• Telephone	Tank	$600	$0.01	$0.01	$300
• Chemicals	Gal	$2,049	$0.04	$0.03	$1,025
• Marketing and Travel	Tank	$1,148	$0.02	$0.02	$574
• Insurance	System	$574	$0.01	$0.01	$287
• Other	Tank	$0	$0.00	$0.00	$0
• Total variable costs	Tank	$52,361	$0.91	$0.87	$26,181
Fixed Costs					
• Rent		$0	$0.00	$0.00	$0
• Equipment		$876	$0.02	$0.01	$438
• License & Fees		$55	$0.00	$0.00	$28
• Interest Expenses		$9,100	$0.16	$0.15	$4,550
• Property Taxes		$1,200	$0.02	$0.02	$600
• Depreciation/Amortization		$14,965	$0.26	$0.25	$7,483
Total fixed costs		$26,196	$0.46	$0.44	$13,098
Total costs		$78,557	$1.37	$1.31	$39,279
Return after costs		$1,814	$0.03	$0.03	$907

Break-even yield - var. costs	37,401 (lbs)	Break-even price - var. costs	$0.91
Break-even yield - all costs	56,112 (lbs)	Break-even price - all costs	$1.37

Table 12. Projected Commercial Production Break-Even Analysis
Fluidized Bed Filter System

Six 10,000 gallon tanks stocked at 5500 fingerlings per tank
Total Gallons 60,000
Total LBS of harvested fish is 57,408

	Unit	Total value or cost	Value or cost per lb.	Value or cost per gal.	Value or cost per tank
Revenues					
• Net Sales	lbs	$80,371	$1.40	$1.34	$40,186
• Total Revenues		$80,371	$1.40	$1.34	$40,186
Variable Costs					
• Purchased Stock		$11,482	$0.20	$0.19	$5,741
• Feed	lbs	$21,097	$0.37	$0.35	$10,549
Labor Expenses					
• Daily Tasks	hrs	$3,489	$0.06	$0.06	$1,745
• Recurring Periodic Tasks	hrs	$1,013	$0.02	$0.02	$507
• System Maintenance	hrs	$1,389	$0.02	$0.02	$695
System Utilities					
• Pump	Tank	$2,365	$0.04	$0.04	$1,183
• Heater	Tank	$1,879	$0.03	$0.03	$940
• Screen Filter	Tank	$210	$0.00	$0.00	$105
• Blower	Tank	$158	$0.00	$0.00	$79
• Water and Sewage	Tank	$3,150	$0.05	$0.05	$1,575
• Building Utilities	Tank	$3,000	$0.05	$0.05	$1,500
• Telephone	Tank	$600	$0.01	$0.01	$300
• Chemicals	Gal	$2,049	$0.04	$0.03	$1,025
• Marketing and Travel	Tank	$1,148	$0.02	$0.02	$574
• Insurance	System	$574	$0.01	$0.01	$287
• Other	Tank	$0	$0.00	$0.00	$0
• Total variable costs	Tank	$53,063	$0.93	$0.89	$26,802
Fixed Costs					
• Rent		$0	$0.00	$0.00	$0
• Equipment		$876	$0.02	$0.01	$438
• License & Fees		$55	$0.00	$0.00	$28
• Interest Expenses		$9,100	$0.16	$0.15	$4,550
• Property Taxes		$1,200	$0.02	$0.02	$600
• Depreciation/Amortization		$13,590	$0.24	$0.23	$6,795
Total fixed costs		$24,821	$0.43	$0.41	$12,411
Total costs		$78,424	$1.37	$1.31	$39,212
Return after costs		$1,947	$0.03	$0.03	$974

Break-even yield - var. costs	38,288 (lbs)	Break-even price - var. costs	$0.93
Break-even yield - all costs	56,017 (lbs)	Break-even price - all costs	$1.37

Table 13. Projected Commercial Production Break-Even Analysis
Submerged Thin Film Filter System

Six 10,000 gallon tanks stocked at 5500 fingerlings per tank
Total Gallons 60,000
Total LBS of harvested fish is 57,408

	Unit	Total value or cost	Value or cost per lb.	Value or cost per gal.	Value or cost per tank
Revenues					
Net Sales	lbs	$80,371	$1.40	$1.34	$40,186
Total Revenues		$80,371	$1.40	$1.34	$40,186
Variable Costs					
Purchased Stock		$11,482	$0.20	$0.19	$5,741
Feed	lbs	$21,097	$0.37	$0.35	$10,549
Labor Expenses					
Daily Tasks	hrs	$3,489	$0.06	$0.06	$1,745
Recurring Periodic Tasks	hrs	$1,013	$0.02	$0.02	$507
System Maintenance	hrs	$2,614	$0.05	$0.004	$1,307
System Utilities					
/TD>	Tank	$0	$0	$0	$0
Heater	Tank	$1,879	$0.03	$0.03	$940
Screen Filter	Tank	$210	$0.00	$0.01	$105
Blower	Tank	$2,786	$0.05	$0.005	$1,393
Water and Sewage	Tank	$3,150	$0.05	$0.05	$1,575
Building Utilities	Tank	$3,000	$0.05	$0.05	$1,500
Telephone	Tank	$600	$0.01	$0.01	$300
Chemicals	Gal	$2,049	$0.04	$0.03	$1,025
Marketing and Travel	Tank	$01,148	$0.02	$0.02	$574
Insurance	System	$574	$0.01	$0.01	$287
Other	Tank	$0	$0.00	$0.00	$0
Total variable costs	Tank	$55,091	$0.96	$0.92	$27,546
Fixed Costs					
Rent		$0	$0.00	$0.00	$0
Equipment		$876	$0.02	$0.01	$438
License & Fees		$55	$0.00	$0.00	$28
Interest Expenses		$9,100	$0.16	$0.15	$4,550
Property Taxes		$1,200	$0.02	$0.02	$600
Depreciation/Amortization		$13,941	$0.24	$0.23	$6,971
Total fixed costs		$25,172	$0.44	$0.42	$12,586
Total costs		$80,263	$1.40	$1.34	$40,132
Return after costs		$108	$0.00	$0.00	$54

Break-even yield - var. costs	39,351 (lbs)	Break-even price - var. costs	$0.96
Break-even yield - all costs	57,331 (lbs)	Break-even price - all costs	$1.40

The break-even yield ranged from 37,401 lbs for the Trickling Filter system to cover just variable costs to 57,331 lbs in the Submerged Thin Film system to cover all costs. The Variable Costs calculations again revealed why the differences were found. The Trickling Filter system had the lowest variable cost of $52,361 and the Submerged Thin Film had the highest at $55,091.

The break-even price ranges from a low of $0.91 per lb in the Trickling Filter system to cover just variable costs to $1.40 per lb to cover all costs in the Submerged Thin Film system. These findings are consistent with previous results of the Aquaculture Lab.

The break-even prices indicated that both the Trickling Filter and Fluidized Bed systems could withstand a small market price drop and at least break-even. However, the Submerged Thin Film system is already at its break-even price so it would become an unprofitable operation if there were a market price decline.

By examining the break-even yields, the same evaluation as under the break-even prices can be made. Both the Trickling Filter and Fluidized Bed systems could withstand a small drop in estimated production of fish and still break-even. But the Submerged Thin Film system is already at its break-even yield so it would become an unprofitable operation if the projected tilapia production goal is not met.

d. Conclusions of the Economic Analysis

The economic evaluation results indicate that a tilapia culture operation has a few important factors that determine its profitability and break-even prices and yields. Labor expense, system utilities cost and different equipment requirements are the key determinants.

The Trickling Filter system had the lowest operating and variable costs and the lowest break-even yield, but relatively high capital equipment requirements . The Submerged Thin Film system had the highest variable cost and break-even yield, but less capital equipment needs. The Fluidized Bed system results generally fell between the other two systems.

The scale of operation in number of tanks is critical to take advantage of economies of scale and generate sufficient revenue to cover costs. Costs such as labor and utilities are lower per tank the larger the tilapia operation. But not all costs per tank decline with tank expansion. Feed and fingerling costs are very important factors that are not subject to economies of scale, although some saving may be realized through purchasing larger quantities at a given time.

Authors and Other Collaborators:

Authors:

Dr. Ying Q. Ji
Aquaculture Coordinator
Minnesota Department of Agriculture
St. Paul, Minnesota 55107
E-mail: ying.ji@state.mn.us

Ira R. Adelman
Professor and Head
Department of Fisheries & Wildlife
University of Minnesota
1980 Folwell Ave.
St. Paul, Minnesota 55108

Jay Maher
Junior Scientist
Department of Fisheries & Wildlife
University of Minnesota
St. Paul, Minnesota 55108

James Skurla
Business Development Specialist
Center for Economic Development
University of Minnesota
Duluth, Minnesota

Collaborators:

Note: titles and affiliations of collaborators at the beginning of the project are used

Dr. Thomas Losordo
NC State University
Department of Zoology
Box 7646
Raleigh, NC 27695-7646

Dr. Michael Semmens
Professor, Department of Civil Engineering
University of Minnesota
150 CME Building
500 Pillsbury Drive S.E.
Minneapolis, MN 55455

Dr. Charles Gantzer
Membran Corporation
1037 10 St. SE
Mpls, MN 55414

Mr. Duaine Flanders
Technical Manager, Morris Office
Agriculture Utilization Research Institute,
P.O. Box 188
Morris, MN 56267

Mr. Ken Reese
President
Glacial Hills Fish Farm
Rt 1, Box 29
Hancock, MN 56244

Mr. Brian Erickson
Agriculture Marketing Specialist
Minnesota Department of Agriculture
90 West Plato Blvd
St. Paul, MN 55123

Mr. Richard Fagen
MinnKota Fisheries
13052 50th Ave. SE.
Granite Falls, MN 56241

Mr. Gary Myers
General Manager
Fish'N Dakota
HC 3, Box 42
Beulah, ND 58523