BRITISH COLUMBIA SABLEFISH AQUACULTURE RISK ASSESSMENT BASED ON THE NATIONAL CODES OF INTRODUCTIONS AND TRANSFERS

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Craig Stephen DVM PhD
Erin Fraser BSc DVM MSc

Centre for Coastal Health
900 5th Street
Nanaimo, BC
V9R 5S5
http://web.mala.bc.ca/cch

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1. Conditions of the Risk Assessment

The Centre for Coastal Health (CCH) was retained by the Department of Fisheries and Oceans (DFO) to undertake an assessment of the risks associated with sablefish farming in British Columbia (BC). The DFO asked the CCH to use the National Code on Introductions and Transfers of Aquatic Organisms[1] as the primary guide for this assessment. The purpose of the Code is to establish the scientific criteria for the intentional introduction and/or transfer of live aquatic organisms. Specifically, the CCH was asked to apply the Code as it relates to the movement of cultivated sablefish from hatcheries to marine pens in British Columbia. The Code focuses on environmental effects that may emerge due to genetic, ecological or disease interactions between the introduced species and other organisms. It does not deal with public health effects or socio-economic issues apart from requiring that there be some tangible benefit from the introduction. The CCH was limited to a risk assessment rather than a risk analysis; wherein the former serves to identify hazards and tries to estimate probability and magnitude of adverse outcomes while the latter includes risk management and risk communication recommendations.

The timeline for this review was six weeks. This schedule and the projects budget did not allow for the generation of original data and restricted the scope and depth to which investigators could pursue existing data. It also prevented a peer-review of this document prior to submission to allow for fact checking of the final report. The CCH lacked the power to oblige the provision of specific data on specific sites, enter into discussions with foreign governments or require people or organizations to provide information. The CCH informed DFO it would welcome information from both supporters and opponents of sablefish farming that was factual in nature and requested DFO’s assistance in accessing this information. This assistance was limited due to ongoing litigation at the time of the review. A small number of parties contacted did not respond to requests for information. The available data are insufficient to allow for quantification of risks.

For the sake of this review, we have assumed that the current technology used for sablefish aquaculture will reflect future practices. This may not be a reasonable assumption as this is a relatively new form of fish culture, and technological and regulatory changes can be anticipated that may influence a number of the key determinants of risks.

Judgements on risk are meant to represent population averages rather than describe the conditions for specific companies, animals or locations. Evaluation of individual level or site-specific risks and impacts requires precise knowledge on exposure levels and individual susceptibilities. Such data were not available for this review. Although some risk assessors attempt to quantify risks in situations of uncertainty through mathematical models, such an approach is beyond the scope of this review due to data deficits, time constraints and fundamental problems in reliably modelling complex ecological interactions.

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[1] http://www.dfo-mpo.gc.ca/Science/aquaculture/national_code_e.htm

2. Sablefish production in BC

Sablefish, also known as black cod, are long lived fish[2] distributed widely along the Pacific coast of North America from the Bering Sea south to Baja California as well as in Asia along the Japanese coast (Kendall and Matarese, 1987). Research and development of sablefish culture has been going on in BC for over 30 years. Dr. Bill Kennedy of the Pacific Biological Station reported in the early 1970's that wild caught juvenile sablefish could be reared in captivity to harvestable size, laying the groundwork for future research on sablefish aquaculture (Anon, 2000; Kennedy, 1971). There is currently a small sablefish aquaculture industry in British Columbia (BC). There is also interest in sablefish culture in Washington, California and Hawaii, with research interest in Oregon and California[3]. Interested U.S. groups included the Makah tribe in northern Washington State. Some of the opportunities and constraints of sablefish cultivation were noted on an Oregon State University website (table 1)[4].

Table 1. Some opportunities and constraints for sablefish culture[a]

Opportunities	Constraints
Faster growth rate than Atlantic salmon (Rust, 2001) Better food conversion ratio than Atlantic salmon (Rust, 2001) Two to three times higher market price than Atlantic salmon (Rust, 2001) High demand from Japan (Rust, 2001) Fishery is fully utilized in U.S. and Canada (Kendall and Matarese, 1987; Rogers and Builder, 1999) Maturity reached at age one year (Love, 1996)[c] Highest growth rate of any juvenile teleost (Sogard and Olla, 2001) Juveniles maintain high growth rate even with a high concentration of individuals (Sogard and Olla, 2000) Observed in oxygen levels as low as 3.5 ppm (Rust, 2001)	Life cycle is not closed (except by the Island Scallop Company in Canada) (Rust, 2001)[b] Limited amount of seed stock available (Rust, 2001) Carnivorous Cannibalistic (Kodolov, 1976, Shenker and Olla, 1986) Only one in 150 females spawned without hormonal treatment (Clarke, 1994) Risk of getting furunculosis (Bell et al., 1986)

[a] References cited in the table were from the original web citation and are not listed in this report's reference section

[b] No longer correct as others are involved in hatchery rearing in BC

[c] Contradicts bulk of other evidence with respect to age of sexual maturation (approx 5yrs)

The BC Ministry of Agriculture, Food and Fisheries (MAFF) reports that marine grow-out of captive sablefish has been carried out successfully on the coast since 1989, but that sablefish culture did not start in earnest until the late 1990's when four marine sites demonstrated the potential for successful commercial production (Anon, 2004). Prior to 1999, sablefish were supplied for culture from wild capture, after which, hatchery stock began to be used. Recent advances in reproduction of held broodstock and rearing of early life stages has allowed for commercial production of juveniles for marine grow-out. Robichaud et al, (2004) stated that the experience with sablefish culture to date has been on a relatively small scale and not on the scale anticipated for

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[2] oldest recorded was113 years, but one study revealed the average age of capture to be between 4 –35 yrs (McFarlane and Beamish, 1983)

[3] http://www.lib.noaa.gov/docaqua/nmai2001.html#nutrition

[4] http://hmsc.oregonstate.edu/projects/msap/PS/masterlist/fish/sablefish.html

commercial production. Clarke (2001) felt that, despite this 30-year history, the culture requirements for this species are not yet well known.

Currently, 43 sites owned by 14 companies have had their salmon marine-cage license amended to allow for sablefish culture (Table 2). The vast majority of sites licensed for sablefish have not yet reared sablefish. We are unaware of their business plans with respect to when or if they intend to exercise their licenses. Since 1997, at any one time, there has never been more than six locations culturing or growing sablefish in captivity. The MAFF reports that in 2003 three BC farms were raising hatchery-origin sablefish[5] and by 2004, there were four sites rearing sablefish: two hatcheries and two grow-out marine sites.

Three hatcheries are licensed to produce sablefish larvae and are involved in technical development of sablefish hatchery methods. Currently, only two of these hatcheries have provided fish for commercial grow-out. The largest hatchery produced 25,000 fish for movement into marine cages in 2004 and plans to produce 2 million per year by 2008. Industry predictions suggest that of the remaining two hatcheries, one has the capacity to provide 350,000 fish per year for grow-out while the third is still in the development phase (G. Minkoff, pers. comm.).

If we assume the average harvest weight is 4 kg[6], and there is a 90% survival to market, an input of 2.3 million fish would produce 8460 metric tons of fish which is 3.5 times the total allowable catch for 2003 and 40% of spawning biomass for the Gulf of Alaska and 35% of global landings.

The industry has not yet established a domestic line of broodstock, having instead to rely on capture of wild fish to serve as their reproductive stocks. One industry source reported to us that broodstock have come from a variety of locations in southern BC including locations off the west coast of Vancouver Island (near Uclulet and Quatsino Sound), Jervis Inlets, Knights Inlet, and Fitzhugh and Thurlow Islands. There has only been one movement of fish (<12) from the Pacific Biological Station (PBS) to a commercial hatchery involving first generation domestic fish that were believed to not be reproductively viable (C. Clarke, pers. comm.).

Success in spawning sablefish in captivity has been limited. Sablefish normally do not spawn in captivity without the aid of hormonal manipulation of females, environmental temperature and photoperiods control, and manual expression of eggs (Solar et al, 1987).

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[5] http://www.agf.gov.bc.ca/fisheries/faq.htm#How%20many%20farms

[6] Estimates of weights, landing and catch from: http://www.canadiansablefish.com/downloads/EconomicStudyFinalApr7.04.pdf

Table 2. BC MAFF records of sablefish licenses for British Columbia 1997-2004.

🟦 = impounded 🟨 = hatchery

LOCATION	1997	1998	1999	2000	2001	2002	2003	2004
Number of sites rearing black cod	2	2	6	5	2	3	4	4
Lees Bay, W.Thurlow Is.								
Whiteley Is., Kyuquot Sound								
Blunden Passage, Baker Is								
Island Scallops	🟦	🟦	🟦	🟨	🟨	🟨	🟨	🟨
Sonora Is, Okisollo Channel								
E. of Maud Is, Discovery Passage								
Bawden Point, Herbert Inlet								
Dixon Point, Shelter Inlet								
St. Vincent Bay, Jervis Inlet	🟦	🟦	🟨	🟨	🟨	🟨	🟨	🟨
Jane Bay, Barkley Sound								
Unique Seafarms								
NE McKay Is, Ross Passage								
NW Sechelt Inlet (Salten)						🟨	🟨	🟨
Bickley Bay, East Thurlow Is								
Thurlow Point S, Nodales Channel								
Brougham Point, E Thurlow Is			🟨	🟨				
W Redonda Is, Doctor Bay								
N side Swanson Is								
E Shore of Bedwell Sound								
Saranac Is				🟨				
E Warn Bay, Fortune Channel								
E Newcomb Point, Salmon Inlet								
Hardy Bay, Port Hardy			🟨					
Upper Retreat Passage			🟦	🟦				
Hecate Bay, Cypress Bay,			🟨					
Shelter Passage, Wishart Is								
Frederick Arm								
Shaw Point, Sunderland Channel								
Herbert Inlet, NE of Binns Is								
Varg Is, Raynor Group								
Doyle Is, Gordon Group								
Bare Bluff Bedwell Sound								
Duncan Is, Goletas Channel								
Thorpe Point, Holberg Inlet								
Althorpe, Sunderland Channel								
Mayne Passage, E Thurlow Is								
Shelter Bay, Richards Channel								
Cleagh Creek, Quatsino Sound								
W Side, Bedwell Sound								
Millar Channel, S Hayden Pass								
Kwakiutl, Nanaimo								
Sablefin Hatcheries							🟨	🟨

Broodstock have been held in sea tanks at the hatchery where key environmental parameters can be closely controlled. Cultured sablefish are typically harvested before maturity and, thus, there has been no reported spawning of females in marine cages (C. Clarke, pers. Comm.).

Eggs require cold, high salinity marine water for optimal hatching and survival. The eggs are very sensitive to environmental stressors. They must be maintained in upwelling conical tanks to prevent settling to the tank bottom and their subsequent death. Eggs that settle to the bottom are very susceptible to fungal infection and death (Clarke quoted in Karreman, 2004). Eggs typically hatch within approximately two weeks. After hatching, larvae are housed together and do not require feeding for 3 to 4 weeks at which time the yolk sac has been absorbed. The fish are first fed on live feed (algae, rotifers and artemia) for 5 weeks after which they are switched to a commercial diet. There are options for biosecurity to preclude the transfer of "fellow-traveller" pathogens with live feed including in-house culture and disinfection of purchased cysts. Survival to this point is typically 5 to10%. Juveniles are transferred to marine cages at weights of approximately 10 grams, which usually is attained by three to four months of age. These fish will be grown-out in marine cages for approximately 1.5 to 2 years before being sent for harvest. Mortality rates in seacages were estimated to range from similar levels as farmed salmon (H. Kreiberg, pers. comm.) to 10% over the grow-out phase (G. Minkoff, pers. comm.).

3. Sablefish Natural History and Status

Figure 1 is modified from the website FishBase and summarizes the basic biological characteristics of the species[7].

Figure 1. Basic biological characteristics of sablefish taken from FishBase

Anoplopoma fimbria (Pallas, 1814)		
Family:	Anoplopomatidae (Sablefishes)	picture by Gotshall, D.W. 
Order:	Scorpaeniformes (scorpionfishes and flatheads)	
Class:	Actinopterygii (ray-finned fishes)	
Max. size:	120 cm TL (male/unsexed); max. published weight: 57.0 kg; max. reported age: 114 years	
Environment:	bathydemersal; oceanodromous; marine ; depth range 0 - 2740 m	
Climate:	deep-water; 60°N - 28°N	
Importance:	fisheries: highly commercial; aquaculture: likely future use; aquarium: public aquariums	
Resilience:	Very low, minimum population doubling time more than 14 years (K=0.2; tm=6; Fec=100,000; tmax=114)	
Distribution:	North Pacific: Bering Sea coasts of Kamchatka, Russia and Alaska southward to Hatsu Shima Island, southern Japan and Cedros Island, central Baja California, Mexico.	
Morphology:	Dorsal spines (total): 19-27; Dorsal soft rays (total): 16-20; Anal spines: 3; Anal soft rays: 15-19. Dorsal fins well separated; 2nd dorsal fin sub equal to anal fin in size and form, and opposite in position. Reaches over 1 m in SL.	
Biology:	Adults found on mud bottoms, from 305 to 2,740 m depth. Young-of-the-year juveniles are pelagic and found on the surface and near-shore waters. Generally localized, but some juveniles have been found to migrate over 2,000 miles in 6 or 7 years. Feed on crustaceans, worms and small fishes. Most of the catch is marketed in Japan.	

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[7] Froese, R. and D. Pauly. Editors. 2004. FishBase. World Wide Web electronic publication. www.fishbase.org, version (06/2004). Specifically: http://www.fishbase.org/Summary/SpeciesSummary.cfm?genusname=Anoplopoma&speciesname=fimbria

Though frequently called black cod, sablefish are not in the cod family but are more closely related to greenlings and rockfish (Scorpaeniformes). Sablefish are most abundant in northern BC and in the Gulf of Alaska. Their entire life cycle takes place in the marine environment.

Adults are typically found along the continental slope at depths of 300 to 1500 m (Clarke et al, 1999). US slope trawl surveys estimated that 30% of the stock biomass is in water deeper than 500 fathoms (>900m).[8] Some adults do stay in mainland inlets; however, they do move out over time, but without a specific time-distance relationship (Beamish and McFarlane, 1988). Growth is very rapid with female average size at maturity of 55 cm. Female sablefish reach maturity between 3 and 5 years. Fifty percent of females and males spawn for the first time at an average age of 5 years (Mason et al, 1983).

Sablefish spawn in January to April along the entire Pacific coast of Canada at depths of approximately 300 to 500 m. Peak spawning occurs in February (Mason et al, 1983; McFarlane et al, 1997). Mason et al, (1983) report that there is no indication of major spawning areas in Johnstone Strait, Hecate Strait or Queen Charlotte Sound rather the majority of spawning occurs along the continental slope. Hatching mostly occurs in March and April at depths exceeding 400 m (Mason et al, 1983). Newly hatched larvae sink in the water column to depths up to 1200 m (Mason et al, 1983). When the yolk sac is approximately half used, larvae begin to ingest small food organisms and move up the water column. Approximately 40 days post hatching, when the yolk sac has been depleted, the larvae appear in surface waters (~200 m) (McFarlane et al, 1997).

Juveniles are highly mobile. For example there is significant juvenile movement from Hecate Strait to the Gulf of Alaska and the Bering Sea[9]. In July and August, juveniles are found in inside waters and may remain there until they reach maturity (Mason et al, 1983). Larval sablefish are found in surface waters over the shelf and slope in April and May. Juveniles migrate inshore during the following six months and rear in nearshore and shelf habitats until the age of two to five, when they migrate offshore and into the fishery[10]. A US National Marine Fisheries Service assessment model indirectly estimated a rate of dispersion of younger fish into deep water at about 4% per year.[11]

There is evidence of resident and dispersal behaviour in BC. Mature fish are believed to be resident, traveling under 200 km (Beamish and McFarlane, 1988). There is not an extensive spawning migration; most recovered tagged fish have been recovered within 100 km (81%) to 200 km (90%) of tagging location. Tagging studies suggest juveniles are more mobile, with some tagged fish travelling over 1800 km in a year (Maloney, 2002) and others being recovered 3000 km from where they were tagged (Shaw and Parks, 1993). Juveniles captured off Vancouver Island tend to move less, but when they do travel, they move equally into northern and southern US waters (McFarlane et al, 1997).

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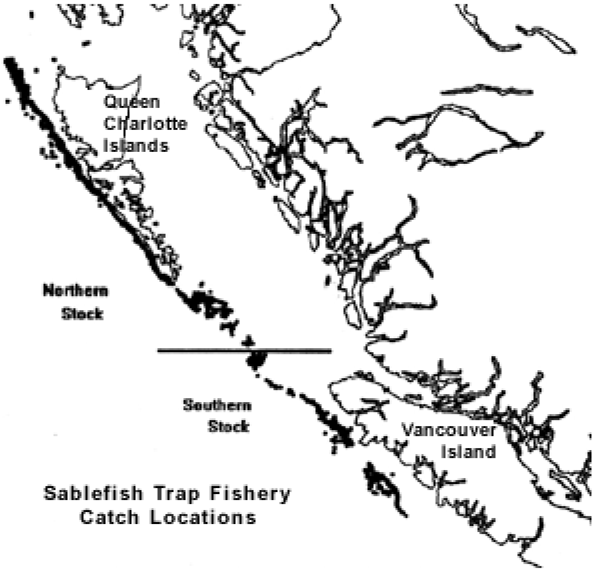
[8] http://www.psmfc.org/tsc/97_TSC_rpt/Attach-e7.htm

[9] http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/sablefish/Sable_LifeHist.htm

[10] http://www-comm.pac.dfo-mpo.gc.ca/publications/speciesbook/groundfish/sablefish_e.htm

[11] http://www.psmfc.org/tsc/97_TSC_rpt/Attach-e7.htm

Figure 2: Sablefish trap fishery catch locations in British Columbia[12]



Juvenile sablefish in BC are typically found in Hecate Strait and off the west coast of Vancouver Island (Shaw and McFarlane, 1997). The distribution of larvae varies considerably among areas and years possibly due to the position and intensity of the northward-flowing coastal current or the oceanographic conditions at depth during the first 40 days before larvae reach the surface (e.g. upwelling conditions transport larvae at depth shoreward) (McFarlane, 1997). More nearshore areas are used in years of high juvenile abundance (R. Kronlund, pers. comm.). Stock abundance has been linked to juvenile status that in turn has been linked to decadal environmental conditions that influence juvenile prey abundance (King et al, 2001).

Tanasichuk (1997) found that euphausiids ("krill") dominated the sablefish diet on the southwest coast of Vancouver Island but species such as Pacific herring, myctophids, Pacific hake, spiny dogfish, salmon, lingcod, arrowtooth flounder, Pacific sand lance, rockfish, and other invertebrates were also eaten. Laidig et al (1997) reported that sablefish in Oregon and California were highly piscivorous with larger sablefish found predominately in the benthos feeding on fish (primarily scorpionfish and rockfish) and cephalopods (e.g. octopus, squid and cuttlefish) while smaller sablefish tending to feed mostly on fish and crustaceans found in midwaters (Laidig et al, 1997). Larvae feed on copepods (primarily copepod nauplii) and strong year classes are thought to be associated with increased copepod abundance (Kendall and Matarese, 1987).

3.1 Current status of stocks

Sablefish management practices, done collaboratively with industry and government, are internationally recognized. "Fisheries and Oceans Canada conducted deterministic stock projections for the years 1998 through 2006 for three fixed levels of recruitment

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[12] http://ats-sea.agr.gc.ca/seafood/sablefish-e.htm

and three fixed levels of fishing mortality. The recruitment levels were 0.6, 1.0 and 1.4 times the mean of the 1966- 94 estimates. The region-specific mortality levels were 0.8, 1.0 and 1.2 times the 1997 estimates. In all but the high recruitment scenarios the biomass is stable or declining slightly"[13]. Kroeger et al (2002), in their discussion on broodstock manipulation, characterized the recreational and commercial sablefish fishery as being in decline.

"The Total Allowable Catch (TAC) for sablefish in 2001/2002 was 2,800 tonnes. The TAC for 2002/2003 was reduced to 2,450 as a precautionary measure resulting from declines observed in the annual survey."[14] The average landings in BC between 1990 and 2002 has been 4245.3 metric tonnes.

Stock assessments performed in BC rely on three indices: 1) commercial trap fishery catch rates; 2) indexing survey catch rates; and 3) relative estimates from monthly tag-recovery data. None of these methods account for juvenile sablefish or sablefish in coastal or inside waters (i.e. all three relate to offshore biomass vulnerable to trap gear). It is unclear which component of stock is selected by these methods because the factors that motivate sablefish to enter traps are not known (Kronlund et al, 2003).

Spawning abundance declined during the 1970s due to fishing mortality, but recovered due to contributions from exceptional year-classes in the late 1970s and reached a peak in 1987. The population declined over the course of the late 1980s and 1990s until 2000 when a modest increase was observed from 2000 to 2001. Sablefish vulnerable to trap gear showed a decreased abundance from relatively high levels in the early 1990s to lower levels in the mid 1990s, after which the rate of decline slowed markedly. In 2001 the north stock area (above 51.25ºN) showed historically low commercial catch-per-unit-effort and indexing survey catch rates but recovered in 2002. The south stock area (below 51.25ºN) has shown a gradual but continued decline from the mid 1990s to 2002. "Analysis of sablefish recruitment indicators from various sources in BC and the US suggested that future production of sablefish should improve over low levels experienced in the 1990s" (Kronlund et al, 2003).

Kronlund et al (2003) report that "the 2001 assessment of sablefish stocks of Washington, Oregon and California north of Point Conception indicated that poor recruitment over the last ten years contributed to a significantly decreased spawning biomass." The spawning stock biomass was estimated to have declined from a high of 122, 000 mt in 1980 to a low of about 60,000 mt in 2000. Data from 2002 show an increase in absolute biomass to 72,000 mt . Gulf of Alaska sablefish abundance is moderate and increased from recent lows, with the projected 2003 exploitable biomass estimated to be 221,000 mt (5.5 percent increase) and estimated spawning biomass for 2003 is 210,000 (2.5 percent increase) (Kronlund et al, 2003).

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[13] http://www-comm.pac.dfo-mpo.gc.ca/publications/speciesbook/groundfish/sablefish_e.htm

[14] http://ats-sea.agr.gc.ca/seafood/sablefish-e.htm

4. The National Code on Introductions and Transfers of Aquatic Organisms and its Application to this Risk Assessment

The National Code on Introductions and Transfers of Aquatic Organisms (hereafter referred to as the Code) states that it is the responsibility of the proponent to provide a detailed description of the life history of the species proposed to be transferred, the characteristics of the receiving waters and the potential for interactions with other species for consideration by the regional Introductions and Transfers Committees (ITC). In addition, the proponent of a transfer may be required to prepare a risk assessment for evaluation by the ITC. The Code relies to a significant extent on the regional ITC for assessing proposals to move aquatic organisms from one water body to another. The BC ITC reported to us that neither a biological review nor a risk assessment has been requested by or provided to the ITC by proponents of sablefish culture and the ITC has not conducted an independent risk assessment beyond consideration of specific requests for transfer (M. Higgins, pers. comm.). The ITC has recently received a report provided by the Fish Health Management Advisory Committee (Karreman, 2004) to guide their recommendations for fish disease screening prior to moving sablefish from hatcheries to marine sites. Prior to this review, the BC ITC had issued 41 licenses for sablefish movement for research, aquaculture and holding for market since 1991.

The federal and provincial/territorial governments rely in part on the Code to allow for maximum benefits associated with introductions or transfers while at the same time avoiding the following risks: (i) harmful alterations to natural aquatic ecosystems; (ii) deleterious genetic changes in indigenous fish populations; and (iii) potential introduction and spread of pathogens and parasites that might accompany aquatic organisms being moved and affect aquatic animal health. Specific risk bearers of concern to the Code are indigenous fisheries resources, habitat and aquaculture (Section 2.4.4). The Code does not specify thresholds to deem when something becomes harmful or deleterious. Section 1.1.5 states that the intent of the Code is to reduce risks while Section 1.1.1 states the purpose of scientific criteria used through the Code is to minimize undesirable impacts. The Code does not say its goal is to eliminate risk, however, in its definitions of the precautionary approach, there is mention of avoiding risks.

Many of the elements of the code are not applicable to sablefish culture as they are concerned with the effects of the introduction of an exotic species. As sablefish will be reared commercially within their historical distribution, they cannot be considered an exotic species. With respect to the definitions in the Code, sablefish farming in BC would be considered the transfer of an indigenous species. Transfers are defined as "shipment of individuals of a species or population from one locations and its intentional release to another within its present range." Release is, in turn, defined as "The liberation of aquatic organisms to the natural environment. Release can be unintentional, as in the escape of organisms from aquaculture facilities or during use as live bait." Therefore, for sablefish, the principle variable of concern to the Code is the escape of sablefish from captivity. For the purpose of this review, we will assume that sablefish aquaculture is and will be conducted in accordance with current laws and policies.

4.1. General Principles of the Code

The following comments (box 1 to 6) are the general principles directly quoted from the Code. Details of the comments following the quotes are found in the subsequent sections.

> ***1**. "Needs and benefits must be evident and well defined for human or natural resource communities for the introduction or transfer of aquatic organisms"*

Socio-economic issues including cultural effects and effects on human health are not included in the Code. The Canadian Sablefish Association (CSA) and other critics of sablefish aquaculture have voiced concerns that sablefish aquaculture is developing at rate that is too quick to allow for adequate adaptive management that will allow for sustainable aquaculture along with protection of the wild sablefish fisheries resource.

There are differences of opinion as to size and nature of overall benefits and costs to culturists and harvesters. Critical assessment of these opinions is beyond the scope of this report not only for lack of comprehensive eco-economic assessment, but also because we are unaware of government criteria for measuring competing needs and opportunities as those existing between sablefish aquaculture and fishing. Section 2.4.4 of the Code advocates for independent socio-economic reviews to be conducted at the discretion of the provincial/territorial authorities. MAFF has stated that they will allow market forces to determine the route of product supply (culture versus capture) rather than impose a single specific means of meeting market demands for seafood products. Decisions on whose economic projections to accept when judging if there are benefits to human communities will be deferred to those agencies responsible for licensing and regulating aquaculture.

The only benefit to natural resources that we can conceive is reduction of harvest pressures on sablefish. Kodolov (1983) concluded that the "paramount cause of the abundance depression in all areas of its range is fishing pressure on immature fish..." It is beyond this review to predict the effects on the ecology of sablefish of reduction in wild harvest rates that may arise due to competition from aquaculture.

> ***2**. "Use of suitable indigenous species for intentional release to unconfined waters from within the aquatic zone or watershed is preferable to the introduction of an exotic species or transfer of indigenous species from other distinct stocks (within and outside Canada). However, there may be instances where it is preferable to use a non-indigenous species that is reproductively isolated from indigenous stocks or that would be unable to survive in the wild."*

Sablefish are indigenous and widespread in BC waters. While they are managed as two stocks, they are considered by many to be a single population throughout their range. To date, sites requesting sablefish licenses and rearing sablefish have been restricted to the area of the southern stock (below 51.25°N) as have all locations for broodstock collection. Therefore, sablefish should not be considered exotic species or introductions from distinct stocks. There is no intention to release the fish into unconfined waters. Physical infrastructure features should prevent the release of larvae from hatcheries and fish will leave marine netpens only unintentionally through escape or accident. Escaped sablefish would likely be able to survive in the wild, but the duration or their survival is speculative at this point.

3. "Ecological risks and benefits of introductions and transfers will be assessed prior to movement, except for those cases which have been reviewed and deemed exempt"

John Cummins MP posed a number of questions associated with sablefish farming and their potential for environmental impact effects in Parliament in September 2003 (K. Wilson, pers. comm.). Interviews with Cummins' staff indicate that these questions remain unanswered.

In May of 2004, the Federal Standing Committee on Fisheries and Oceans issued a letter to the Minister of Fisheries and Oceans specifically requesting a "comprehensive environmental impact analysis of sablefish aquaculture in British Columbia be completed under the Canadian Environmental Assessment Act, the Fisheries Act, or the Navigable Water Protection Act before any commercial sablefish farming operation is authorized to proceed". The environmental risks of sablefish farming have not, to our knowledge been subject to a previous risk assessment. DFO reported to us that none of the facilities licensed for sablefish have completed an assessment by the Canadian Environmental Assessment Agency (A. Thomson, pers. comm.). The BC Fish Health Advisory Committee produced advice to the Introduction and Transfers Committee on screening criteria that might be required before a transfer of sablefish from a hatchery to a sea cage-rearing site. This advice was based in part on a review of disease issues generated by Pacific Marine Veterinary Services (Karreman, 2004), but was not a risk assessment of sablefish culture.

Movements to date have been assessed on a local level by the Introductions and Transfers Committee, which is guided by the National Code. A total of 41 licenses for movement have been approved by the ITC between 1991 and 2004.

In an e-mail provided to us for this review, the ITC noted the following:

- "The ITC takes into account the disease, genetic and environmental impacts that may occur for each movement, using the best available knowledge of the day. "
- "Wild collections of Sablefish transferred to an aquaculture facility or research facility either have to undergo a full Canadian Fish Health Protection Regulation (CFHPR) schedule II health screening, and/or go into a facility with the capabilities of treating the effluent to minimize the risk of spreading disease agents of concern."
- "The ITC concluded that West Coast Sablefish populations are contiguous from Alaska to California. It is unclear if Sablefish stocks appear within the

Strait of Georgia. Therefore, brood stock caught on the outside of Vancouver Island is required to undergo health screening prior to introduction to the inside waters of Vancouver Island."

- "Sablefish moving from one facility to another within the Strait of Georgia are considered as a same zone movement as no resident stocks are present in this area. Therefore these types of movements are not seen to present a large risk for the transfer of disease to resident stocks or for genetic or ecological concerns if an escape is to occur."
- "Over the past 5 years, there have been 29 applications to transfer Sablefish either into research facilities or licenced aquaculture facilities in British Columbia. Of these signed Section 56 Licenses, 15 have had specific conditions attached to the transfer which would have included one or more of the following: Having animals undergo a health check for the Canadian Fish Health Protection Regulations (CFHPR) Schedule II list of salmonid pathogens; effluent treatment at the receiving facility; and/or no movement out of the receiving facility without written ITC approval. As well as the above conditions, research facilities housing Sablefish have regularly submitted dead or moribund fish for post-mortem analysis at the PBS laboratories."
- "The remaining applications that did not have specific conditions applied to the Section 56 licence were either going to a research facility with effluent treatment in place, were a same zone movement (see below), or were a repeat of a previous movement to a licenced facility."

4. ***"Assessment of proposals from an ecological perspective will include a review of potential genetic and disease impacts on indigenous fisheries resources, aquaculture operations and habitat".***

This report is an attempt to provide information in these areas but cannot provide a quantitative risk assessment due to the lack of definitive information on sablefish natural history, sablefish culture, and specific data relevant to estimating and quantifying risks. The ITC considers all of these features in their deliberations.

5. ***"In the spirit of the 1999 Agreement on Interjurisdictional Cooperation with Respect to Fisheries and Aquaculture, consultations should take place between and among neighboring jurisdictions, (including those in the USA and France) on proposals to introduce exotic species, or to extend the range of organisms, in shared watersheds. Neighboring jurisdictions should also be consulted if an introduction, transfer or range extension proposal might impact stocks within a watershed but outside the receiving province***"

The CCH lacked the authority to engage other jurisdictions in consultations. Information provide by DFO indicate that such consultations have not taken place on specific issues of sablefish movements (A. Thomson, pers. comm.). Since sablefish are not exotic to BC and the current culture locations are within the normal range of the species, it is unclear how this guiding principle has to be applied in this case.

The Pacific Northwest Fish Protection Committee representing Washington and Alaska has not yet discussed the issue of sablefish farming (R. Brunson, pers. comm.).

An October 2004 letter from Governor Frank Murkowski of Alaska to Premier Gordon Campbell has asked the BC government to delay the start of sablefish farming until (1) "adequate research" on the impacts on marine environments and fisheries resources is conducted, (2) socio-economic studies are completed and (3) Canadian fish farmers employ technologies to prevent any harmful interactions between farmed fish and natural stocks. We, therefore, assume that this letter will serve to initiate inter-governmental discussions.

***6.** "Precautionary Approach will be adopted. 'States should apply the precautionary approach widely to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment. The absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures' (FAO 1996, 2001). If the outcome (impact) is uncertain, priority should be given to conserving the productive capacity of the native resource."*

Canada's Oceans Act requires the government to promote the wide application of the precautionary approach to the conservation, management and exploitation of marine resources, in order to protect these resources and preserve the marine environment. DFO's position on the application of the precautionary principle to aquaculture can be found on-line.[15] This site is unsatisfactory from a specific decision making perspective, as it does not provide guidance on how to weigh various sources and types of information or how to consistently apply a threshold for uncertainty at which point the precautionary principle will be applied. MAFF also lacks an operational guideline for the application of the precautionary principle to specific decisions. Gislason (2004) concluded that there is an "overall lack of operational guidelines for applying the precautionary approach in BC's fisheries and aquaculture sectors."

The precautionary principle is a fundamental principle of sustainable development (DPWS, 2001). However, it remains unclear how this principle is consistently and rationally applied in issues of sustainable development and environmental protection, especially when the full breadth of sustainability indices is not considered. It cannot be expected that proponents and opponents of aquaculture will apply this principle in a similar fashion. The core debate revolves around whether a "weight of evidence" or

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[15] http://www.dfo-mpo.gc.ca/aquaculture/policy/pg014_e.htm.

"society's chosen level of protection" should be the main determinant of a precautionary decision[16]. While some emphasize the importance of ensuring that decisions are science-based others argue that risk management decisions ultimately reflect judgements and social values, and should therefore be more explicitly values-based. These perspectives are apparent in the issue of sablefish cultivation and cannot be resolved by this report. The lack of inclusion of social issues in the Code complicates application of this principle.

4.2. Specific Elements of the Code

4.2.1. Entry Risks

When assessing both the genetic and ecological risks associated with a transfer, the Code asks the following to be assessed:

- The probability that the introduced species successfully colonizes and maintains a population in the intended area of introduction
- The probability of spreading beyond the intended area of introduction. For species confined in a location, the Code takes this condition to mean the probability of escape into the local environment from confinement.

Table 3 summarizes the major ways sablefish cultivation could plausibly result in interactions with components of its environment. Table 3 does not assign significance to these interactions, but simply indicates the major classes of hazards and risk bearers that are of concern to those conducting, managing and critiquing marine aquaculture.

A genetic interaction requires a fish to live long enough to reach reproductive age and then successfully attract a mate. Direct ecological interactions (wherein a cultured sablefish directly affects an element of its environment through contact, disease transmission, competition or predation) also require a period of survival that will allow interactions with wild animals. Therefore, both genetic and direct ecological interactions are largely dependent on the ability of a cultured fish to leave confinement and survive long enough to interact with other marine biota to produce a measurable effect in non-cultured species. Indirect ecological effects of sablefish culture may result from products that are released from the rearing facility (including waste feed, excreta, pathogens/parasites, drugs, chemicals, fuels or other products) or by consumption of resources to allow culture to occur (such as fuel, feeds, or space). Indirect interactions will relate largely to management practices such as waste control, siting and health management.

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[16] http://www.ec.gc.ca/econom/proceeding_e.htm#62

Table 3. Major forms of interaction of cultured fishes with components of the culture environment

	Resource competition	Predation	Disease	Genetics	Biotic wastes	Abitoic wastes[a]	Resource allocation[b]
Wild sablefish	x	x	x	x	x	x	
Other wild fish	x	x	x		x	x	
Cultured salmon			x		x	x	
Other marine organisms	x	x	x		x	x	
Human health			c		x	x	x
Abiotic environ					x	x	x

[a] Includes drugs and chemicals used for veterinary or animal management, chemicals used for other infrastructural purposes including antifoulants, fuel spills etc

[b] Includes use of feed components and foreshore uses

[c] The presence of fish disease agents in BC waters that are known to cause human disease are very rare and thought to be low probability events with low to moderate significance.

4.2.2. Escape probability

4.2.2.1. Escapes from Hatcheries

Sablefish hatcheries are land based facilities to date, suggesting the only route of escape for larvae or eggs would be through wastewater drains or by vandalism. Our visit to one hatchery revealed that wastewater is passed through a 37 micron filter before being passed through sand filtration. This would preclude escape from the hatchery. The hatchery we visited was also not on the foreshore, suggesting vandals would need to break into the locked facility and transport the fish to sea. We can conclude that unassisted escape is not possible from such a facility and vandalism would require highly motivated people with the ability to capture and move the animals in a manner that does not affect their survival and thus seems to be a very unlikely event. We conclude, therefore, that the probability of escape from hatcheries with similar infrastructure would be near zero. Extrapolation of this conclusion to other hatcheries assumes similar barriers to escape.

4.2.2.2. Escapes from Sea Pens

The current management plan for housing sablefish follows requirements set forth by MAFF for marine culture of finfish. The MAFF goal is to get to zero-escapes for the marine finfish aquaculture industry[17]. To date, there have been no reports to MAFF or DFO of sablefish escaping from sea cages (B. Harrower, pers. comm.; A. Thomson, pers. comm.). Regulations governing marine fish culture require escapes to be reported to the province.

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[17] http://www.agf.gov.bc.ca/fisheries/escape/escape_prevention.htm

Every marine fish farm in the province is supposed to have a best management plan that includes precautions to avoid net damage and fish handling that could lead to escapes. The Aquaculture Regulations under the BC Fisheries Act states the following under section 3:

> *(2) A holder must take reasonable precautions to prevent the escape of aquatic plants and fish from the holder's aquaculture facility and from a containment structure or an attachment structure in the aquaculture facility.*
>
> *(3) A holder must take all reasonable measures to control, mitigate, remedy and confine the effects of an escape or a suspected escape of aquatic plants or fish from the holder's aquaculture facility*
>
> *(4) Reasonable precautions and reasonable measures under subsection (2) and (3) in the case of a marine finfish aquaculture facility must include compliance with the standards of practice in Appendix 2 of this regulation.* (Appendix 2 of these regulations contains Standards of Practice for Marine Finfish Aquaculture Escape Prevention and Response).

As salmon aquaculture is subject to the same regulations regarding escape management as are sablefish, it is relevant to consider escapes from salmon sea cages to help estimate the potential for future escapes from sablefish farms. This extrapolation requires the assumption that sablefish are not more or less able or likely to escape from a sea pen than a salmon. This assumption is untested to our knowledge, therefore, the extrapolation must be made with some caution.

The 2003 joint MAFF/MWLAP Annual Inspection report on Marine Finfish Aquaculture Sites[18] noted occasions where escapes were not reported to government as per regulations, but found this to account for a small (unspecified) number of fish lost during handling or harvesting. While most inspected sites had best management plans, 32% (25/77) failed to show documents that their plan had been reviewed and endorsed by the holder, three facilities did not have a copy on site and two had not developed a plan. The implications of these deficits on escape prevention and management is unknown. All 77 inspected facilities did have escape response plans. The inspection report noted that in 2003, DFO issued seven permits to aquaculture companies for the recapture of escaped Atlantic salmon. The report did not clarify if these permitted recaptures were undertaken or if the permits were provided in case of a later need. There was a high level of compliance for net inspection and care. This audit suggests a high level of compliance with current regulations among marine cage operators as the deficits noted were not likely to have significant effects on increasing the likelihood of escape. However, the audit also noted that the zero-escapes level has not been reached.

Table 4 presents BC MAFF's summary of reports of salmon escapes from farms in the marine environment. The numbers of escapes fluctuated between years, however,

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[18] http://www.agf.gov.bc.ca/fisheries/aqua_report

table 4 suggests a pattern in which the highest average escapes per year (averaging approximately150,000 fish/yr) occurred in the first six years of tracking, the subsequent nine years averaging approximately 50,000 fish/yr and the last two records years averaging slightly over 10,000 fish/yr. This suggests an improvement in escape prevention over time.

By assuming a 5kg average weight at harvest, we can estimate the total number of salmon harvested per year in BC from 1998-2002 using MAFF statistics[19]. Using these numbers, we can estimate an escape rate average for 5 years to be 0.49%/yr (range 0.01-0.98%). This is an overestimate of escape rates as it accounts only for a population size at harvest and not the average population size at risk for escape through the marine production cycle. Moreover, if recent trends hold, the years 1998-2002 are higher than current year's escape rates and what may be predicted for future escape rates.

Table 4: BC MAFF reports of farmed salmon escapes into the marine environment[20].

Number of Reported Escaped Farmed Salmon into the Marine Environment 1987 to 2003					
Year	Chinook	Coho	Atlantic	Steelhead	Annual Total
1987	22,422	0	0	32,576	54,998
1988	2,000	0	0	0	2,000
1989	390,165	0	0	0	390,165
1990	165,000	0	0	0	165,000
1991	229,500	0	6,650	0	236,150
1992	59,632	0	9,546	0	69,178
1993	12,113	0	9,000	0	21,113
1994	2,300	0	62,809	0	65,109
1995	5,000	1,000	51,883	0	57,883
1996	0	0	13,137	0	13,137
1997	38,956	0	7,472	0	46,428
1998	1,900	0	80,975	0	82,875
1999	0	0	35,954	0	35,954
2000	36,392	0	31,855	0	68,247
2001	0	0	55,414	0	55,414
2002	9,098	100	11,257	0	20,455
2003	9	1	30	0	40
TOTAL	974,487	1,101	348,060	32,576	1,356,224

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[19] http://www.agf.gov.bc.ca/fish_stats/aqua-salmon.htm

[20] http://www.agf.gov.bc.ca/fisheries/escape/escape_reports.htm

We have attempted to forecast potential sablefish escapes with the following assumptions:

- Sablefish escape rates will be similar to salmon as they are held and regulated the same
- Escape rates documented for 1998-2002 are reflective of future escape rates until 2008.
- Escape rates range from 0.01-0.98% (based on estimated salmon escape rates) and appear to be decreasing.
- The estimate number of sablefish put to sea by 2008 is approximately 2,300,000 per year and that all of these fish will be in marine pens in the same year.
- We will assume a range of mortality from 2-10% from introduction to sea to harvest providing a range of final populations at risk from 2,185,000 to 2,277,000 fish.

Based on these assumptions, the number of escaped sablefish by 2008 could range from 219 to 22314[21]. If the 2003 salmon escape data reflects future sablefish escape rates, the numbers would be significantly lower to the point of being less than 5-10 per year. It is reasonable to assume that the sablefish escape rates will mirror current reports for salmon given that no escapes have ever been reported from marine pens for sablefish in BC. Please note that it is with some reluctance that we present the preceding escape forecast because of the use of very rough approximations of unknown reliability due to the untested (but we feel reasonable) assumptions used in the calculations. One factor that may increase the risk of escapes is the habit of sablefish to rest at the bottom of pens (C. Clarke, pers. comm.). If a marine cage site lacked adequate bottom predator nets, there may be increased incidents of predator attack with net damage and escapes. The forecast does not include a consideration of the number of escapes per incident. Catastrophic failure in containment or recapture could allow a larger number to escape. Conversely, improvements in escape prevention technology could allow for a number even smaller than forecasted.

We were unable to determine the total number of sablefish in the wild as no survey we found accounted for adults, juveniles and larvae across their entire range, therefore, we cannot compare this hypothesized escape number with the total population of sablefish. However, we can confidently say that the number of wild fish greatly exceeds even our highest forecasted number of escapes.

4.2.2.3. Probability of spreading beyond the area if escapes occur

Relevant to the issues of survival and the potential for genetic and ecological impacts, is how far a field could one expect an escaped sablefish to move. Data shows that some juvenile sablefish can move very long distances but that the majority of adults stay within a smaller range. Wisehard and Aebersold (1979) reported that 80% of tagged sablefish stay within a 73 nautical mile area but that some sablefish can move

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[21] Escape calculations: 2,185,000 fish x 0.01% (escape rate) = 219 fish
2,177,000 fish x 0.98% (escape rate) = 22314 fish

thousands of miles. Juvenile sablefish tagged in nearshore waters can widely disperse and will likely follow underwater features to deeper water as they age (R. Kronlund, pers comm). The distance a sablefish moves is directly related to time, in that, the longer an animal survived post-tagging, the greater the distance it is likely to be from the tagging site. This suggests a gradual movement rather than a seasonal or annual migration. As cultured sablefish are harvested prior to sexual maturity, we assume that there would be a greater likelihood than not that there would be some escapees that travelled considerable distances from their site of escape, gradually heading to areas off the continental shelf over the course of months to years, if we further assumed they can survive long enough to travel that distance.

4.2.2.4. Likelihood of survival of escapees

There are no data to our knowledge that characterize the capacity for an escaped sablefish to survive in the wild. An experiment involving the release of hatchery-reared turbot estimated post-release mortality to be 14% per day over the first 9 days post survival (Sparrevohn et al, 2002). We do know that sablefish are subject to predation by fish such as Pacific cod and bocaccio[22] (McFarlane and Beamish, 1983), therefore, it can be expected that some of the escaped sablefish would be lost to predators. While it may be hypothesized that cultured fish may be less likely to evade predators than fish reared in the wild, there is no information to our knowledge on the capacity of cultured sablefish to escape predators. Dr. Jeff Marliave of the Vancouver Aquarium Marine Science Centre has been rearing marine fishes for several years and opined that escaped sablefish reared on pellets would likely have no difficulties foraging in the wild, but this was an opinion not based on observation or specific experience with sablefish.

A variety of papers suggest cultured salmonids (both enhancement and commercial production fish) as less fit than wild fish. Bakke[23] for example, suggested that some transplanted Pacific salmon stocks are less productive than locally adapted populations, and that hatchery populations are generally less productive in nature than native locally adapted populations. However, it must be remembered that salmonid enhancement programs do get regular and significant returns of the fish they culture, indicating a reasonable capacity to compete and survive in the wild.

Data from Washington and BC indicate that a small proportion of total number of escaped farmed salmon are recovered annually (tables 5 and 6). Sparrevohn et al (2002) suggested a 28% catch rate for released hatchery-reared turbot. None of these data take into account recovery method and effectiveness, but it can be assumed that only a proportion of all escapees are susceptible to recovery efforts. The reasonable extrapolation from these data would be that in the absence of sablefish specific data, it is reasonable to conclude that a proportion of escaped sablefish will survive given that they are escaping into waters for which they are evolutionarily adapted, but the likelihood or duration of survival cannot be quantified.

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[22] http://www.dfo-mpo.gc.ca/csas/Csas/English/Research_Years/2001/2001_148e.htm

[23] Bakke B. On line reference. Straying of hatchery fish and fitness of natural populations. http://research.nwfsc.noaa.gov/publications/techmemos/tm30/bakke.html

Table 5: DFO's Atlantic salmon watch data reveal the following trends with respect to the proportion of total escapes recovered in marine waters:

Year	Number of Atlantic Salmon recovered in BC marine waters	Recoveries as a proportion of the total escapes for the same year
1987	1	0.002%
1988	106	5.3%
1989	8	0.009%
1990	2	0.001%
1991	31	0.01%
1992 [a]	349	0.5%
1993	4543	21%
1994	1037	1.6%
1995	678	1.2%
1996	673	5.0%
1997	2664	5.7%
1998	136	0.2%
1999	190	0.5%
2000	7834	11.5%
20001	179	0.3%
2002	562	2.7%

[a] first year of the BC Atlantic Salmon Watch Program

Table 6: Analysis of Washington State data on farmed salmon escapes and recoveries[24].

Year	#escaped/# salmon produced per year (%)	# of escapees recovered/ # salmon produced per year (%)	Year	#escaped/# salmon produced per year (%)	# of escapees recovered/ # salmon produced per year (%)
1990	NA [a]	0.05	1997	17	0.11
1991	NA	0.07	1998	2.4	0.005
1992	NA	0.007	1999	9.5	0.003
1993	NA	0.01	2000	NA	0.001
1994	NA	0.02	2001	NA	0.001
1995	NA	0.01	2002	NA	0.0002
1996	5.3	0.007			

[a] No escapes recovered, but zero escapes will not be assumed

4.3. Section Conclusion

Many of the genetic and ecological risks of concern to the Code are dependent on the ability for sablefish to escape confinement and enter natural waters. We can conclude that escape from marine pens is possible, but the number escaping per year at anticipated production levels for the next four years will be very-to-extremely low on average in comparison to the size of the wild population of sablefish. Past experience with salmon farms suggest that accidents can result in escape rates significantly higher than average, while competent management can result in escape rates lower than average. Escaped fish are not all likely to survive, thereby reducing the effective

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[24] http://www.wdfw.wa.gov/fish/atlantic/comcatch.htm

population size capable of interacting with wild sablefish or other marine organisms. However, the true escape and survival rates are not known at this time. If the technology we witnessed is reflective of standard hatchery practices, escape from hatcheries can only occur through vandalism.

5. Genetic Risks

In the aquaculture debate, there is the specific concern that hybridization between wild and cultured fish will introduce genetic material that will reduce the fitness of wild stocks. There are two main reasons why genetics can be an important consideration in conservation of a species[25]. First, the rate of evolutionary change in populations is proportional to the amount of genetic diversity that is available in a given population. A decrease in genetic diversity can decrease the rate and scope of possible evolutionary change in response to an environmental change. Second, the degree of genetic variation within an individual is related to its fitness. A decrease in the heterozygosity in populations may be a sign of a decrease in the ability of a population to survive.

It is assumed that phenotypic characteristics that affect fitness are multilocus phenotypes. The effects of the addition of genetic material from cultured sablefish into wild sablefish populations would be complex and depend on the genetic variation of wild and cultured populations, their relative fitness and the amount of genetic exchange that takes place.

For cultured sablefish to exert genetic effects on wild sablefish populations, there must be opportunities for genes to flow from cultured to wild fishes. Furthermore, to have a negative effect these genetic exchanges would have to reduce the overall fitness of wild stocks and/or affect genetic diversity to reduce the capacity of wild sablefish to adapt to ecological change.

5.1 What is the nature of gene flow in wild sablefish?

Kimura et al (1998) felt that "tag-recovery data support a two-population hypothesis through the North American range: an Alaska population ranging from the Bering Sea, including the Aleutian Islands and extending down trough the Gulf of Alaska to northwest Vancouver Island; and a west coast population extending from southwest Vancouver Island to Baja California." However, these two populations intermix off northwest Washington and southwest Vancouver Island and to a lesser degree off southern Washington and Oregon (Kimura et al., 1998). Genetic studies have generally shown that significant gene flow occurs throughout the North American range (Kimura et al., 1998). While managing the stocks as two groups based on fish movements, DFO claims that genetic evidence supports the contention there is a single sablefish population[26].

Work conducted on Alaska and Washington sablefish concluded that sablefish are one of the most genetically diverse fish species documented at that time (Wishard and Aebersold, 1979). This same study suggested that there were no genetic differences in the features analysed throughout the Gulf of Alaska, but some differentiation was

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[25] http://cronus.uwindsor.ca/units/glier/conservationgenetics/main.nsf/032ecd0df8f83bdf8525699900571a93/896ffc80669fbfc885256b9c0043049b!OpenDocument

[26] http://www-comm.pac.dfo-mpo.gc.ca/publications/speciesbook/groundfish/sablefish_e.htm

evident between Washington and Alaskan samples. However, the authors placed no biological significance on these, as they were only relative differences.

Personal communications with Dr. Kristi Miller (Pacific Biological Station) revealed that a survey for genetic variation has not been done for BC sablefish. Therefore, it is not possible to comment on the nature of genetic variation or distribution of specific alleles in BC sablefish populations. Dr. Miller reported to us that work in other marine fish suggests that there can be significant variation among species with some in BC being homogenous throughout their range while others contain structures that relate to specific regions.

Some evidence suggests that there are discrete groups of sablefish. Whitaker and McFarlane (1997), for example, found that sablefish inhabiting seamounts off the west coast of Vancouver Island represented discrete stocks based on using parasites as biological tags. However, tagging results and parasite studies show that these seamounts are populated by immigrating fish from other locations rather than by self-sustaining, locally adapted populations (R. Kronlund, pers comm.; Kabata et al, 1988). Kabata et al (1988) suggested that differences in parasite fauna between seamount groups might represent ecological rather than genetic differences.

The conservation of genetic diversity within an individual species is an important factor in its survival in the face of environmental changes and disease. Recent research has indicted that diversity within some model species can be distributed unevenly such that disproportionate amount of the diversity is concentrated in small sub-populations, even when the population is well-mixed (Rauch and Bar-Yam, 2004). This work showed that there could be sharp boundaries in diversity between distantly related organisms without extrinsic causes such as barriers to gene flow or past migration events. The implications of this work is unknown for sablefish, but does emphasize the point that the lack of data on genetic diversity of wild populations is an impediment to quantifying the risks of new paths for gene flow that could result due to anthropogenic effects. However, the burden of evidence and opinion we found supports the notion of significant movement of genetic material throughout the range of sablefish.

5.2. Opportunities for introduction of cultured genomes into wild stocks

5.2.1. Escapes

The frequency of a specific phenotype in a population is directly related to the population allele frequency. The rarer a specific genetic characteristic is, the lower the likelihood that the trait associated with a specific gene will be manifested. It would therefore follow that the more frequently wild and cultured sablefish interbreed, the more frequent will be the introduction of unique genotypes that may arise due to domestication and the greater the likelihood that any phenotypes associated with those introduced alleles will be manifested in the wild.

For gene flow to occur, escaped fish must survive in the wild until sexual maturity (50% mature by 5 years), be fit enough to produce gametes and successfully mate, move to a location where gametes produced can hatch and subsequently survive to breed. These conditions affect the probability that the average escapee will successfully hybridize with a wild fish. We have established above that it is reasonable to assume that cultured sablefish may escape from net pen marine cages and that a proportion of those escapes will survive. We have also concluded that the ratio of escaped to wild sablefish will be low when viewed from the perspective of the entire population. This suggests a low probability of an escaped sablefish breeding with a wild sablefish; therefore, the exchange of genetic material will be infrequent.

Personal communications from industry and DFO (G. Minkoff, C. Clarke) indicate that the waters of the Georgia Straight do not reach depths sufficient to support development of sablefish eggs, suggesting that an escapee would have to move offshore for spawning to result in successful transmission of genetic material to a subsequent generation. King et al (2001) state that fish in marginal environments (<640m) do not contribute to reproduction unless they migrate to deeper waters. Since tagging data suggest that juvenile sablefish do move offshore with time and age, but there is not a spawning migration, we can conclude that some escapees may move to the same spawning area, but not all escapees would move to the same area at the same time. Population genetic models intended to determine if the number of escaped sablefish would be capable of influencing the multiple phenotypic traits that affect fitness by breeding with wild fish would have to take into account the likelihood that an escapee would survive, move to deep waters and successfully mate. Such a model is beyond the scope of this report.

5.2.2. Spawning in marine netpens

It has been suggested that sablefish culture may increase the rate of introduction of unique genetic material beyond what could occur by escapes, if the fish spawned in marine netpens. Successful sablefish spawning is highly dependent on a favourable environment and a critical population size (Morrison and Zurbrigg, 1993). Spawning of sablefish is cued by photoperiod (Morrison and Zurbrigg, 1993) and temperature (C. Clarke, pers. comm.), thus limiting the number of times to once per year that one would expect caged sablefish to spawn.

Both the report provided by the provincial government (Anon, 2004), peer-reviewed literature and interviews with industry and DFO researchers (G. Minkoff and C. Clarke, pers. comm.) indicate that sablefish will not be able to successfully breed in a marine cage setting for a number of biological reasons. First, the conditions under which sablefish are reared do not seem to be conducive to spawning. While all factors influencing natural spawning are unknown, salinity, temperature and hydrostatic pressure are thought to play a role under natural conditions (Solar et al, 1987). Broodstock held at sea do not experience sufficiently cold water to induce egg development. Cold water temperatures occur too late in the season to allow sablefish held in sea pens to develop eggs in time for the natural spawning season (C. Clarke, pers. comm.). Spawning behaviour of captive female sablefish has required hormonal induction (C. Clarke, pers comm). Current production conditions will see reared sablefish being marketed at 1.5 – 2 years of age, whereas sexual maturity does not occur until they are 3-5 years old typically. Broodstock are currently removed from marine cages and held at the hatchery, precluding the release of gametes into the marine environment.

Second, if broodstock were in the future to be held in marine cages after sexual maturity and spawning were to occur, the conditions around most cages would have to mimic natural conditions to ensure egg survival. Specifically, there would need to be sufficient depth and high enough salinity to provide the eggs with the conditions required. Eggs in the wild sink to approximately 1000 m within 18 days of fertilization (King et al, 2001). At these depths and salinities, the eggs are neutrally buoyant and float mid-water. At salinities less than 28% (as may be found in the parts of the Straight of Georgia and other nearshore areas), eggs are negatively buoyant and sink (Clarke et al, 1999). It can be anticipated that egg survival would be very low for those that did not maintain their position in the water column because sablefish eggs are not adapted to incubation on the ocean floor. Data provided by MAFF showed that none of the sea cage systems licensed for sablefish are sited in water exceeding 95 m; ranging in depths from 14-95 m. These data do not take into account if local oceanography could facilitate movement of eggs to deeper waters soon enough to maintain egg viability until depth and proper salinities were reached. Given that eggs are highly susceptible to bacterial or fungal infections if they touch a surface (C. Clarke, pers. comm.), released eggs would have to stay mid-water until they reach adequate depths to allow development and hatching. The probability of such an occurrence seems remote after discussing this scenario with various government scientists, but we did not conduct an oceanographic inventory to estimate the likelihood in a more rigorous fashion.

Third, there can be a low fertilization rate (50%) and high mortality rate of eggs in captivity (90-95% by weaning) (Clarke et al, 1999) suggesting that even if eggs were shed, only a small proportion would survive.

Based on the three lines of reasoning above, it seems reasonable to conclude that spawning within the marine cages would be an extremely unlikely route through which genetic material from cultured fish would enter the wild gene pool.

5.3. Effect of introduction of cultured sablefish genes into wild populations

5.3.1. Reduced genetic diversity

Some research in Atlantic salmon farms has shown substantial frequency differences between farm and wild populations in selected genetic markers and a significant reduction in mean heterozygosity over minisatellite loci examined in the farmed fish (Clifford et al, 1998). Such work has raised concerns that hybridization of wild and farmed fish will affect wild fish genetic diversity.

Genetic diversity within a population may be lost via four related processes: founder effects, demographic population bottlenecks, genetic drift or inbreeding[27]. The founder effect refers to changes in allele frequencies in newly arisen populations because of random sampling of the much larger gene pool of a "parental" or original population, usually resulting in decreased variability. Cultured fish, if established on a limited broodstock, may suffer from the founder effect. The significance of this effect on sablefish is unknown because (1) we do not know the overall level of diversity in wild BC sablefish; (2) we do not know if the broodstock used to date reflect a portion or full spectrum of the diversity of the wild stock and (3) we do not know how future broodstock will be managed for diversity. Reports from industry indicate that broodstock has been collected from a variety of locations around Vancouver Island (see section 2). It seems plausible that cultured fish could suffer to some degree from the founder effect. However, hybridization of a small number of less diverse sablefish seems unlikely to result in a marked reduction in diversity of the numerically larger wild population.

A bottleneck occurs when there is a severe reduction in the breeding population, decreasing the variability that could be transferred to offspring. Again, while cultured fish may in theory undergo a bottleneck if breeding was poorly managed, introduction of their variability to wild stock would not result in a bottleneck for the wild stock.

Random sampling of gametes each generation that can produce changes in allele frequencies over time drives genetic drift. It is more pronounced in small populations. Again, introduction of cultured fish should not affect drift in wild stock in a manner that would reduce genetic diversity. If we are to accept that there are not genetically distinct local populations on a scale smaller that the northern and southern groups, then we can conclude that random genetic drift will not be the cause of significant loss in genetic variability, as this typically is the case only for very small populations.

Finally, inbreeding is defined as the breeding with self or close relatives more frequently that would be expected by chance. The likelihood of an escaped farmed sablefish finding a closely related sibling for breeding seems very remote given the size of the wild population, the variety of locations from which broodstock have been selected and the vast range over which sablefish live and move.

When discussing the potential genetic interactions of wild and farmed salmon, Petersen (1999) concluded that the periodic insertion of genetic material from farmed salmon into populations of wild salmon of the same species would, in the long-term, be beneficial to wild stocks as it could increase diversity by providing more “raw material for genetic variation” and therefore for natural selection to work with, allowing the wild fish to be able to adapt to environmental changes. This comment was, however, unsubstantiated by factual observations and is not supported by many others who feel conservation of genetic diversity unaffected by anthropogenic influences is an important goal of conservation biology.

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[27] http://www.cws-scf.ec.gc.ca/birds/gene/diver_e.cfm

The magnitude of effects due to reduced genetic diversity are unknown due to lack of information on the relationship between diversity and fitness outcomes, but it can be anticipated that there may be a relationship between a higher magnitude of effect with a greater reduction of diversity. A large-scale diversity reduction would require significant contribution from cultured fish to the sablefish population breeding population. It can be concluded that the likelihood of cultured fish making a significant contribution to the wild breeding populations is very low at this time due to the anticipated number of escaped fish that will be able to survive to breed. This probability will increase as the number of escapes increase and the number of wild fish decreases. The relatively young age of this industry and lack of selective breeding suggests mechanisms that cause reduced genetic diversity in cultured stocks may not have had enough time to produce marked effects on cultured sablefish genetics. Lack of data on genetic variation of sablefish relegates this last statement as supposition rather than fact.

5.3.2. Introduction of genes that reduce fitness

As there are no data that compares genetic variability of wild and cultured stocks, we cannot determine how genetic differences would relate to fitness differences. Initially, wild and domestic sablefish should be very similar genetically as broodstock are being derived from the wild. If cultured fish are being selected under different conditions than their wild counterpart, one could expect a divergence of inherited characteristics. The greater the difference between wild and farmed sablefish would result in greater effects of interbreeding. The time it takes to reach a significant state of divergence, where significance is measured by the prevalence of alleles that lead to traits that could influence wild fish fitness, is unknown and is at this time only speculated that they will arise. Given that we do not know the degree of difference between wild and farmed sablefish nor the difference between groups of wild sablefish, we cannot anticipate the impacts of wild-farmed interbreeding. One could assume that effects will be greater if culture techniques result in substantially different genetic diversity due to broodstock selection and breeding programs. One can also assume that, regardless of the difference, the more opportunities there are for interbreeding, the greater the likelihood of genetic effects

Given the lack of evidence of small locally adapted sablefish populations, we have assumed that any genes introduced from cultured facilities would have to “compete” with at least the genomes of the entire southern or northern populations. Given evidence that there is exchange of genetic material between these two groups, it could be further argued that any introduced genes would have to compete with the entire genome of sablefish. If it is assumed that the escaped population will be a relatively small size in comparison to the wild population, then in order for an introduced trait to gain prominence in the wild population, offspring inheriting that trait would need to be at some survival advantage, or at least not disadvantaged, so that the trait could be propagated by subsequent successful breeding. The last statement does not assume that the introduction of any unique genetic material from cultured fishes would incur a survival advantage to hybrids of wild and cultured fish that is desirable from the perspective of protecting the genetic heritage of wild sablefish. It is also important to note that the presence of unique genetic material in domestic stock is hypothesized and not proven to exist.

It is reasonable to assume that the cultivation of sablefish could result in a reduction in fitness for any cultured stock that enter the wild if it is true that evidence in salmon can be extrapolated to sablefish. Experience in salmon culture has suggested that salmon in enhancement facilities and those reared for commercial culture are less well-adapted and less likely to reproduce in wild settings than their wild counterparts. For example, McGinnity et al. (1997) reported that survival of the progeny of farmed salmon to the smolt stage was significantly lower than that of wild salmon.

While it is one thing to conclude that domestication may reduce fitness of cultured fish in the wild and that interbreeding between wild and escaped farmed fish is possible, it is another thing to consider that such characteristics will be propagated in the wild population. Sablefish, unlike salmon, are long-lived species capable of multiple reproductions and are not linked to specific natal areas, thus resulting in numerous opportunities for genetic mixing. Moreover, there is a lack of information on the heritability of specific sablefish traits. These factors preclude one from estimating the effects of wild-cultured hybridization at this time.

5.3.3. Reduction of effective population size

If an immigrating or introduced fish mates with the native cohort, but those matings do not result in viable offspring, then the introduced animals have effectively removed the native mates from the breeding population, thus reducing the effective population size. This concern has been raised for salmon where relatively small numbers of native returning salmon may be numerically outweighed by escaped farmed salmon (Gross et al, 1999). This does not seem a likely significant genetic risk for sablefish due to the lack of evidence of discrete locally adapted spawning populations and the anticipated much higher ratio of wild to escaped fish.

5.4. Section Conclusion

The rate of genetic exchange between wild and cultured sablefish has to date been zero as there are no reported escapes or spawning in marine cages. Evidence suggests that spawning while in marine cages is extremely unlikely. If the assumption that escape numbers will be extremely low in comparison to the size of the breeding wild population and that not all escapees live long enough to move offshore where successful reproduction can occur, then it must be concluded that the probability of genetic risks is also extremely low.

As sablefish have genetic mixing throughout their range and there is no evidence yet of locally adapted strains there is less opportunity for introduced genetic material from cultured fish to be maintained and selected for in wild populations. The lack of information on the heritability of specific fitness traits and the genetic differences of wild and cultured fish make it impossible to draw conclusions on the potential magnitude of effects at this time. However, it is reasonable to conclude that such effects would not be detectable in the near future as the founder stocks used for sablefish are still wild stocks that have not undergone generations of selection due to domestication.

6. Disease Risks

The Code states its concerns associated with disease involve the introduction and spread of pathogens and parasites that might accompany aquatic organisms being moved and affecting aquatic animal health. Animal health is not defined in the Code, but we will take it to mean a self-sustaining population that can meet ecological and economic expectations and not merely the absence of specific diseases or disease causing agents. Population size, especially for commercially important fish such as sablefish, is therefore a critical component of population health. There are four basic processes that determine the number of individuals in a population: birth, death, immigration or emigration. While some authors have linked wildlife movement patterns (such as migration routes) to strategies to avoid certain pathogens or parasites, we are unaware of information that demonstrates fish diseases to be causal variables affecting immigration or emigration patterns. Therefore, for this review, we will largely consider the potential for diseases associated with sablefish culture to affect the death and birth rate first of wild sablefish and, to lesser extent, other marine organisms.

6.1. Diseases, infections and infestations of sablefish

Zurbrigg (1993) describes sablefish as "placid and resistant to disease." He goes on to state that they thrive in well-managed impounds. US studies on the survival of sablefish fisheries suggest that sablefish appear to be hardy animals, especially young sablefish captured in shallow water[28]. Mortality reports by Zurbrigg (1993) of sablefish that were wild-caught as juveniles and reared in captivity include deaths associated with high summer temperatures (>10°C), low salinities due to run-off, density stress and infected wounds. He notes that the use of raw fish or offal for feeding can result in the transmission of anasakid parasites and mycobacteria. Such practises are not being used in BC to our knowledge.

A DFO report on rearing wild-caught sablefish in a bag cage system reported most health problems were associated with trauma due to capture and captivity[29]. At harvest, these fish had heavy infestations of anasakid worms and a few unidentified skin ectoparasites.

Karreman (2004) summarized the experience with sablefish health problems at the DFO research facility as follows:

> *Deformities, eye lesions and nutritional problems were common in rearing experiments. Some, such as eye lesions were linked to holding tank design. Infectious diseases were restricted to furunculosis and vibriosis. Furunculosis did occur, typically at higher water temperatures. Vibriosis was deemed "problematic." Other problems, especially sub-clinical problems, are not properly characterized due to the lack of routine disease screening.*

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[28] http://www.psmfc.org/tsc/97_TSC_rpt/Attach-e7.htm

[29] http://www-sci.pac.dfo-mpo.gc.ca/aqua/AQ/aq89.pdf

Table 7 summarizes all infectious and parasitic agents we were able to find after review of reports by Robichaud et al (2004) and Karreman (2004) supplemented with our own literature review and interviews.

Table 7: *Bacterial, viral and parasitic agents reported in sablefish in the published literature and in the DFO fish health database (1971-present), agents associated with disease in sablefish and the type of stock (wild or cultured) where agent was found.*

Agent	Number cases in BC sablefish reported in DFO database (1971-present)	Number of sablefish cases from DFO database thought to be associated with disease	Published reports of agent in sablefish	Type of stock with agent (C=cultured, W= wild)
BACTERIA				
Aeromonas salmonicida	13	11	Evelyn, 1971	C, W
Aeromonas spp.	1	1	None	C
"Chlamydia-like agent"	None	None	Kent et al, 1998	W
Myxobacteria	3	3	None	C
Pseudomonas sp.	1	1	None	C
Renibacterium salmoninarum	2 (1 unconfirmed)	1	Bell et al, 1990 (experimental infection)	C (experimental)
Sporocytophagosis	2	1	None	C
Vibrio spp.	6	4	Gores and Prentice, 1984	C
Photobacterium spp	None	None	None	C Kreiberg, pers. comm..
VIRUS				
Viral Hemorrhagic Septicemia virus	1 (positive by RT PCR but not by culture)	none	No clinical disease or agent recovered in challenge studies (Traxler et al., 1998)	W
Papillomatosis (retrovirus)	None	None	Brocklebank, 1996	C
PARASITES				
Anisakis sp.	22	1	Kabata and Whittaker, 1984	C, W
Brachyphallus crenatus	None	None	Kabata and Whittaker, 1984	W
Capillaria sp.	None	None	Kabata and Whittaker, 1984	W
Ceratomyxa anoplopoma	None	None	Moser, 1976	W
Copepods	3	None	Kabata and Whittaker, 1984	C, W
Corynosoma sp.	None	None	Kabata and Whittaker, 1984	W
Davisea anoplopoma	None	None	Moser and Noble, 1975	W

Agent	Number cases in BC sablefish reported in DFO database (1971-present)	Number of sablefish cases from DFO database thought to be associated with disease	Published reports of agent in sablefish	Type of stock with agent (C=cultured, W= wild)
Derogenes varicus	None	None	Kabata and Whittaker, 1984	W
Didymozoidae gen. sp	None	None	McDonald and Margolis 1995	unstated
Digenea gen. sp	None	None	McDonald and Margolis 1995	unstated
Fellodistomum breve	None	None	Kabata and Whittaker, 1984	W
Genolinea laticauda	None	None	Kabata and Whittaker, 1984	W
Gonocerca japonica	None	None	Whitaker and McFarlane, 1993	W
Grillotia heptanchi	None	None	Kabata and Whittaker, 1984	W
Hysterothylacium aduncum	None	None	Kabata and Whittaker, 1984	W
Lecithaster gibbosus	None	None	Kabata and Whittaker, 1984	W
Lecithochirium exodicum	None	None	Kabata and Whittaker, 1984	W
Lepeophtheirus sp.	None	None	Poynton, 1993	unstated
Leptotheca informis	None	None	Moser and Noble, 1976	W
Leech	1	None		C
Loma salmonae	1 (microsporidia, species not confirmed)	None	Kent, 1998	W, C (not confirmed as Loma)
Naobranchia sp	None	None	Poynton, 1993	W
Naobranchia occidentalis	None	None	McDonald and Margolis, 1995	unstated
Opecoelina sp.	None	None	Kabata and Whittaker, 1984	W
Parahemiurus merus	None	None	Kabata and Whittaker, 1984	W
Phocanema decipiens	None	None	Kabata and Whittaker, 1984	W
Podocotyle atomon	None	None	Kabata and Whittaker, 1984	W
Pseudopecoelus vulgaris	None	None	Kabata and Whittaker, 1984	W
Pseudoterranova decipiens larva	None	None	McDonald and Margolis 1995	unstated
Scolex pleuronectis	None	None	Kabata and Whittaker, 1984	W
Stephanostomum californicum	None	None	Kabata and Whittaker, 1984	W
Trichodina	2	1	none	C, W

It must be noted that the DFO database considered wild sablefish to be sablefish captured from the wild and used in captive breeding whereas cultured fish were those that had spent their entire life in captivity or had been wild caught but in captivity for more than 6 months.

The only diseases listed in the DFO database as being the primary reason for fish losses were furunculosis, motile Aeromonad septicemia, Pseudomonas infection, Sporocytophagosis and Vibriosis. Viral Hemorrhagic Septicemia was originally categorized as a primary cause but subsequent findings suggested this to be an incorrect classification (see below). These reports of agents being the primary cause of losses accounted for only 18 of the 141 reports (13%) on sablefish diagnoses (Karreman, 2004) suggesting most of the DFO data involved cases in which the isolated agents were not associated with fish losses or were considered incidental findings or secondary contributors to disease. The same can be said for the single isolation of Photobacterium spp that was found in conjunction with a case of atypical furunculosis (H. Kreiberg, pers. comm.). Some species of Photobacterium are known fish pathogens whereas others are normal commensal organisms. The 141 reports were from 73 cases of which 59 were from experimental work being done on sablefish culture at the Pacific Biological Station. The DFO database, therefore, has a bias towards cultured fish, predominantly reflecting the situation at one non-commercial culture facility. It, therefore, cannot be taken to be an accurate representation of the patterns of disease or infection seen at other culture operations or in the wild.

Furunculosis was the most frequent diagnosis in the DFO database. The only disease listed in Noga's (1996) index for sablefish is furunculosis. Anecdotal reports have indicted that furunculosis has been a problem for sablefish culture because infected fish suffer high mortality rates. Robichaud et al (2004) support these reports by citing two publications stating that furunculosis has been associated with mortalities in cultured sablefish. Kreiberg et al (2001) reported atypical furunculosis in wild caught sablefish held in captivity. Captivity is not a requirement for diagnosis of furunculosis as Evelyn (1971) identified a case of spontaneous furunculosis in a wild caught sablefish shortly before it died.

Vibriosis was the next most common diagnosis in the DFO database. Karreman (2004) reported that the Provincial Animal Health Centre has diagnosed this disease in farmed sablefish as well, usually in association with poor water quality events. Vibrios are common marine organisms that can be found on healthy fish as well as associated with disease.

Neither we nor Karreman (2004) found reports of nodaviruses in sablefish. This virus has been associated with disease in other marine finfish. Though Karreman (2004) states that this is a disease listed by the World Animal Health Organization (OIE), we did not find it listed in Chapter 1.1.3 of the Aquatic Animal Health Code (Diseases Listed by the OIE).

Disease diagnostic data produced by the Provincial Animal Health Centre specific to a producer is considered confidential by the government and therefore could not be provided to us for the review. Aggregated data from the provincial marine finfish disease surveillance program did not include any reports of sablefish disease or mortality rates. It should be noted that current sablefish sea pen producers were not yet in the provincial system and would, therefore, not have been included in the summary data.

One sablefish hatchery provided us with results of disease screening tests conducted on their fish by the Provincial Animal Health Centre in 2004 (table 8)

Table 8: Results of disease screening for a BC sablefish hatchery.

Tests	Numbers examined	Results
Bacteriology	57 fish sampled from 5 tanks; samples were pooled by tank	Bacterial growth was observed in 4 out of 5 tanks. Two *Vibrio* bacteria were identified: one *Vibrio alginolyticus* (generally considered to be an opportunistic pathogen) and one unspecified (but serologically negative for *Listonella anguillarum* type 1 and 2 and *Vibrio ordalii*).
Virology	57 fish sampled from 5 tanks and pooled into groups of 5	Culture (CHSE, EPC, SSN1 cell lines) and PCR (Nodavirus, IPN, ISA, Piscirickettsia, IHN and VHS) tests were run. All samples were negative.
Histology	56 fish sampled from 5 tanks and grouped by tank number	The only clinically significant finding was skeletal muscle degeneration in one fish possibly suggestive of a nutritional myopathy

6.2. Requirements for diseases of sablefish culture to affect wild fishes

For a pathogen or parasite of cultured sablefish origin to have an effect on wild fishes, the wild fish must be susceptible to the disease agents, there must be opportunities for the agents to be transmitted from the cultured to wild fish and upon infection the disease agent must exert an effect on the wild fish in a manner that puts the population at risk of increased death or decreased reproductive rates.

6.2.1. Shared susceptibility

Table 7 suggests that most of the agents associated with BC sablefish to date have (i) not been associated with diseases (ii) were found largely in wild fish and (iii) were parasitic in nature. However, these features of table 7 should not be taken to reflect the true nature or rates of disease or infection in sablefish, either cultured or wild, as the contents of the table have not been generated through systematic study of diseases in sablefish and have not been able to account for sub-clinical effects that could limit productivity. While it would be irresponsible to speculate as to which specific agents may be found in sablefish in the future, it would also be naïve to think we have a complete list of all known infectious and parasitic agents to which sablefish are susceptible. It is essential to interpret table 7 only as a list of agents that have been found on sablefish and not as an indicator of the effect of those pathogens as the reports were generally intended to seek the infectious or parasitic agent and not to correlate those findings with individual or population disease outcomes.

The inclusion of viral hemorrhagic septicemia virus (VHSV) in table 7 is controversial. The positive finding was generated from a fish during a sardine die-off from the virus, resulting in opportunities for sample cross-contamination (Traxler, 2004). Furthermore, the test used to find the positive result (a PCR test) is incapable of determining if the recovered viral particles came from a viable virus or not. Traxler et al (2004), attempted to experimentally produce infection and clinical diseases with infectious VHSV in sablefish but without success. Traxler (2004) also reported that a survey of 363 wild caught sablefish failed to reveal evidence of either of these viruses, though the method for screening was not described in the report. In related studies Traxler (2004) was unable to induce infection or disease with Infectious Hematopoietic Necrosis Virus under experimental conditions after injection into sablefish.

Some of the reports supplying table 7 provide insufficient detail too allow for speculation on cross-species susceptibility. For example, the Genera of sea lice reportedly found on a sablefish (Lepeophtheirus) has at least eight known species, each with different hosts reported (McDonald and Margolis, 1995). Although Poyton's report (1993) does not state the species of *Lepeophtheirus* found on sablefish, Karreman (2004) indicated that *L. parviventris* has been found. McDonald and Margolis (1995) restricted the host range of *L. parviventris* to rock sole and walleye Pollock. McDonald and Margolis (1995) do not list any *Caligus* or *Lepeophtheirus* species as parasites of sablefish. This conflicts with observations at the Pacific Biological Station of some sea lice on sablefish held in a bag cage trial (H. Kreiberg, pers. comm). Unfortunately, insufficient information is available to draw final conclusions on the host specificity of different sea lice species under different environmental and aquaculture conditions. Such information would be relevant to assessing the likelihood that sablefish held in sea cages on the same farm as salmon could contribute susceptible hosts to a population involved in endemic or epidemic levels of sea lice infestations at marine finfish farms.

A review of the available fish health literature will quickly reveal that other agents in table 7, including *Aeromonas* spp, *Renibacterium, Vibrio, Trichodina, Loma, Myxobacteria* and *Anasakis* are found in a wide range of fish hosts. It can, therefore, be concluded that sablefish share some susceptibilities to disease agents with other marine fishes, including wild, enhanced or cultured salmon, but that we cannot assume that all disease-causing agents or parasites infecting sablefish will affect other fish species equally.

Tables 7 and 8 can also be used to reach the conclusion that the disease agents recovered in sablefish to date have previously been either exclusively found in wild sablefish or, when found in cultured sablefish, involve organisms known to exist in wild fish before the start of salmon or sablefish culture. Stephen and Iwama (1997) provide more details on the history of pathogen findings in BC finfish aquaculture.

6.2.2. Opportunities for transmission

The probability of a pathogen or parasite being transmitted is critically dependent on the number of infectious individuals in the population. For example, work on sea lice in Norway demonstrated that the infection pressures from sea lice are the product of the number of fish in the system, and the number of lice per fish (Heuch and Mo, 2001). Estimates of transmission probabilities are, therefore, dependent on estimates of prevalence of infectious individuals in the population. Unfortunately, there are no estimates of prevalence of sablefish pathogens and parasites. Kabata and Whittaker (1984) did note that parasites were relatively rare in wild sablefish, likely due to the fact that they live in deep waters, feed relatively sparsely and therefore have fewer opportunities for acquiring parasites through ingestion of their intermediate hosts. They go on to conclude that, except for the non-specific ubiquitous nematode *Anasakis*, few parasites could be considered abundant in sablefish. Whitaker and McFarlane (1993) calculated proportions of wild sablefish sampled for 10 different parasites from a high of 28.6% to a low of 0%. These proportions varied with parasite as well as sample location. The authors concluded that the rates seen were low and these parasites could not be regarded as being frequent in sablefish. However, such qualitative statements are insufficient to estimate sablefish parasite prevalence and thus to begin to calculate transmission probabilities.

For a pathogen or parasite to cause an effect on a population, it must be transmitted from an infected individual and then persist to be transmitted to a sufficient number of susceptible individuals to realize an impact on population birth and death rates. Epidemic theory tells us that five variables determine whether or not an infectious or parasitic agent will persist in a population (Anderson, 1991):

- density of the hosts
- probability of transmission per contact between susceptible and infectious hosts,
- disease-induced mortality rate
- per capita death rate of uninfected hosts
- rate of recovery from infections

There are no data on the values of these variables for wild or captive sablefish or on the thresholds required to maintain a pathogen or parasite in any fish populations. We cannot, therefore, model the probabilities of pathogen entry or persistence or the likelihood that a disease agent originating from a sablefish farm could enter and be transmitted within a group of wild fish or vice versa without relying on extrapolations from other species or general assumptions.

Predictions of the risk of transmission of disease are pathogen, population and environment specific. For example, Paisley et al (1999) conducted a quantitative risk assessment that showed that the probability of introduction of the parasite *Gyrodactylus salaris* to a Norweigian river via transfer of salmon smolts to an existing salmon farm was extremely low primarily due to the low probability that the transferred smolt become infested. The total risk was very sensitive to changes in the salinity of the water at the sea site. Changing the pathogen of concern, the smolt infestation rates, water salinity, smolt transfer rates and other variables would undoubtedly affect the final numerical value attributed to the risk. The value of Paisley's report is not the specific risk assessment, but the illustration that only broad determinants of risk can be evaluated to estimate general patterns of risk unless one conducts site-specific and pathogen- specific risk assessments.

Pathogens and parasites can be transmitted from one fish to another in a number of ways, the specific route varying with the disease agent.

Direct Transmission

Occurs when there is immediate transfer of an infectious agent to a susceptible fish in a manner that allows infection. This can include direct contact with an infected fish, egg-associated transfer or contact with the agent that was shed into the immediate environment from an infected fish.

Indirect Transmission

Occurs when there is an intervening factor (living or non living) that moves the agent from the infected to the susceptible fish. This can include contact with contaminated material in the environment, secondary hosts, vectors or waterborne routes. Indirectly transmitted agents usually require a suitable environment to allow survival between host infections.

For direct transmission to occur, either wild fish would have to enter the holding tank/pens containing cultured sablefish, the cultured fish would have to escape containment or wild fish would have to be directly exposed to pathogens shed into the immediate environment of cultured sablefish. At the one hatchery we visited, it would not be possible for wild fish to contact fish in the hatchery. Under bag culture conditions as described by a DFO trial using floating bag technology, direct contact by fish entering the pens is also unlikely. Our own personal observations of salmon sea cages confirm that a variety of non-cultured fishes can be found around and in aquaculture pens. However, our observations do not include how these wild fish, (including perch, herring, juvenile pollock, tubesnouts and others) interface with sablefish in a cage and therefore, we cannot comment on the frequency or likelihood of interactions that would result in direct transmission of infectious agents. Work conducted by Kent et al (1998) demonstrated that non-salmonids captured in or near sea pens did share some of the same pathogens as caged salmon, suggesting the possibility of transmission, but that paper could not establish the direction or frequency (if any) of movement of pathogens between the wild and cultured fish.

Direct transmission by escaped sablefish contacting and interacting with wild fish outside of a pen would be dependent on escape and escapee survival rate. Given that sablefish begin to form close aggregations or schools throughout their pelagic juvenile phase (Sogard and Olla, 2000), it is plausible that surviving escaped sablefish would aggregate and possible that the school of escapees could join into a school of wild sablefish juveniles. Schooling behaviour results in close contact and, thus, increases the probability of situations that would allow direct transmission of disease-causing agents. What is unknown is the frequency with which schooling sablefish interact in a manner that would result in transmission of an infective dose from an escapee to a wild sablefish. This would be, in part, dependent on the ratio of escapees to wild fish in the group, the prevalence of infectious individuals among the escapees, the duration of infectiousness after escape, and the nature of the organism and its specific infectious dose and transmission needs. Evidence suggests that sick fish tend not to be part of the main school (Stephen and Ribble, 1994; Stephen And Iwama, 1997). The risk of transmission from clinically ill sablefish to others in the school would be reduced if sablefish demonstrate this same behaviour.

Tagging data suggests that juvenile sablefish tagged in inlets can disperse widely, raising the concern that an infected fish would be able to disseminate pathogens or parasites widely (R. Kronlund, pers. comm.) However, these tagging studies do not take into consideration the effects of infection or infestation on dispersal patterns. The effects on infection with different agents on sablefish energetics and movements are unknown. If a fish was infected with an agent that would cause clinical disease, it is likely that the probability of survival would be low for that fish due to predation and reduced capacity to compete for resources. Alternatively, if the sablefish were infected with an agent that did not affect its capacity to survive and disperse, the implications of transmission of such an agent to other sablefish would be reduced due to the inability of the agent to affect survival and movement. The latter statement does not take into account the possibility that an infectious or parasitic agent that doesn't affect survival in the short term might lead to more chronic effects that influence long-term survival and/or fecundity. It also does not take into account the potential for asymptomatic carriage. For example, a single sablefish was found to remain infected with *Renibacterium salmoninarum* 165 days after experimental intraperitoneal injection of the organism (Bell et al, 1990) (the significance of this observation for natural transmission is unknown). There are no data on the sub-clinical carriage rates in sablefish or duration of infectiousness for the pathogens listed in table 7 leaving us unable to quantify probabilities of transmission.

A number of the parasites listed in table 7 require secondary or intermediate hosts, many of which need to be ingested by the sablefish to result in infestation. Feeding commercially prepared processed feeds will greatly reduce the possibility of sablefish being exposed to these intermediate hosts. Evidence from salmon farming support this conclusion as surveys for Anasakid parasites in farmed salmon have failed to find this parasite which is commonly found in wild salmon (Deardorff and Kent, 1989).

If an endemic disease outbreak was to occur within a marine cage or a hatchery, it is plausible that the concentration of some pathogens or parasites in the waste stream and surrounding waters might increase, thus increasing the probability that wild fish may encounter a disease-causing agent. For this encounter to result in infection, the disease agent would have to remain viable in the environment. Environmental tolerance varies with pathogen and parasite. Given that the agents anticipated for sablefish will be similar to those for salmon, we refer the reader to a more detailed discussion of this issue in the BC Salmon Aquaculture Review (Stephen and Iwama, 1987). The likelihood, therefore, of a wild fish becoming infected by a pathogen shed into the waters around a marine cage would be affected by the environmental tolerance of the agent, the route of transmission, the required infectious dose compared to the dilution of pathogen in the water and the susceptibility of wild biota. None of these data are available for sablefish and little for salmonids in marine settings. Information from other farmed fishes to date would suggest that transmission of infectious agents between wild and farmed fish is possible, with most evidence revealing infection of farmed animals from the wild (Stephen and Iwama, 1987).

Difficulties in tracking transmissions in natural conditions can be expected to make it harder to demonstrate transmission from farmed to wild fish than vice versa.

Significant debate has evolved internationally about the contribution of fish farms to the total sea lice infestation burden of wild salmon. The concern that sablefish farms will contribute to wild salmon louse burden has also been raised in BC. Anecdotal reports provided to us suggest that sea lice are found on wild caught sablefish as well as on sablefish held in captivity (H. Kreiberg, pers. comm.). In the European setting where farmed salmon outnumber wild salmon in many locations, it has been concluded that farm salmon are more likely to infect wild and farm smolts, and also other farm salmon (Butler, 2002). Extrapolation of these and similar results must be done with caution for sablefish because we have (1) no data on the prevalence of lice on sablefish in captivity, (2) no data on the suitability of sablefish as a host for lice that are important to salmon and (3) limited information on the proportional contribution of sea lice from finfish farms in BC to wild populations. In addition, unlike the European setting, for BC sablefish, wild fish will outnumber farmed fish under current production predictions.

The likelihood that a wild marine animal will be exposed to a pathogen from the hatchery or marine cage is reduced if:

- the pathogen load at the culture site is kept low by water management, proper bio-security including appropriate use of disinfectants and antibiotics, and proper fish health management;
- fecal wastes are minimized in the effluent by increased feed conversion rates and waste management practices and,
- the effluent is diluted such that the concentration of discharged pathogens is below the average concentration required to induce an infection.

Data provided by one hatchery indicated that filtration and settling of wastes is being conducted at some facilities. Such systems are a reasonable way to reduce pathogen load but cannot be expected to eliminate all pathogens. Even a 0.37-micron filter as used by some facilities, while able to remove many parasites from effluent, would not screen out most bacterial or viral pathogens as demonstrated in table 9. However, the use of multiple filtrations, removal of solid wastes and sand filtration would be expected to significantly reduce pathogen or parasite load in wastewater. Data from human watershed management would support the contention that passage of pathogens through the ground reduces the concentration and viability of many environmental pathogens, suggesting similar practices would have similar benefits for hatcheries. The addition of ozonation, ultraviolet treatment or other forms of disinfection would further reduce the likelihood of escape of any endemic pathogens back into receiving waters. We are unaware of reliable peer-reviewed data from which to speculate on how well hatchery waste management practices or simple dilution at marine cage sites are able to reduce pathogen concentrations to levels before the infectious dose needed for the typical wild fish.

Table 9: Size of potential bacterial and viral fish pathogens

Agent	Type	Size
BACTERIA		
Most bacteria are between 1-2 μm (J. Prescott pers. Comm.,)		
VIRUSES		
Herpesvirus	Herpesvirus	110-200 nm
IHN	Rhabdovirus	22 x 60 nm
IPN	Birnavirus	60-75 nm
nodavirus	Nodavirus	30 nm
papillomatosis	Retrovirus	100 nm
VHS	Rhabdovirus	22 x 60 nm

There are data available that demonstrate that different pathogens have different environmental tolerances. This report did not provide enough time to generate a table that summarizes the different ways environmental factors limit the transmissibility of marine agents. These characteristics affect the ability of a shed agent to survive in the environment long enough to meet another susceptible fish to be transmitted. For example, it can be expected that the intermediate stages of sea lice can survive in the marine environment off a host for a significantly longer period than many fish viruses (See Stephen and Iwama, 1997 for more discussion on this issue). It is unreasonable to consider all pathogens or parasites the same with respect to their environmental survival and ability to be transmitted from cultured to wild fish or vice versa. We can assume that some pathogens will move between wild fish and cultured sablefish, but cannot make conclusions on the frequency and majority of direction of such exchanges or make pathogen specific statements on transmission dynamics.

6.2.3. Effect on population

Some of the information and opinion we found indicated that some infectious diseases, such as furunculosis, and some environmental diseases, such as the effects of holding, or inadequate environmental conditions, could result in mortality in cultured sablefish. No data was found that showed a role for disease or parasitism in wild sablefish population regulation. This is likely a reflection of a lack of research rather than the lack of a role.

It is possible that a wild fish or invertebrate will be exposed to a potential pathogen of aquaculture waste origin. However, predicting the outcome of that exposure is more difficult. If the wild animal is healthy and has an intact immune system and if it has had some previous exposure to an indigenous parasite, it is more likely than not that the animal will be able to cope with the exposure and limit it to either mild infection or self-limiting disease. If disease was to develop and its effects to multiply, the exposed animal would then have to adequately contact similarly susceptible animals to propagate the infection.

Most of what is known about the effects of pathogens and parasites on fish is based on lethal or severe disease effects on cultured or enhanced salmonids. Some data are emerging to demonstrate sub-clinical production limiting effects of diseases on wild fishes, but none were found for sablefish. Therefore, we are left to speculate the effects of infection or infestation by any of the agents listed in table 7 on individual sablefish, sablefish populations or other wild fish populations.

It is well established that pathogens and parasites can increase the death rate of their hosts and decrease their fecundity (McCallum and Scott, 1994). A variety of studies have revealed the importance of disease as a mortality factor in wild mammals, birds, insects, and, to a lesser degree, fish. The ability of a bacteria or virus to regulate a host population is dependent on its pathogenicity exceeding the host population growth rate (Anderson and May, 1979b). As sablefish are highly fecund species whose population numbers are linked to environmental conditions affecting larval survival, the race between the effects of a disease and population growth rates would vary with year and varying environmental conditions. For diseases to be additive to regular environmental limits, the disease would either have to persist from the time of origin until times of harsh environmental conditions or would have to be introduced at the times when decadal environmental effects are realized.

It has been argued that the effects of disease are compensatory, killing hosts that would have died anyway. Some authors have suggested that epidemics of disease tend not to play an important ecological role in wild fish populations below a certain optimum density, but may limit excessive population growth by acting as a density dependent factor regulating the number and type of organisms that can thrive in a given environment (Croze, 1981; Moller and Anders, 1986; Smith and Scott, 1994). Others have provided evidence that pathogens and parasites affect basic ecological parameters such as immune function, genetic diversity, behaviour, predation, mate selection, reproductive success, community structure, species diversity and demography (Spalding and Forrester 1993; Dobson and Hudson, 1986; Thrusfield, 1986). For example, parasitism was judged to be one of the main causes of death in fish in a Manitoba lake but the effects were not through direct mortality (Szalai and Dick, 1991). In this case, fish that were infected with the parasites were smaller than non-infected fish; smaller fish in this system were more susceptible to predation. A similar relationship was noted in the Netherlands where cormorants caught a disproportionately higher number of fish infected with a tapeworm (*Lingula intestinalis*) than non-infected fish (van Dobben, 1952). Mesa et al (1998) demonstrated that Chinook salmon challenged with *Renibacterium salmoninarum* (the etiologic agent of bacterial kidney disease) were more susceptible to predation by northern squawfish and smallmouth bass under experimental conditions.

Pathogens and parasites can amplify the effects of other regulating factors. For example, they can intensify the effects of low levels of nutrition, thus making an important contribution to density-dependent population regulating effects (Anderson and May, 1979a). Although some authors have concluded that disease is a significant force structuring fish communities (Li et al, 1987 in Mesa et al, 1998), the lack of ecological and epidemiological data has limited our understanding of the mechanisms and magnitude of disease effects. Despite a strong theoretical underpinning, there are very few field-based studies that conclusively evaluate the role of disease in fish populations. Difficulties in collecting many of the key variables needed to understand disease-induced population regulation in wild populations makes conclusions regarding the role of disease hypothetical rather than a measured parameter. Therefore, we are resigned to making a reasoned argument rather than presenting a measured outcome to answer the question of whether or not disease has sufficient impact to make it a fisheries management priority.

Literature on the population effects of disease in fish is sparse. Two types of impacts due to diseases predominate the literature; mortality and loss of markets; the latter arising from mortality or trade restrictions being imposed because of disease (Rohovec et al, 1986). These impacts have been reported in hatchery or farmed fish in most cases. However, there are some reports of impacts in wild stocks. Whirling disease, for example, is thought to be the primary cause of dramatic decreases in the size of wild trout populations in some American states (Walker and Foster, 1998). The cost of whirling disease in California and Michigan due to direct control efforts and impacts on fisheries has been estimated at several million dollars per state (Hedrick, 1996). To rid their rivers of an apparently introduced parasite (*Gyrodactylus* sp.), the Norwegian government poisoned all fish in many rivers in an attempt to eliminate suitable parasite hosts (Johnsen and Jensen, 1991). This dramatic action has resulted in both drastic economic and ecological costs. A few other studies have associated parasites with effects on reproduction. Infections with *Kudoa paniformis* in Pacific hake have been associated with dose-related depressions in female fecundity (Alderstein and Dorn, 1998). Outbreaks of *Ichthyophonus hoferi* in North Sea herring were estimated to have significant effects on stock size (Patterson, 1996). While significant initial proportional mortality rates due to novel infectious diseases in local populations have been described, no examples were found in the literature that followed a wild fish population after the occurrence of a new disease to assess medium to long-term impacts. There were also no reports found that evaluated impacts of fish pathogens or parasites from an ecological integrity viewpoint.

Historically, only a small number of diseases, such as furunculosis, Gyrodactylosis, ulcerative dermal necrosis, Ichthyophonus infections and a few other bacterial pathogens, have been associated with widespread, conspicuous epidemics in wild fish (Patterson, 1996; Bakke and Harris, 1998). This most likely reflects the fact that significant disease problems in wild stocks go unnoticed or unrecorded (Traxler, 1986; Moller and Anders, 1986) rather than reflecting an absence of disease in wild settings. This is particularly true for chronic parasitic infections that do not result in mass mortalities (Kent and Fournie, 1993).

One can challenge the proposition that the presence of pathogens or disease invariably results in undesired population effects. Yasutake et al (1986) detected six different parasite species in Columbia River coho, but did not find any relationship between parasite burden and survival. A wide number of parasites, bacteria and some viruses were detected in wild fish in northern BC, but only *Ceratomyxa shasta* was associated with disease (Anon., 1984). Similarly, there are jurisdictions that have *Myxobolus cerebralis* present without apparent effects on wild stocks (Modin, 1998). The results of a project that tried to plant infectious pancreatic necrosis virus (IPNV) infected fish into Rocky Mountain lakes showed how difficult it is to transfer the infection to resident fish, let alone to maintain the virus without ongoing introductions of new infected fish (Yamamoto and Kilistoff, 1979). This reflects the experience in European lake net pen culture of trout where investigators could find no evidence of transfer of IPNV from escaped, presumably infected trout to wild stocks (Stephen and Iwama, 1997). These experiences are similar to when trout with bacterial kidney disease and furunculosis were purposely introduced into wild conditions with minimal transfer of disease to wild trout (Krueger and May, 1991). In a review of diagnostic results and surveys of wild fish in Great Britain, Bucke (1993) found only three events since the turn of the century where diseases possibly impacted wild fish, despite a long history of opportunities for disease interactions between wild and cultured stocks. All of these cases must be interpreted cautiously as the level of population surveillance was unspecified in these reports.

While there are some authors and opinions that have linked impacts on wild fish populations with diseases associated with fish culture, it is our view that these are associations[30] and not established cause-effect relationships. This statement does not imply that diseases of aquaculture origin do or do not exert an influence on wild fish populations. Rather, it reflects the fact that studies to date have failed to consider the complexity of factors interacting to regulate populations and have failed to apply comprehensive epidemiological methods capable of attributing population risk in the face of a suite of confounding variables. Given that the associations have been made inductively by accumulation of reports, rather than analytically by statistical methods and quantification of the magnitude of association, one must conclude there is insufficient information to make causal conclusions. One can however support contentions that existing associations can be the basis for valid hypothesis. However, at this time, we are left to postulate possible effects rather than enumerate measured impacts.

The Salmon Aquaculture Review was unable to find conclusive evidence that indigenous disease agents were transferred from sea pen cultured to wild salmon in a manner that resulted in ecological effects (Stephen and Iwama, 1997). A similar conclusion could be reached for sablefish. These conclusions do not imply that no effect is present, but that there are not the data to fulfill accepted criteria for epidemiological causation.

6.3. Exotic agents

An exotic disease is typically defined as a disease that is characteristic of another region or area and not of the population or region of concern. As sablefish travel over much of the northern Pacific Ocean, one could argue that that all diseases of that region to which sablefish are susceptible are endemic to the general sablefish population. However, as there is evidence that most individuals do not move throughout their entire range after the age of maturity (<200 km) and that there are differences in

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[30] Last (1983) states that events are said to be associated if they occur together more frequently than one would expect by chance. When strictly used in an epidemiological sense, an association requires statistical dependence between two events. However, the term association is more frequently used in accordance with the dictionary definition "to bring together or into relationship in any of various intangible ways." Most associations of aquaculture and wild fish disease rely on the common rather than statistical use of the word. In either case, an association is only one of several criteria required to prove cause-effect relationships.

parasite fauna on different seamount sablefish populations, it could also be argued that there are differences in what might be considered an endemic or exotic diseases through the life experience of different groups of sablefish throughout the population's entire range. The regulatory view of exotic diseases refers to political rather than ecological boundaries.

Exotic pathogens are typically introduced to a region either by the movement of animals, animal products or environmental media (water, mud) that can sustain the microorganism during transfer. An exotic pathogen could be moved into BC by sablefish culture if:

- Sablefish were imported from a location in the northern Pacific that had a unique pathogens or parasites than sablefish in the receiving waters
- Sablefish were exposed to exotic pathogens during cultivation and then moved to other locations

As there are no data on regional variations on the presence of parasites or pathogens throughout the entire sablefish range (apart from a study at seamounts on parasite fauna) or on how much exchange there is of disease-causing agents as sablefish move, we cannot draw conclusions on the probability of the first circumstance. However, the frequent intermixing of fish throughout large areas of sablefish range suggests the potential for pathogen and parasite sharing through the range, decreasing the likelihood that unique pockets of non-parasitic infection exist.

In terms of the second circumstance, the primary source of an exotic agent would be cohabitation of sablefish with farmed salmon and exchange of disease agents between these two groups. The lack of evidence of an introduction of an exotic disease agent in salmon in BC to date suggests this to be a low probability event (Stephen and Iwama, 1997). Marine cages are currently terminal destinations for sablefish. At the hatchery we visited, there were no plans to bring fish back to the hatchery for broodstock. There would, therefore, be little or no opportunity for fish exposed to exotic pathogens either from farmed salmon or some other means to move an acquired agent beyond the site of exposure apart from escape. It is plausible that a disease agent could enter a hatchery with its intake water. The disease screening data provided to us (table 8) did show that some opportunistic pathogens are present in hatchery water, but these would be endemic and not exotic pathogens. All of the viruses and bacteria associated with sablefish to date have been recognized in other marine species in BC prior to the start of aquaculture (Stephen and Iwama, 1987). All parasites reported in sablefish have been found in wild sablefish. Finally, given that broodstock are taken from the natural range of sablefish, it is not possible for broodstock to introduce exotic agents into aquaculture settings using the term exotic agent in a regulatory sense. There seems, therefore, to be little opportunity for sablefish farms to be exposed to or disseminate disease agents exotic to British Columbia waters.

The introduction of an exotic agent has the potential to result in large magnitude outcomes in terms of restriction in trade of aquaculture products and in terms of the effects of exposure of naïve populations to a new agent. It is important to note that there is, to our knowledge, no circumstance where an introduced disease has caused the extinction of an otherwise healthy wild population. However, there are many instances where introduced diseases have resulted in severe restrictions in the range of wild animals or have caused dramatic reductions in host numbers. Because of these possibilities, the introduction of an exotic disease is always a high priority for risk management of any agricultural species regardless of how low the probability might be.

6.4. Disease Prevention and Control

The importance of good hygiene and farm management cannot be underestimated as a significant way to prevent or reduce the transmission of pathogens and parasites from farms to wild fishes. For example, Valtonen and Koskivaara (1994) concluded that parasites found on farmed salmonids were unlikely to effect the fish parasite fauna of wild fish in a lake-receiving farm effluent because of high standards of maintenance and hygiene on the study farm that kept problems caused by parasites under control. The authors did see the potential for the farm to contribute to wild fish parasite fauna, but recognized the role of health management in reducing that risk.

As a condition of provincial licensing, all marine salmon farms require fish health management plans. These plans result in requirements for disease prevention, biosecurity and disease management intended to limit the frequency, prevalence, dissemination and effects of diseases on fish farms. As sablefish are being reared at sites with salmon largely, most producers rearing sablefish will have salmonid fish health management plans in place. As these management plans are based to a large degree on common principles of disease prevention and control, most of the plans should be applicable to sablefish. There are currently efforts to review the plans to modify specific details for variables unique to sablefish.

Fish movement regulations in BC prevent the movement of sick fish. The BC ITC is developing disease screening requirements specific to sablefish, though the lack of diagnostic tests specific to sablefish and the lack of inventory on all sablefish pathogens suggest this approach may be imperfect. Both of these steps reduce the likelihood of the movement of cultured sablefish moving pathogens or parasites.

We found no published information available on the clinical management of sablefish disease, therefore, we cannot conclude if available drugs will be more, less or equally effective in sablefish as for salmon. As there are no drugs licensed specifically for sablefish, all drugs used will have to be under veterinary prescription. In addition, there are no licensed vaccines available to prevent sablefish diseases. This increases the reliance on the industry for biosecurity and husbandry for disease prevention and management.

Drugs and vaccines have and can be legally used for sablefish under appropriate veterinary supervision. Although there have been no controlled trials to date, experience with the use of furunculosis and vibriosis vaccines in captive sablefish suggest these products can offer some degree of protection (C. Clarke, pers. comm.). All medicated feed used in fish must be used under veterinary prescription. There is a provincial program requiring feed mills to report medicated feed uses. Information from the provincial government indicates that there are no reports of antibiotic being added to sablefish feed. The reliability of these reports was partially confirmed by direct questioning of one feed mill (H. Hannah, pers. comm.). This lack of data does not preclude the possibility of antibiotic use in sablefish because (1) we were unable to request veterinarians provide us with their prescriptions; (ii) antibiotics can be added to feed directly on farms and thus would not be part of the provincial database and (iii) personnel were unavailable for interview at the other feed mill making medicated fish feeds.

6.5. Section conclusion

We do not know the full suite of diseases to which sablefish will be susceptible. We know that they are susceptible to some of the same diseases as pen reared salmon, wild salmon and other wild fishes. Given experience in other aquaculture settings, it is likely that there will be an exchange of disease-causing agents between sablefish and salmon reared in captivity at the same site and plausible that there will an exchange of disease-causing agents between cultured sablefish and wild marine fishes. The direction, frequency and magnitude of these exchanges cannot be specified based on existing data. Therefore, one can only conclude that such exchanges are possible but cannot estimate their probability.

Culture conditions will prevent or greatly reduce the probability of sablefish contributing a variety of parasites from culture conditions to wild fishes because dietary differences precludes or reduces exposure to intermediate hosts.

The magnitude of effects of transmission of shared diseases agents from cultured to wild fish is unquantifiable for the following reasons:

- there is insufficient scientific evidence to attribute a relative risk of any disease to declines or regulations of wild fish populations.
- there are no studies examining the effects of specific infectious agents on wild sablefish and only anecdotal reports of the effects of specific disease-causing agents on cultured sablefish
- there are no studies that document the frequency of transmission from farmed fish to wild fish of specific disease agents relevant to sablefish
- there are little data on the susceptibility of wild fish to the endemic disease agents or no data on if increasing the prevalence of these agents in the environment could overwhelm innate or acquired resistance in wild fishes.

7. Other Ecological Risks

Under the Code, ecological effects in addition to genetic and disease effects are to be considered. Such ecological interactions include (i) indirect effects on species or ecological features in the vicinity of the marine cages or hatchery and (ii) direct effects on other species or wild members of the same species through predation or competition. Many of the concerns voiced about ecological effects of sablefish farming mirror those raised about marine pen salmon farming.

We were unable to find evidence apart from anecdotal reports that there are specific areas of preference for juvenile sablefish on the BC coast. R. Kronlund (pers. comm.) suggested that there are no discreet sablefish nursery areas, rather that varying parts of the inshore areas are used as stock size changes. We cannot, therefore, specify locations where juveniles would be at highest risk for wild-farm interactions.

Beamish and McFarlane (1983) reported capture of adult sablefish in mainland inlets. Larval sablefish are found in surface waters as deep as 200 m in Hecate Strait and off the west coast of Vancouver Island and begin to move offshore at approximately 3 years of age (King et al, 2001). Larval, juvenile and adult sablefish may, therefore, be expected to reside in the same general waters in which aquaculture takes place, although it is expected that the adults of breeding age will generally be found offshore and many of the inshore animals will be at depths greater than those at which sablefish will be held in marine cages (i.e. >95 m). Indirect ecological effects from aquaculture would be of concern largely for immature sablefish given that evidence from salmon farming shows most waste discharge or environmental alterations are restricted to within relatively short distances from the farm site and the fact that mature sablefish are typically found off the continental shelf where there is no aquaculture. Direct ecological effects on juveniles would require either escape from cultivation or juvenile wild sablefish entering sablefish net cages. Direct effects on mature sablefish residing in deeper waters offshore would require the escape of cultivated fish and their subsequent movement to locations of residence of mature fish.

7.1. Indirect ecological effects

Given that the production methods for sablefish are very similar to those used in salmon, that marine cage rearing of sablefish is subject to the same regulatory requirements for waste discharge and escapes as for salmon, and the locations proposed for sablefish farming are currently the same as those used for salmon, it is reasonable to assume indirect effects from sablefish farming will be similar in character as for those attributed to salmon farming. It is, thus, reasonable to conclude that, at its current levels, sablefish cultivation and rearing at sea will have a lower probability of adverse effects and a lower overall magnitude (with respect to spatial scale of effects) of effects due to the significantly lower biomass produced and smaller number of sites rearing sablefish when compared to salmon farming in BC. The lower biomass produced should result in less food consumed, less waste produced, less chemicals used and less habitat used than for salmon farming. In addition, observations from hatcheries suggest sablefish have a better food conversion ratio than salmon, thus resulting in lower waste output (H. Kreiberg, pers. comm.). Similar information on performance in sea cages was not found.

If technology used at the hatchery we visited is applied to other hatcheries with respect to waste management (37 micron filtration with removal and composting of solid wastes followed by natural sand filtration of effluent water), the indirect impacts of sablefish hatcheries on local ecosystems should on average be less than for hatcheries used for salmonid enhancement or commercial production. Unfortunately, unlike for freshwater hatcheries, there are not yet specific regulations in place for the operation of marine hatcheries; therefore, requirements are site specific. This is unlike the situation for marine sablefish farms that are subject to the same performance-based waste management regulations as salmon farms. These regulations require best management plans intended to work towards constant reductions in waste discharge, contingency plans for spills, improvements in feeding and feed conversion, safe removal of dead fish, reduction of attraction of wildlife to wastes and fish kill contingencies[31]. The regulations also require monitoring within a month of peak biomass or relocations and sets standards for compliance. Fines and penalties are associated with lack of compliance.

Information provided in table 10 from industry suggests that the operations of a sablefish hatchery is capable of creating waste water that are significantly lower in a variety of water quality measurements when compared to municipal waste discharged to sea.

Table 10: *Waste water measurements from a sablefish hatchery in comparison to levels recorded for human waste discharged as reported by members of the aquaculture industry.*

Water Quality Variable	Sablefish Hatchery Effluent	Municipal Waste Discharge 1	Municipal Waste Discharge 2
Biological Oxygen Demand 5 day mg/l	<5.1	100-200	220-300
Total Suspended Solids mg/l	17.8	100-200	200-300
Fecal Coliforms (million colonies per 100ml.)	0	3-5	3-5

These industry data also showed that the hatchery effluent was different than the influent for total ammonia (influent 0.05, effluent 0.29 mg/l) and total suspended solids (influent 13, effluent 17.8 mg/l). Even though different, effluent measurements were within allowable discharge levels. Difference in influent and effluent for pH, temperature, nitrate, salinity, and biological oxygen demand were insignificant and not consistent.

A number of reports including the BC Salmon Aquaculture Review have evaluated the risks of waste discharge from aquaculture and their impacts on benthic communities. Most have concluded that such effects are the most likely ecological impacts to be

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[31] http://www.qp.gov.bc.ca/statreg/reg/W/WasteMgmt/256_2002.htm#section8

realized through marine fish farming, but they will be restricted spatially to the vicinity of the farm site. There is debate regarding the duration of those effects if the aquaculture operation is removed. In response to the Salmon Aquaculture review, BC Ministry of Water, Lands and Air Protection have developed new performance based finfish aquaculture waste control regulations[32]. MWLAP audits industry monitoring data by periodic field sampling. These same requirements apply to sablefish farms, therefore, we can assume that concerns outlined in the Salmon Aquaculture Review with respect to indirect ecological effects from waste discharge should be similarly managed or mitigated for sablefish. We were unable to find specific data that was used to critically evaluate the efficacy of this regulatory regime on preventing, reducing or mitigating environmental impacts.

It can be reasonably expected that a certain portion of drugs and disinfectants used at a marine cage site or hatchery would enter the environment with the effluent. Accumulation of some associated chemical residues near the point of discharge is possible, but will depend on the amount of solid material discharged. For dissolved chemicals, the spatial extent of impact will depend upon dilution of the waste stream within the rearing system and the rate of dilution after discharge (GESAMP, 1997). The absence of data on the environmental fate and effects of many of the aquaculture drugs and disinfectants complicates assessment of their risks (GESAMP, 1997). There is little field data on the biological responses to chemical residues in receiving waters under typical production conditions. Drugs and chemicals used to treat or prevent disease in salmon (and assumed to potentially be used for sablefish in the future) will be modified to some degree through physical and biological processes so that the amount remaining in wastes will have substantially less biological activity than the amount original delivered to the fish (Stephen and Iwama, 1997). Predicting synergistic, additive or antagonistic effects is difficult or impossible for most chemicals, including those used in aquaculture. None of the drugs that are considered by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Pollution (GESAMP1997) to be high risk to humans and the environment are allowed for use in Canada and we are aware of no evidence that they have been used in BC. Unlike other forms of agriculture, there is a very high involvement of veterinarians in drug use prescription and monitoring and a very limited number of drugs that can be used in aquaculture. As no drugs are, to our knowledge, licensed for use in sablefish, they will have to be provided under veterinary prescription. These factors limit the number and amount of drugs that can enter the environment. The Veterinary Drug Directorate has begun to consider environmental impacts when licensing new veterinary drugs. Unfortunately, an evaluation of the nature of environmental reviews done for currently available drugs was beyond the scope of this project.

It can be anticipated that vaccines will be developed for sablefish over time. As some vaccinations are delivered by baths, it is possible for vaccine to enter the waste stream. Waste vaccine product discharged with effluent would present little, if any, risk to organisms in the receiving environment because: (1) current regulations require aquaculture vaccine to be killed products incapable of causing disease; (2) their

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[32] http://wlapwww.gov.bc.ca/epd/epdpa/industrial_waste/agriculture/aqua_home.htm

effectiveness will reduce quickly after exposure to environmental conditions and, (3) their concentrations will be diluted before release and upon mixing with marine waters.

Telfor and Robinson (2003) felt that the carrying capacity for aquaculture needs to address:

- what determines the productivity of the environment
- what the farmed animals consume/produce in terms of food/wastes
- how the environment responds to waste loadings
- how much change is permissible.

Data limitations that complicate determining the first three points could, with sufficient will among stakeholders, be overcome. However, addressing the fourth point is more problematic given our poor ability to predict the ecological and economic effects of specific environmental changes.

Apart from the aforementioned difference in probability and magnitude, we cannot foresee how sablefish culture will produce significantly different indirect ecological hazards than for marine salmon culture with respect to indirect ecological effects. We cannot quantify the probabilities and magnitudes with the available data. We refer the reader to the Salmon Aquaculture Review and the government's response to the recommendations from the review for a more in-depth discussion of the nature of indirect ecological hazards that could be postulated for sablefish farming and the steps taken to prevent or mitigate risks arising from those hazards.

7.2. Direct ecological effects

Krebs (1994) describes six forms of species interactions:

- Competition: Two species use the same limited resource or harm each other in some way while seeking a resource
- Predation: One species eats all or part of another animal species
- Herbivory: One species eats all or part of a plant species.
- Parasitism: Two species live in an obligatory association in which the parasite depends metabolically on the host.
- Disease: An association between a pathogenic microorganism and a host in which the host suffers.
- Mutualism: Two species live in close association with each other to the benefit of both

Of concern to this risk assessment are competition, predation and disease.

While a variety of opinions exist about the nature and significance of competition between wild and escaped farmed fish or between hatchery reared and wild fish, Weber and Fausch (2003) suggest that there have been very few studies that have been designed to deal with variables confounding the effects of competition. This, the authors concluded, has resulted in most studies being able to only generate circumstantial evidence that competition between wild and cultured fish results in negative effects on wild fish.

For aquaculture sablefish to compete with other species in such a way as to exert a negative effect they must be striving to exploit a shared resource and the cultured fish must have a competitive advantage. There is no evidence that wild sablefish are resource limited with respect to food or habitat at the present time (R. Kronlund, pers. comm.) Basic mathematical model for competition such as the Lotka-Volterra and Tilman's models (see Krebs 1994 for details on models) reveal that there are a few key factors determining the effects of competition. Critical are the relative sizes of the populations competing (where size is standardized for rate of resource extraction), the rate of change in population size and the rate of supply of the resource being competed for. The anticipated relatively small number of escapees as compared to wild fish places the escapees at a disadvantage to "win" competitions with the whole of the wild sablefish population. Of more concern would be the capacity for locally significant competitive effects. Evidence of discrete populations, such as those on seamounts, suggests the possibility of local competition. It is not known how resident populations at localities such as seamounts would respond to the influx of escaped fish. However, we suspect this would not be a significant effect with the anticipated number of escapees as seamounts populations typically receive immigrants from other locations to maintain population size. We were unable to find evidence of smaller nearshore sablefish that are restricted by oceanography or resource distribution to unique areas of the coast that would be liable to competitive effects due to the immigration of escaped fish.

Laboratory data suggests that sablefish can withstand prolonged periods of starvation (6 months) without showing signs of stress (Sullivan and Smith, 1982 in Norris, 1993). Other researchers concluded that sablefish had the physiological capacity to compensate for changing metabolic needs associated with a variable food supply (Norris, 1993). These two facts suggest a capacity to withstand short to medium-term competition, though the duration of this ability would likely vary with depth and temperature.

In a series of experiments, Sogard and Olla (2000) showed that social interactions with conspecifics caused only minor impacts on the growth of juvenile sablefish. They felt that during feeding and foraging behaviour is independent with little energy being dedicated to food defence and no evidence of a feeding hierarchy or interference competition, unlike for some salmonids. If food resources became limited, disparity in sizes within a group could result in differential effects including cannibalism, predation effects and exploitative competition. Unless escapees resulted in schools where there was significant increases in exploitative competition or increased rates of cannibalism it seems unlikely that a comparatively smaller number of escapees would exert significant competitive pressures on wild juveniles This may not be the case with respect to local competition effects if large scale escapes occurred.

Predatory fish play a major role in fish ecosystems and changes in abundance of major predators will have ecosystem effects (Bax, 1991 in Laidig et al, 1993). Predator effects are a product of predator abundance and feeding rate (Laidig et al, 1993). Predation pressures will occur if sablefish in cages or after escape eat significant amounts of wild biota. As sablefish become increasingly piscivorous as they age and prey selection is determined by fish size, the main predation pressures would likely be on fish that are smaller than sablefish escapees. Sablefish prey primarily on rockfish, herring and squid in Canadian waters (McFarlane and Beamish, 1983). We were unaware of any data that examines the rate of consumption of wild biota by individual sablefish while in marine pens, however, it can be postulated that the amount cumulatively consumed by penned sablefish will be less than could be expected for salmon farms due to the lower number of sablefish that will be produced in the foreseeable future.

Observations of escaped farmed salmon suggest that these fish will take some time to adapt to consuming wild prey and therefore, will not contribute to predatory pressures immediately after escape but that a proportion of recaptured escaped farmed salmon (6-13%) do have wild prey in their stomachs (Alverson and Ruggerone, 1997). The Salmon Aquaculture Review found little evidence to suggest that caged salmon are significant consumers of wild fish (Alverson and Ruggerone, 1997). Alverson and Ruggerone (1997), using 1996 data for salmon concluded that the use of night lights at marine pens did not result in noticeable predation by caged fish on wild fish. Therefore, if we assumed similar predatory behaviour, we would conclude that sablefish would make little contribution as a predator while in cages and small effects when escaped. However, we do not know if the assumption of similar predatory behaviour is valid.

Rates of predation by escaped sablefish would be important if there were significant numbers of escapees, those escapees maintained a group of sufficient size to exert locally significant predation pressures and there were prey species at risk due to additive effects of introduced predators. While sablefish are known to be cannibalistic this behaviour is density related. Therefore, we suspect that cannibalism would not be significant once escapees disperse. There are no known specific nursery areas for sablefish, rather, juveniles exploit greater or lesser areas of inshore environments in relation to the juvenile stock size (R. Kronlund, pers comm.). Therefore, farms could not be located in a manner that would avoid critical juvenile nursery areas and, thus avoid risks of escaped fish cannibalizing smaller wild sablefish.

The presence of the reproductive population of sablefish at depths away from juveniles, the high fecundity of sablefish and their longevity help sablefish withstand decadal periods of unfavourable environmental conditions (King et al, 2001). Sablefish also seem able to better withstand periods of poor water quality (such as low dissolved oxygen) and more dense conditions than salmon (H. Kreiberg, pers. comm.). These features of sablefish suggest a capacity to withstand some of the effects of anthropogenic disturbances that may arise due to aquaculture. However, how cumulative negative effects, especially if coupled with adverse environmental conditions, would affect longer-term effects on populations or the threshold for environmental change that would induce negative impacts on wild sablefish are unclear.

Mills et al, (2004) concluded that the ultimate outcome of interactions between native species and invasive species (specifically mosquitofish and least chub) depends on the number of simultaneous negative interactions (competition and predation), which depends on relative body sizes of the species. Whereas larger more rapidly growing fish may be better able to escape predation, they increase their vulnerability to competition in the face of limited resources. The number of species a particular type of fish encounters must multiply such interactions.

7.3. Section conclusion

Based on currently available data[33], there is no reason to believe that the nature of the environmental hazards presented by sablefish aquaculture due to competition, predation or waste discharges would be noticeably different than for salmon aquaculture.

It is reasonable to conclude that the ecological risks considered in this section are less probable and likely to be of a lesser magnitude than salmon farming simply due to the comparably lower biomass of sablefish produced than salmon. In addition, the lack of specific bottlenecks (such as estuaries) or limited critical habitat where competition and predation effects could be more intensive on juvenile sablefish places them at less risk that salmon. Furthermore, the lack of resource or habitat limits on sablefish, their mobility and their capacity to cope with natural environmental change provides sablefish more capacity to cope with anthropogenic change than salmon. We can, therefore, conclude that sablefish farming, at its current and 4-year projected level of production will have less ecological effects than salmon farming.

We cannot draw conclusions as to the specific effects these smaller, but plausible ecological effects may have on wild sablefish populations due to information deficits.

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[33] Lack of information on the behaviour of cultured fish in cages and upon escape could affect the validity of this statement.

8. Salmon aquaculture as a basis for assessing sablefish risk

Because of the lack of a previous assessment, some parties have turned to information generated from other forms of aquaculture, most frequently marine cage salmon farming, to bolster their position that sablefish farming does or does not pose undesirable environmental risks or risks to wild fisheries. It is beyond the scope of this review to re-assess all the data supporting claims for or against the nature of environmental impacts from salmon farms or to assess the adequacy of regulations to prevent or mitigate any such risks. These questions have been considered by others including the 1997 BC Environmental Assessment Office review of salmon aquaculture, the 2000 Auditor Generals Assessment on the federal role in assessing and managing the effects of salmon farming in BC on wild salmon stocks and the Federal standing committee on the role of the federal government in aquaculture. The nature of information used to generate the aforementioned reports ranged from personal opinion, testimony and interviews to small-scale data collection and critical reviews of the scientific literature. None prospectively undertook scientific evaluations of environmental effects of salmon farming. A brief overview of these and other reports is presented below.

8.1 Summaries of recent assessments of environmental risks from salmon farming

8.1.1. Auditor General's Report

This report suggested that DFO is managing aquaculture on the basis that salmon farming poses an overall low risk to wild salmon and habitat, yet the Department was not certain when it would have enough information to assess and to mitigate against cumulative environmental effects. The report concluded that DFO lacked the scientific information needed to ensure that its monitoring and enforcement activities protect wild salmon and salmon habitat from the potential effects of aquaculture and that the Department had not yet made adequate progress on identifying priorities for research on the effects of wild-farmed salmon interactions. The report recommended an adaptive management approach that applied new knowledge and assessed effectiveness of regulations. DFO's response to the Auditor General's report highlighted a variety of funding and regulatory initiatives that were to be undertaken to remedy the deficits the Auditor General noted including a 5–year Program for Sustainable Aquaculture (2000-05) supporting regulatory and scientific efforts, harmonization of federal and provincial roles, refining application of the Fisheries Act to aquaculture and the development of the National Aquatic Animal Health Program. At the time of our review, we were unaware of any assessment of the outcomes of these measures anticipated by the department, such as improved aquatic animal health in wild and farmed populations and further reductions in antibiotic and pesticide use.

8.1.2. Federal Standing Committee

A 2001 standing committee of Fisheries and Oceans recommended that the government invest more into research on the environmental, ecological and human health effects of salmon farming. It also advised government to refine how the precautionary principle would be applied to aquaculture development. The report of the 2003 Standing Committee focussed more on the way DFO balances it role as a regulator and enabler of aquaculture rather than on an objective review of risks. It did however recommend that DFO act in a manner to remedy the many deficits in knowledge and to act according to the precautionary principle when decisions must be made in the absence of definite information.

8.1.3. Salmon Aquaculture Review of the BC Environmental Assessment Office

Released in 1997, this report concluded that salmon farming in the mid-1990's presented low overall risks. However, the report urged caution because there was evidence with which to plausibly hypothesize potential risks for which policies and practices at that time were inadequate to prevent or mitigate. The provincial government has moved towards acting on the recommendations of the report. Thirty-nine of the 49 recommendations have been adopted as they were put forward in the Salmon Aquaculture Review[34]. Another six have been partially implemented. Four recommendations have not been adopted either because a different approach has been taken to address the topic or because the recommendation is not applicable to current programs or to provincial activities or responsibilities. The effectiveness of these changes has not, to our knowledge, been critically assessed, although tangible positive outcomes are evident, such as a reduced rate of escape, the requirement for fish health management plans and the implementation of government based disease surveillance.

8.1.4. Leggatt Inquiry[35]

Though not involving the provincial government or the salmon farming industry, this inquiry took place in 2001 and concluded that open cage salmon farming should be stopped and the moratorium on salmon farming then in place in BC be maintained.

8.1.5. Pacific Fisheries Resource Conservation Council[36]

The authors of a report on the effects of salmon aquaculture on the natural environment conclude that the topic is rife with uncertainties that will not be resolved even if current research priorities are addressed. Because of these uncertainties, the author recommended a cautious approach to salmon farming.

8.1.6. SFU Continuing Studies in Science: Aquaculture and The Protection of Wild Salmon. March 2000 workshop[37]

The common theme to the reports presented in this workshop was that there was a lack of specific information to discount possible threats salmon aquaculture might impose on wild salmon. Conversely, it was noted that this lack of information also fails to prove such risks occur in an ecologically significant manner.

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[34] http://www.agf.gov.bc.ca/fisheries/faq.htm#implemented

[35] http://www.davidsuzuki.org/files/Leggatt_reportfinal.pdf

[36] http://www.fish.bc.ca/reports/pfrcc_making_sense_report.pdf

[37] http://www.sfu.ca/cstudies/science/aqua.htm

8.1.7. US NOAA technical report on risks to evolutionarily significant runs of chinook and chum salmon in Puget Sound from Atlantic salmon farms[38].

This report focussed on the risks to threatened coho runs in Puget Sound from Atlantic salmon farming and concluded the following:

Low risk concerns

- That Atlantic salmon will increase the incidence of disease in wild or hatchery reared salmon
- That escaped Atlantic salmon will compete with wild salmon for habitat or food
- That salmon farms will significantly impact critical salmon habitat, especially in comparison to other accepted coastal activities

Little risk

- Atlantic salmon will hybridize with Pacific salmon
- Atlantic salmon will colonize specific Chinook and chum habitat in the region or will prey on Pacific salmon
- Atlantic salmon will be vectors for exotic disease introduction
- Antibiotic resistant bacteria of aquaculture origin will affected wild salmonids

No risk

- Effects of transgenic salmon on wild stock is zero as none were being cultured

8.1.8. Scottish Association for Marine Science and Napier University: review and synthesis of the environmental impacts of aquaculture[39].

This report concluded that the most obvious pollution effect from fish farms were impacts on the seabed. However, severe effects were generally confined to a few hundred metres at most from the farm site and the total area of seabed used for this purpose was judged insignificant in terms of the total coastal resource. Lack of data made it impossible to judge the effects of farms on the occurrence of harmful algae blooms, but despite models suggesting the possibility of the effects, the review deemed this to be insignificant except in unique nutrient loaded sea lochs. The authors of this report also felt there was insufficient long-term data to determine the effects of medication and antifoulant chemical use or the effects of transfer of parasites or pathogens to wild fishes. Genetic effects of interbreeding of escaped and wild Atlantic salmon was judged to be a major threat to wild salmon due to their status in Scotland.

8.1.9 Other reports on the effects of salmon farming

Nash (2003) consolidated five literature reviews on aspects of Atlantic salmon farming in the Pacific Northwest and concluded the following. The two issues that appeared to carry the most risk for the region were the impact on the sediments beneath net-pen farms from bio-deposits, and the accumulation of heavy metals (zinc and copper). Both of these risks could be remediated within 1–2 years with fallowing. This conclusion concurs with Belias et al (2003) who felt that the effects of coastal aquaculture in the eastern Mediterranean were most significant immediately under net pens. Vizzini and

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[38] http://research.nwfsc.noaa.gov/publications/techmemos/tm53/tm53.pdf

[39] http://www.scotland.gov.uk/cru/kd01/green/reia-00.asp

Mazzola (2004), however, concluded that impacts of wastes released from land-based fish farms into the Mediterranean were negligible. Nash (2003) carries on to identify issues of low and little to no risk.

Low risk issues

- physiological effect of low dissolved oxygen levels in the water column;
- toxic effect of hydrogen sulfide and ammonia emanating from the bio-deposits;
- toxic effect of algal blooms which might be enhanced by the dissolved inorganic wastes;
- changes in the epifaunal community caused by the accumulation of organic wastes;
- proliferation of human pathogens, and fish and shellfish pathogens in the environment;
- increased incidences of disease among wild fish; and
- displacement of wild salmon in the marketplace by farmed salmonids.

Little to no risk issues

- escape of a non-native species and possible hybridization with other salmonids, colonization of salmonid habitat, competition with native species for forage, predation on indigenous species, and as vectors for the introduction of exotic pathogens;
- impact of antibiotic-resistant bacteria on native salmonids and
- human health and safety concerns regarding possible heavy metal contamination of farm products, rendered animal products in animal feeds, genetically modified (GM) ingredients in fish feeds, ingredients and additives in animal feeds, residual medicines and drugs in farmed products, biological hazards in farm products, transgenic farm fish, workers' safety, public safety and navigational hazards, and impacts on nearby property values.

Nash's (2003) conclusions on genetic interactions of Atlantic on Pacific salmon differ from the assessment of risk of farmed Atlantic salmon in wild Atlantic salmon. For example, experimental work by McGinnity et al (2003) suggest that interbreeding of wild and farmed Atlantic salmon can depress fitness and it is further postulated that this reduction could have significant impacts on threatened wild salmon stocks. Such findings support concerns expressed in the Scottish review mentioned above. However, Nash's (2003) conclusions are similar to those of Noakes et al (2000) who concluded that salmon farming poses a low risk to wild Pacific salmon stocks, especially when compared to other potential factors.

There are many other papers that deal with specific aspects of environmental impacts of aquaculture. Many of these papers present conflicting interpretations of the nature of risk aquaculture presents to coastal ecosystems. These papers are generally unsuited to a meta-analytical approach as few attempt to quantify risks in a rigorous, controlled fashion. We are therefore left to conclude that there are outstanding issues of environmental effects of aquaculture that cannot be conclusively proven or disproven based on existing science alone.

8.2 Section conclusion

There are sufficient similarities in practice and policies during the marine rearing stage of both salmon and sablefish to suggest that there would be an overlap of hazards and risks. Therefore, it is logical to look at salmon farms to provide some information, however, it does not follow that the nature of that information would allow for confident prediction or serve as the basis of evidence-based policy decision-making. Table 11 illustrates this point by highlighting some key differences that could affect the manifestation of environmental hazards. It illustrates that direct application of the results of salmon farming environmental assessments must be done with some caution.

Table 11: *A comparison of some broad differences in hazards and risk issues between sablefish and salmon aquaculture.*

Issue	Sablefish	Salmon
Genetics	Escaped fish could interact and interbreed with wild fish of the same species	Atlantic salmon in BC will not encounter the same species with which to bred, but Pacific salmon, if fertile could
Genetics	There is significant gene flow throughout the entire population with no evidence of locally adapted populations	Locally adaptation on a stream basis is a feature of salmon life histories, making local populations more vulnerable to outside genetic influences
Ecological and genetics	There is evidence of movement of fish and genetic material throughout large areas of the range	Several small local populations exist that could be influenced by an influx of escaped fish
Ecological	Sablefish are not currently habitat or resource limited	Several salmon strains are threatened by habitat loss
Commercial production versus wild stocks	The number of sablefish anticipated to be commercially produced in the near future is significantly smaller than the wild population	In the Atlantic, the number of farmed salmon outnumber wild salmon in many areas
Level of commercial production	The anticipated production of cultured sablefish is much less than for salmon, thereby reducing the magnitude and probability of many potential hazards in comparison to salmon farming	
Disease	There has been very little	There is much more

Issue	Sablefish	Salmon
	work on sablefish disease. What exists is largely a listing of pathogen or parasite findings and a few reports of diseases on farms	known about the types of diseases salmon get because of work in commercial and enhancement settings. This allows for more experience on control and treatment

The reviews summarized above reveal that there is insufficient data to make definitive conclusions with a high degree of confidence regarding the nature, magnitude or probability of a number of environmental concerns associated with salmon farming. In general, reviews have concluded that the most significant impacts on salmon farms will be restricted to the immediate vicinity of the farms, most noticeably on the benthos, though opinions vary on how long it would take a benthic area to recover from farm impacts. There is also consensus that many of the other hypothesized risks cannot yet be ruled out with certainty using scientific data. However, opinions vary with respect to the threshold of certainty required to conclude a risk is of no concern. In general, where a review concludes that salmon farming is high risk, it is because we are unable to exclude the possibility of ecologically important impacts and because biological analogy suggests some important risks are possible. Alternatively, when the industry is judged to not be high risk, it is seen as being of overall low risk because of lack of evidence of impacts to date and biological analogy suggests certain risks are unlikely.

Most reviews and reports we are aware of look at specific effects of salmon farming or other forms of finfish aquaculture on the environment in isolation rather than assessing them within the context of other factors affecting risk bearers. None we could find examined the effects of salmon farming from a systems perspective or dealt with issues beyond documenting changes in the immediate future. None were capable of predicting the effects on the sustainability of wild aquatic populations or on ecosystem function. Many were, however, able to produce observations that allowed for reasonable hypotheses to be formed regarding the potential for environmental effects in the immediate to short-term future. Some reports are capable of establishing associations between aquaculture variables and environmental outcomes but failed to fulfill standard criteria for establishing causal relationships.

From a social perspective, the ongoing debate on the effects of salmon farming in BC suggests that there is a not a shared public consensus that would allow all to agree on salmon farming environmental impacts.

We can conclude that, from an objective evidence-based risk assessment, using salmon farming as a model will not allow for exact prediction of sablefish farming risks simply due to the prevailing uncertainty about salmon farming. However, it serves as a reasonable subjective analogy due to similarities in production practices and regulatory framework, and the ecological conditions of marine rearing. If one were to accept salmon farming as a subjective analogy, then one would have to accept the fact that, in BC, the existing level of knowledge and opinion has not remedied concerns of industry critics and thus may not facilitate discussion of sablefish farming.

The utility of salmon farms as the model for assessing sablefish risks will depend on social values, namely how one weighs the available information, the nature of current legislation and political decisions regarding the application of the precautionary principle. It is important to recognize that the inability to predict ecological effects affecting sustainability questions is not unique to sablefish. Indeed, Environment Canada concluded that, "Canada's current sustainable development information and knowledge base is inadequate to provide for a foundation for informed public debate and evidence-based decision making".[40] Comprehensive tools to integrate the diversity of scientific and social information or to resolve conflicts in coastal zone systems associated with sustainability issues are virtually non-existent.[41] Central to this issue is (i) the lack of evaluation of industry-environment interactions that take into account the synergistic and antagonistic relationships that result from multiple stressors acting within a larger system and (2) the lack of critical understanding regarding which kinds of programs and institutional arrangements can most effectively use science for sustainability.

The assessment of risks associated with sablefish aquaculture will ultimately depend on how decision makers choose to deal with uncertainty.

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[40] Sustainable Development Strategy 2001-2003. Environment Canada. http://www.ec.gc.ca/sd-dd_consult/pdf/sds2001_2003_final_e.pdf (referenced May 28, 2004).

[41] http://www.unites.uqam.ca/dgeo/geoid/

9. Overall risk assessment

The Food and Agriculture Organization (FAO, 1996) recognizes the following:

- all aquaculture activities have some impact;
- these impacts should not be considered negligible unless proved otherwise (e.g. in aquaculture development, introduction of exotic species, or water diversion projects);
- the complex and evolving ecosystem in which aquaculture takes place will never be perfectly understood;
- the development and implementation of aquaculture development policy are therefore always affected by uncertainty;
- the decision-making process and sector's compliance with the decisions and regulations add their own uncertainties;
- impacts of aquaculture activities (particularly large-scale, extensive aquaculture) on the aquatic system may sometimes be difficult to predict accurately; and
- consequences of errors on the resources, the environment and; ultimately; the fisher's community may be only slowly reversible.

We agree that sablefish farming will, as all coastal activities, leave an ecological footprint, thus having some environmental impacts. **We further believe that the likelihood, magnitude and spatial scale of the impacts sablefish farming at its current and 4 year predicted levels of production will be less than what occurs for salmon farming** primarily because the numbers of sablefish produced (and hence biomass) will be significantly less than the numbers of salmon commercially produced by aquaculture in BC. This, in turn, reduces the number of sablefish that might escape and encounter wild fishes or disseminate hazards. It also reduces the ecological footprint of sablefish farming in comparison to salmon farming, including waste discharges. When or if sablefish production levels increase significantly beyond the forecasts we were given, this conclusion must be re-assessed.

Genetic effects are less likely than for salmon because of the one population nature of sablefish as compared to the presence of many locally adapted salmon populations. This reduces the likelihood that the influx of genetic material from cultured fish will influence population genetics in a manner that affects survival. The use of Atlantic salmon in BC virtually eliminates genetic interactions with wild salmon. However, there are still a small number of Pacific salmon producers in BC. We believe that the risk for the former situation (Atlantic salmon in BC) is lower than for sablefish farming but for the latter (Pacific salmon in BC) is higher than for sablefish based on the presence of locally adapted wild salmon populations that are threatened or at risk. This risk is currently further reduced by the use of wild broodstock that can be anticipated to be similar to wild sablefish. If sablefish farming increasingly domesticates its broodstock in a manner that results in maladaptive traits for wild fish and there are significant declines in wild population numbers so that escapee numbers compared to wild are sufficient to exert genetic influences, this conclusions may change.

Sablefish population status and structure make them currently less vulnerable to ecological effects than salmon as salmon have specific critical habitat requirements for reproduction and juvenile rearing, there are threatened local salmon populations, and there are significant pressures on salmon from habitat loss. The long life span, high fecundity, evolution to withstand decadal environmental changes, separation of life stages and mobility all provide sablefish with some environmental resilience. How this capacity will reflect their ability to deal with anthropogenic effects of aquaculture is unknown. However, the lack of locally threatened or endangered sablefish and lack of resource and habitat limitations makes the risk level less than for salmon.

There is less likelihood that sablefish aquaculture activities would significantly impinge on critical habitat because sablefish are not dependent on specific nearshore areas for reproduction, there are no reported critical juvenile rearing habitats, fish tend to move out of nearshore areas to offshore sites for most of their lives and the population range is large. If future research reveals critical specific locations for juvenile sablefish, then siting criteria should prevent locating fish farms in those locations. If the technology noted on our one hatchery site visit is reflective of future technology for other hatcheries, there are more opportunities for environmental control, waste management and biosecurity than can be realized at many salmon hatcheries, especially enhancement facilities, thus making sablefish hatcheries less risky.

The FAO's second point of negligible impacts is not informative, as the term negligible is not defined by measurable outcomes. Our conclusions do not place a numerical value on risks, rather, they place them with respect to assessments of salmon farming. Sablefish farms are subject to the same measured performance standards as salmon in marine pens and provincial waste discharge licenses do require hatcheries to meet measurable standards as well. It is our understanding that sablefish farms are in compliance with those standards. The zero-escape target is an ideal to date, but a tangible goal that sablefish farming has so far been able to meet according to reports to government. If one accepts these measured outcomes as representative of negligible effect, then one must accept that sablefish has to date shown negligible effects for these outcomes to date.

More generally, if one accepts our conclusion that the nature of risks of sablefish farming are similar to but of lower likelihood and magnitude to those of salmon farming and further accept the statement that the government's response to the Salmon Aquaculture Review has resulted in an adequately protective management framework, one would then have to conclude that the management of sablefish farming is acceptable as the regulations used for marine rearing of salmon and sablefish are the same.

If, on the other hand, one feels that salmon farming regulations provide inadequate environmental protection, then specific thresholds of protection must be specified and more empirical data must be collected or modelled to determine if the lower biomass produced by sablefish farming creates conditions that exceed these thresholds. One would need to take into account differences in the ability of regulations to deal with differences in risk management that arises from the lower production of cultured sablefish when compared to salmon.

Criteria for acceptability thresholds can be based on (1) known cause-effect relationships that allow one to predict when an undesired outcome occurs, (2) cost:benefit ratios, (3) social and cultural criteria. In all cases, social/political criteria tend to be the final determinant of the level for acceptability. Science, though often looked to as the arbitrator of environmental questions in aquaculture, is hampered by significant uncertainties. Faced with the inevitability of several sources of uncertainties in real situations, a probabilistic approach can be used as an alternative to deterministic analysis (Barg, 1992). Methods such as Baysian decision analysis are increasingly being used to assist in areas of high uncertainty. Such approaches still require some evidence or consensus as to when a change becomes unacceptable.

10. Recommendations

Steps must be taken to continue to evolve the debates associated with sablefish aquaculture from one based on opinions to one based on evidence. An important step would be to ensure ongoing support for aquaculture-environmental interactions research such as encouraging the BC Aquaculture Research and Development Committee or Aqua-Net to develop capacity to evaluate hazards associated with sablefish in a socially acceptable and scientifically sound manner.

Environmental management of coastal industrial activities, including sablefish aquaculture, should apply an adaptive management approach that includes critical assessment of management and regulatory effectiveness.

Efforts must be taken to improve Canada’s general ability to assess environmental impacts from a more integrative perspective that takes into account ecosystem scale effects and social concerns

Efforts must be taken to operationalize the Precautionary Principle so it can be more meaningfully applied to issues of aquaculture management. Future social science research must be dedicated to understanding how this precautionary principle can be rationally applied to support environmental management decisions before the term precautionary principle becomes an unworkable cliché with respect to resolving environmental development conflicts.

Increased capacity in risk assessment is required to allow the DFO, ITC, and CEAA to access required information in a timely manner. In addition, there is a need to reach consensus upon the time at which a formal risk assessment is conducted along the process of developing a new species for aquaculture. The ITC should ensure adequate risk assessments and biological reviews are completed for new species before translocation permits are provided. CEAA reviews should also be undertaken at the start of a new commercial development. After initial risks are reviewed, risk management approaches developed from initial reviews can be applied to subsequent applications until site specific or movement specific information is acquired.

Government must be more diligent in proactively investigating and communicating assessments of future aquaculture developments in advance of growth of novel aquaculture opportunities.

An independent social risk assessment that considers economic, cultural and legal issues associated with sablefish farming should be conducted to complement this report and allow for a more comprehensive risk assessment.

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12. Personal Communications

Dr. Gidon Minkoff
Sablefin Hatchery
Saltspring Island, BC

Dr. Craig Clarke
Research Scientist
Aquaculture Division
Pacific Biological Station, DFO
Nanaimo, BC

Henrik Kreiberg
Research Biologist
Aquaculture Division
Pacific Biological Station, DFO
Nanaimo, BC

Dr. Kristi Miller
Research Scientist
Aquaculture Division
Pacific Biological Station, DFO
Nanaimo, BC

Rob Kronlund
Program Head – Sablefish
Pacific Groundfish Science Section
Pacific Biological Station, DFO
Nanaimo, BC

Mark Higgins
Biologist
Introductions and Transfers Committee Member
Aquaculture Division
Pacific Biological Station, DFO
Nanaimo, BC

Andrew Thomson
Senior Aquaculture Officer
Aquaculture Division
Habitat and Enhancement Branch, DFO
Nanaimo, BC

Dr. John Prescott
Chair, Department of Pathobiology
Ontario Veterinary College
Guelph, ON

Bill Harrower
Manager, Regional Operations
BC Ministry of Agriculture, Food and Fisheries
Courtenay, BC

Dr. Jeff Marliave
Vice-President Marine Science
Vancouver Aquarium Marine Science Centre
Vancouver, BC

Dr. Heather Hannah
Health Management Veterinarian
BC Ministry of Agriculture, Food and Fisheries
Abbotsford, BC

Karen Wilson
Constituency Assistant
Office of John Cummins, M.P
Delta, BC

Ray Brunson
Committee Chair
Olympia Fish Health Center
Olympia, Washington

Others providing specific information not cited as personal communications

Dr. Andrea Osborn
Fish Health Veterinarian
BC Ministry of Agriculture, Food and Fisheries
Courtenay, BC

Erik Wickham
Executive Director
Canadian Sablefish Association
Vancouver, BC