ENVIRONMENTAL IMPACTS OF MARINE AQUACULTURE
ISSUE PAPER

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I. Introduction

Marine finfish aquaculture is one of the most hotly debated resource issues on the West Coast. Atlantic salmon (*Salmo salar*) fish farms, especially those in British Columbia, have received much of the attention. Concerns include disease transfer, pollution from net-pen facilities, impacts from escaped salmon, and cumulative ecosystem impacts.

There are numerous opinions on the severity of the environmental impacts of marine flow-through fish farms. For example, the National Oceanic and Atmospheric Administration (NOAA Fisheries) downplays threats posed by the net-pen farming industry to native salmonids in the Pacific Northwest (Nash 2001, Waknitz *et al*. 2002). Waknitz, *et al.* (2002) define the adverse impacts to Essential Fish Habitat[1] from salmon farms as "low", and states there is "little risk" that farmed Atlantic salmon will escape and colonize rivers inhabited by Puget Sound Chinook (*Oncorhynchus tshawytscha*) and Hood Canal summer-run chum salmon (*O. keta*). On the other hand, the Oregon Invasive Species Council recently listed Atlantic salmon as one of its "100 Most Dangerous Invaders to Keep Out of Oregon in 2005". In addition, in April 2005, Albertsons grocery chain wrote a letter to Salmon of the Americas, an organization of salmon-producing companies in Canada, Chile and the United States, stating that it has seen little or no progress on the environmental concerns it raised about farmed salmon in 2003. Albertsons went on to state its intention to offer customers sustainable raised farm salmon that are produced and managed under appropriate guidelines and standards (DiPietro 2005a).

This paper provides an overview of environmental issues attributed to marine open ocean or flow-through fish farms, with an emphasis on Atlantic salmon. There are also brief sections on sablefish (*Anoplopoma fimbria*) and tuna (*Thunnus spp.)*. There are numerous studies, opinions and position papers on the marine fish farm issue from environmental, industry, provincial, Federal, university, state and international entities. The majority of the information provided here is from peer-reviewed and government studies, though industry and environmental organization positions and studies are also included. The document, "Making Sense of the Salmon Aquaculture: Debate by the Pacific Fisheries Resource Conservation Council" (Garner and Peterson 2003), is often cited here because of its relevant information, balanced views, and well thought-out conclusions.

II. Contaminants

Concerns have been raised about the level of contaminants (e.g., polychlorinated biphenyls dioxins, and furans) in farm-raised salmon. Fish accumulate contaminants through their feed. Fishmeal is a high protein feedstuff that comes from species including anchovy (*Anchoa sp.*), anchoveta (*Anchoveta sp*.), herring (*Clupea sp.*), menhaden (*Brevoortia tyrannus*), capelin (*Mallotus villosus*), and sand eel (*Ammodytes sp*.).

Please refer to Table 1 for a synopsis of contaminant studies on farmed salmon. One

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[1] Essential Fish Habitat (EFH): In 1996, Congress passed the Sustainable Fisheries Act (Public Law 104-297) which amended the habitat provisions of the Magnuson Act. The re-named Magnuson-Stevens Act (Act) calls for direct action to stop or reverse the continued loss of fish habitats. Toward this end, Congress mandated the identification of habitats essential to managed species and measures to conserve and enhance this habitat.

controversial study reported that farmed salmon have 16 times the dioxin-like PCBs found in wild salmon and eating farmed salmon increases lifetime cancer risk (Environmental Working Group (EWG) 2003). A study by Hites *et al*. (2004b) also caused much debate, and reported the following:

- farmed salmon have significantly higher contaminant burdens than wild salmon
- consumption of farmed salmon may result in exposure to a variety of persistent bioaccumulative contaminants with the potential for an elevation in attendant health risks
- consumption of farmed Atlantic salmon may pose risks that detract from the beneficial effects of fish consumption

The EWG study was widely criticized because, among other things, it based its conclusion on a small sample size (10 farmed salmon), and therefore was scientifically invalid. Butterworth (2004) down-played the Hites studies saying that, by any measure, the risk from eating farmed fish is extremely small.

To reduce contaminants levels and dependence on fish meal and fish oil, the fish feed industry is developing feeds incorporating vegetable sources of proteins (wheat, soy and corn) and oils (soy, olive flax) into commercial trout and salmon diets.

Elevated levels of contaminants have been found in wild stocks as well. In April 2005, the Washington Department of Fish and Wildlife (WDFW) and NOAA's Northwest Fisheries Science Center released a study showing significantly higher levels of certain contaminants (PCBs) in Puget Sound salmon – particularly Chinook salmon – than salmon in other areas of the Pacific coast (O'Neill *et al.* 2005). According to WDFW, these findings are consistent with an analysis of 210 Puget Sound Chinook fillet samples collected from 1992 to 1996 by WDFW during a study conducted for the Puget Sound Ambient Monitoring Program.

Table 1: Recent studies of contaminants in salmon and other species and reviews of those studies.

Study/Review	Findings
Hites *et al*. (2004a) Sample Size: 2 metric tons of farmed and wild salmon (700 salmon)	• Farm-raised salmon from Europe have higher PBDE levels than those raised in North America - both European and North American farm-raised salmon have higher PBDE levels than those farm-raised in Chile. • Among wild salmon species, Chinook had significantly elevated PBDE levels relative to the other wild species. • Frequent consumption of farmed salmon and wild Pacific Chinook salmon will increase human dietary exposure to PBDEs much more so than consumption of most other wild Pacific salmon.
Hites *et al.* (2004b) Sample Size: same as Hites *et al*. (2004a)	• Organochlorine contaminant concentrations are significantly higher in farmed salmon than in wild salmon (e.g. coho). • Farmed salmon from Europe are significantly more contaminated than farmed salmon from South and North America. • Consumption of farmed salmon may pose risks that detract from the beneficial effects of fish consumption (i.e. Omega-3s). • Farmed salmon should not be eaten more often than one to two times per month (based on EPA consumption advice levels).
Foran *et al*. (2005); Sample Size: see Hites *et al*. (2004a)	• Consumption of farmed salmon at relatively low frequencies results in elevated exposure to dioxins and dioxin-like compounds with a commensurate elevation in estimates of health risk.
Hayward *et al*. (2004) Sample Size: See Appendix 1	• PCB levels from highest to lowest were as follows (ng/g wet weight): bluefish (*Pomatomus saltatrix*) > rockfish (*Morone saxatilis*) > Atlantic salmon > wild Alaskan Chinook salmon > wild Alaskan coho salmon (*Oncorhynchus kisutch*)
Environmental Working Group (2003) Sample Size: 10 fish	• Farmed salmon have 16 x the PCBs found in wild salmon, four times the levels in beef, and 3.4 x the levels found in other seafood. • 800,000 people face a lifetime cancer risk of more than one in 10,000 from eating farmed salmon, and 10.4 million people face a cancer risk exceeding one in 100,000.
Jacobs *et al*. 2002 Sample Size: 13 fish for tissue samples, 8 salmon feeds from 4 sources.	• The study confirms previous reports of relatively high concentrations of PCBs and indicates moderate concentrations of organochlorine pesticides and PBDEs in farmed Scottish and European salmon. • Diets based on marine fish oils likely are contributing greatly to the contamination of farmed salmon by PCBs, PBDEs, Etc. • The possible contribution to dietary intakes of organohalogen compounds from farmed salmon could clearly be significant for high consumers, particularly if the person is pregnant or breast feeding.
Tuomisto *et al*. (2004) [Response to Hites (2004b)]	• Hites (2004b) recommendation restricting consumption of farmed salmon appears to be "nonscientific", because the outcome of the analysis was totally driven by a political variable – whether to ignore the health benefits of fish.
Euro. Food Safety Auth(2005)	• Concluded that with respect to their safety for the consumer there is no difference between wild and farmed fish.
Butterworth (2004) [Response to Hites (2004b)]	• According to the EPA's (1999) calculations, a one in 100,000 lifetime risk of cancer risk would result in approximately 3,000 cases of cancer in the U.S. population (currently 300 million) over 70 years if everyone ate at least eight ounces of raw farm-raised salmon per month at current PCB levels. By any measure, this is an *extremely* small risk • By way of contrast, the Harvard Center for Risk Analysis currently puts a person's odds of dying from heart disease at one in 397.
Julshamn *et al.* (2001) Study by the Institution of Nutrition - Norway	• Concentrations of arsenic, cadmium, mercury, lead, DDT and PCB in salmon fillets are low compared with maximum limits for contaminants in seafood set by the EU and Codex • Concentrations of arsenic and mercury in salmon fillets appear to have declined between 1995 and 2001, and the concentrations of DDT and PCB in salmon fillets show a similar trend in the period from 1998 to 2001. • Mercury content in fish feed decreased between 1996 and 2001
Canadian Food Inspection Agency (1999)	• Dioxin-furan and PCB levels in fish feed and fish meal would not be expected to result in fish having dioxin-furan or PCB levels above the Canadian Guidelines for Chemical Contaminants and Toxins in Fish and Fish Products • Dioxin-furan and PCB levels in fish oil do not exceed the Can. Guidelin. for Chem. Contam. and Toxins. in Fish and Fish Prod.

III. Organic Salmon

Organic foods are the fastest growing foods in agriculture and production is expected to increase 240 fold by 2030 (NOAWG 2005). Negative press on farmed salmon has helped to expand the market for organic (i.e. "environmentally friendly") farmed salmon. Some of the criteria for organic farm-raised salmon include lower contaminant levels, low net-pen densities and using a natural yeast-based feed pigment (*Phaffia*).

The group, EcoFish, is a distributor of all natural premium quality seafood from environmentally sustainable fisheries. Although the group sells mostly wild products, they do offer other products such as farm-raised shrimp from an "eco-friendly", state-of-the-art aquaculture facility; rainbow trout (*Oncorhynchus mykiss)* from a small family operated farm in Wisconsin that are cleaned by hand; and catfish (*Ictalurus punctatus*) from Idaho's "most pristine gravity-fed, mountainside hot-springs." EcoFish labels its product to inform consumers of how many meals can be consumed per month without exposing themselves to dangerous levels of mercury and PCBs.

Currently, there is an absence of standards for farmed aquatic species recognized by U.S. Department of Agriculture (USDA). To address this issue , the USDA created the National Organic Aquaculture Working Group (NOAWG) to propose standards for consideration by the USDA. In May 2005 the NOAWG submitted a report to USDA's National Organic Program on proposed organic standards. The proposed standards include feed, health care, animal origin, and living conditions. These standards do not cover organic standards wild stocks. The USDA has yet to announce the members of the task force responsible for devising organic standards for wild-caught fish.

IV. Atlantic Salmon Escapes and Interceptions

Periodically and sometimes in large numbers, farm-raised Atlantic salmon escape into the wild. Concerns have been raised about the impact to wild salmon stocks from these escapees. Although escape events were reported in British Columbia and Washington State in 2004, the number of escaping salmon has decreased in recent years. **Table 2** shows Washington State and British Columbia escape events in number of salmon.

Escaped Atlantic salmon adults show up in commercial and recreational catches in Washington, British Columbia and Alaska **(Table 3)**. There is one documented instance of an Atlantic salmon caught in the Bering Sea (Brodeur and Busby 1998). For further information on interceptions in Alaska (Seeb 2003), go to http://www.psmfc.org/ans_presentations/SeebJ.pdf and for British Columbia, Washington and Alaska escapes and interception data, go to http://www.psmfc.org/ans/atlantic-salmon-data.html.

Of significant note, indications are that Atlantic salmon escapees have successfully spawned in the wild in British Columbia **(**Volpe *et al*. 2000). Juvenile salmon were found on Vancouver Island in the Tsiska River in 1998, as well as in 1999 and 2000. Juveniles have also been found in the Amor de Cosmos (1999-2000) and Adams River (1999). There have been concerns raised about competition between steelhead and Atlantic salmon juveniles (Volpe 2000). However, Fleming (2005) points out that "Atlantic and Pacific salmon do not interbreed successfully. If escapees find themselves on the opposite coast, this substantially reduces the likelihood that they will ecologically overwhelm local salmon populations." However, concerns remain that if escape events continue, that at some point the constant propagule pressure[2] could result in the establishment of a viable Atlantic salmon population. In reviewing the literature, we did not find any further reports of Atlantic salmon successfully spawning on the West Coast in the wild (i.e., discovery of wild juveniles) since the 2000 sightings.

Since 2003 WDFW, with funding from Pacific States Marine Fisheries Commission (PSMFC), has been assessing the presence of Atlantic salmon in selected freshwater streams primarily using snorkel surveys. As of June 30, 2005 a grand total of four hundred sixty two snorkel and spawning surveys have been completed in one hundred and twenty-two streams and rivers (**See Appendix 4**). In 2003, an estimated 1,000 to 2,000 Atlantic salmon juveniles were found in Scatter Creek (Chehalis River basin) (**See Appendix 3)**. Three Atlantic salmon juveniles were also found in Cinnabar Creek (Cowlitz River basin). The source of the Scatter Creek fish was the Cypress Island Atlantic Salmon Smolt Production Facility. According to WDFW, there is no evidence that these fish were the wild progeny of escaped pen-reared Atlantic salmon. The Cinnabar Creek fish were also from an Atlantic salmon hatchery. In 2004, snorkelers found one juvenile fish in Scatter Creek and none in Cinnabar Creek. Scoop traps on both the Chehalis and Cowlitz Rivers have captured Atlantic salmon for a number of years (**See Appendix 3**). There is no evidence to date that these fish are wild progeny.

In 2004, Alaska Department of Fish & Game (ADFG) biologists surveyed three streams: the Situk River (Yakutat), Ford Arm (Sitka) and Ward Creek (Ketchikan). Although adult Atlantic salmon have been found in these streams in past years, the ADFG survey did not find the presence of either juveniles or adult salmon (Piorkowski 2005).

Table 2. Number of Atlantic salmon escaping from Washington and British Columbia fish farms, 1996 through 2005 (to date).

Year	Washington State (1)	British Columbia (2)
1996	107,000	53,104
1997	369,000	56,891
1998	22,639	91,168
1999	115,000	35,730
2000	0	68,947
2001	0	57,968
2002	0	18,380
2003	0	ND
2004:	24,552	39,400 (3)
2005	2,500	ND

(1) Atlantic salmon
(2) Aggregate of Atlantic and Chinook salmon juveniles and adults
(3) Unconfirmed by DFO

[2] The total number and frequency of pests arriving at the same time is termed the "propagule pressure" and has been directly linked to the likelihood of establishment when environmental conditions at the recipient site are conducive to the survival of adult or other life-stages (Underwood and Fairweather 1989; MacIsaac et al. 2002; Occhipinti-Ambrogi and Savini 2003).

Table 3. Marine and (Freshwater) Captures of Adult Atlantic Salmon in Washington, British Columbia and Alaska

Year	Washington (1)	British Columbia (2)	Alaska (3)
1987		1 (1)	
1988		106 (0)	
1989	52	8 (0)	
1990	453 (7)	2 (3)	1
1991	970 (58)	31 (8)	7
1992	157 (9)	349(48)	2
1993	167 (83)	4,543 (23)	27
1994	338 (40)	1,037 (50)	27
1995	128 (79)	678 (57)	23
1996	138 (39)	673 (211)	135
1997	2,119 (152)	2,664 (129)	77
1998	25 (23)	136 (90)	155
1999	31 (11)	190 (184)	19
2000	15 (1)	7,834 (131)	81
2001	20 (0)	179 (116)	35
2002	2 (0)	562 (40)	6
2003	0	ND	3
2004	8	ND	1

(1) Washington Department of Fish and Wildlife: Commercial and WDFW Hatchery Recoveries, sport catch not included.
(2) Department of Fisheries and Oceans, Canada
(3) Alaska Department of Fish and Game

V. Habitat Impacts

Net pen marine aquaculture operations directly release waste and uneaten food into the environment, which impacts both water quality and the benthos. According to Goldburg *et al.* (2001), there is a wide body of literature that documents levels of organic matter underneath cage operations that can change the chemical and biological structure of the sediment.

Below is an excerpt from a review on this issue by Gardner and Peterson (2003):

- Despite recognition of environmental impacts of salmon farming on the seabed, generally, there appears to be no evidence of impacts on wild salmon. In theory, however, indirect effects on wild salmon related to changes in the food chain, as well as cumulative effects, are possible.

- Wild salmon could be negatively impacted if disposal of diseased morts or blood water coincides with their migration or spawning activity. This was one of the primary concerns of those who [unsuccessfully] sought the court injunction against possible pollution of the Fraser River by disposal of fish farm morts and blood water in early 2002. However, at other times and places, it is unlikely that diseases would be transmitted to wild fish from infected farm morts or blood water.
- Because wild salmon are migratory, they are unlikely to be exposed to antibiotic residues from salmon farms at levels that would be harmful. Similarly, the toxic effects of algal blooms are unlikely to affect wild salmon.

Hardy (2000) points out that a salmon farm of 200,000 fish releases as much fecal solids per day as 62,595 people.

Waknitz, *et al*. (2002) says that dissolved nitrogen that is added to the water column from salmon farms is essentially not measurable more than nine meters away from the perimeter of the farm. He also cites several studies that show there is no measurable effect on phytoplankton production near salmon farms, even in countries that have substantial development of salmon farms. Additionally, salmon farms in Puget Sound had little to no effect on levels of dissolved oxygen (DO) in the water column immediately adjacent to the farms. Heinig (2000) reported the following about the benthic habitat impacts from salmon aquaculture facilities in Maine:

- Several studies at abandoned salmon aquaculture sites have shown that substantial recovery of the benthos occurs within a relatively short time, *i.e.* twelve to eighteen months, after abandonment. We should therefore take the necessary time to develop environmental regulations that are protective of the environment and its living resources, but also realistic and reasonable.
- … the benthic data presented [in this document] support the conclusion that impacts to the benthos resulting from finfish net-pen aquaculture operations are generally confined to the immediate vicinity of the net-pens, *i.e.* within 30 meters of the net-pens. This conclusion is not unique … to Maine. Findlay *et al.* (1995) arrived at a similar conclusion after intensive study of a site off of Swans Island, Maine. Crawford *et al.* (1999) also reached the same conclusion after analyzing benthic data from salmon farms in Tasmania.
- These results continue to support the conclusion that the effects of the net-pen operations on relative diversity of the benthos are generally confined to within 60-80 meters of the structures.
- Despite the numerous studies, monitoring efforts and discussions throughout the world over the past two decades concerning the environmental impacts of aquaculture, specifically salmon net-pen aquaculture, the determination of what constitutes acceptable and unacceptable impacts remains generally undecided and controversial. Consequently, the establishment of industry performance standards and definition of the mixing zone in which those standards must be met has been exceedingly difficult.

Alston *et al.* (2005) conducted an environmental evaluation of open-ocean submerged cages in Puerto Rico to assess possible environmental effects of the culture of mutton snapper (*Lutjanus analis)* and cobia (*Rachycentron canadum)* in submerged open-ocean cages. Their results indicated there was no evidence of anaerobic sediments beneath the cages, that inorganic nitrogen near the cages was similar to background levels and that macroinvertebrates populations and sediment were only affected directly beneath the cages just before harvest when feeding rates were highest. Costa-Pierce and Bridger (2002) reviewed benthic impact studies from around the world (**Appendix 2**). Most of these studies were done in nearshore or protected aquaculture sites. Two reports of monitoring open ocean aquaculture sites in the U.S. provided no evidence of benthic impact from open ocean operations (Bybee and Bailey-Brock 2003; Grizzle *et al*. 2003).

In the U.S., stricter effluent regulations on marine net-pen farming (e.g., treatment of effluent) are unlikely at this time. In 2004, the U.S. Environmental Protection Agency (EPA) released new guidelines for fish farms entitled, "Effluent Limitations Guidelines and New Source Performance Standards for the Concentrated Aquatic Animal Production Point Source Category." The standards do not set numerical limits on total suspend solids from net-pens. Rather, EPA guidelines require operators to use best management plans (e.g., feed management and solids management plans). The EPA said that because of the nature of the wastes generated from net-pen facilities, they "did not identify any advanced treatment technologies or practices to remove additional toxic and non-conventional pollutants that would be economically achievable on a national basis beyond those already considered."

VI. Disease Transfer

Concerns have been raised about disease transfer from farmed to wild stocks. Weber (2003) states that "In the crowded conditions of net-pens, pathogenic organisms that occur at low levels in the wild, or not at all, may reach epidemic proportions. In addition to killing tens of thousands of farmed salmon each year, disease and parasites can be transferred to wild fish populations."

There are several studies however, that do not paint as ominous a picture. According to Waknitz, *et al*. (2002) in their review of potential disease impacts from farmed salmon on Puget Sound Chinook and chum salmon wild stocks:

- The expectation that Atlantic salmon will increase current disease incidence in wild and hatchery salmon is low.
- There is little risk that existing stocks of Atlantic salmon will be a vector for the introduction of an exotic pathogen into Washington State.
- There is little risk that the development of antibiotic-resistant bacteria in net-pen salmon farms or Atlantic salmon freshwater hatcheries will impact native salmonids, as similar antibiotic resistance often observed in Pacific salmon hatcheries has not been shown to have a negative impact on wild salmon.

Gardner and Peterson (2003) raised some concerns of the potential threat posed by diseases from fish farms:

> **Bacteria:** Wild Pacific salmon are somewhat vulnerable to pathogenic infections from bacteria even though they are generally well adapted to the bacteria found in B.C.'s coastal waters.

> The concern over the potential for transfer of furunculosis from farmed to wild salmon is warranted despite the lack of direct evidence, but the effective use of vaccines substantially reduces the risk. Antibiotic resistance caused by the use of antibiotics on salmon farms does not appear to create risks to wild salmon. Bacteria pose the lowest risk to wild salmon, among the three fish health issues considered.
>
> **Viruses:** The potential for farm sources of viral pathogens to increase infection of wild fish is reduced by the natural resistance of Pacific salmon to enzootic viruses. As well, the literature does not provide evidence of viruses that have caused problems at farms having negative effects on wild salmon. Nevertheless, migrating salmon could be exposed to viruses such as infectious hematopoietic necrosis (IHN) from farms at levels higher than those to which they are accustomed; and in other jurisdictions, infectious salmon anaemia (ISA) has been found to transfer from farms to wild fish. The risk that the exposure will be effective enough to cause infection increases when farm sites provide a reservoir for the virus, especially if diseased fish are not culled. Good husbandry and lower stocking densities on the farms can reduce the threat that salmon farms will act as reservoirs of viruses by making farm fish less vulnerable to infection; however, these efforts are currently limited by the lack of effective treatments for viruses. The level of risk posed to wild salmon by viruses of farm origin is intermediate to the higher risk from sea lice and the lower risk from bacteria.

Freshwater salmon hatcheries may also provide some insight into the disease transfer risk to wild fish posed by fish being put into crowded conditions. With the exception of erythrocytic inclusion body syndrome, the origins of pathogens in hatcheries are often generated from wild fish through water supplies and other transmission means (CBFWA 1996). Another study indicates that the incidence of pathogens in naturally spawning fish is higher than in hatchery fish (Elliot and Pascho, 1994). According to Gardner *et al*. (2004):

> No studies illustrating negative *fish health interactions* between enhanced and wild salmon could be found through [our] research. Nevertheless, the potential for disease transfer between enhanced and wild fish does exist since conditions in hatcheries can promote the spread of disease, which in theory, can then be transferred to wild fish through water or fish-to-fish.

VII. Sea Lice

It is known that marine salmon farms have contributed sea lice (*Lepeophtheirus sp.*) to wild fish and that sea lice can kill juvenile fish, even at low infestation levels, and there is suggestive evidence of impacts to wild populations (Gallaugher *et al*. 2004). Krkosek *et al*. (2005) found that infection in chum and pink salmon (*Oncorhynchus gorbuscha*) that were near a fish farm was 70 times greater than natural levels and exceeded ambient levels for 30 kilometers along two wild salmon migration routes. However, the Association of Aquaculture Veterinarians of British Columbia (AAVBC 2005) called the mathematical scenario put forth by Krkosek et al. of how sea lice might be transmitted from farmed salmon to wild salmon as “too simplistic in its approach and therefore potentially seriously misleading in its conclusions.”

Also, the work of Morton (2005) calling attention to the negative impacts of sea lice on wild stocks in British Columbia cannot be ignored. Further expansion of the Norwegian farmed Atlantic salmon industry will in part depend on limiting escapes from netpens (first priority) and reducing the sea lice impacts on wild fish (second priority) (Torrissen 2005). Other reviews also raise concerns on this subject (Garner and Peterson, 2003):

> Causality in the spread of sea lice from farmed fish to wild fish in British Columbia has not yet been proven to the highest standard of scientific scrutiny. However, the combination of scientific results from Europe, preliminary studies of lice on juvenile salmon in B.C., and knowledge of sea lice-salmon dynamics presents a body of compelling evidence that sea lice from salmon farms do impact wild salmon. The main areas of uncertainty relate to how large or severe impacts will be, rather than to whether or not they will occur. McVicar, summarizing a 1996 ICES workshop on sea lice, concluded that "lice from salmon farms will contribute to lice populations in wild salmonids, but the extent and consequences of this have not been quantified." (McVicar 1997, p.1101)

Since 2003, Fisheries and Oceans, Canada (DFO) has conducted a marine monitoring program to determine the incidence and severity of sea lice infection rates in juvenile salmon in the Broughton Archipelago, British Columbia area, and to examine whether juvenile salmon migration corridors exist in the complex passages in that region. One objective of this study is to track the movement of buoyant particles through circulation models (DFO 2005):

> These particle tracking experiments have the potential to aid in our understanding of the transport and dispersion of parasitic organisms such as sea lice from different point sources in the region. The data required to validate the circulation models will be collected in 2005 by placing additional current meters in key locations in the Broughton. In addition, additional river discharge, wind and oceanographic data will be collected. Once the credibility of the circulation model has been established, particle tracking experiments that simulate transport and dispersion under a variety of scenarios can be used to test hypotheses and permit a better understanding of dispersal and ecology of sea lice.

The Canadian group Aquanet[3] is also in the process in developing a risk factor model to estimate the impact of sea lice infestation from fish farms on native stocks. Go to http://www.aquanet.ca/English/research/ei18_04.php for further information.

British Columbia's Ministry of Agriculture, Food and Fisheries requires Atlantic salmon farmers to monitor for sea lice on a monthly basis. To see monitoring results go to http://www.agf.gov.bc.ca/fisheries/health/Sealice_monitoring_results.htm

[3] AquaNet is Canada's research network in aquaculture. It was established in 1999 as a collaborative research network involving universities, industry, government and non-government organisations, with an annual budget of $3.6 million.

VIII. Chemicals and Therapuetants

The chemical malachite green (dye) has been used to treat fungal infections and parasites on farmed fish. It gained popularity as a cheap alternative to more expensive treatments. Considered to be a potential carcinogen, it is banned in the United States, Canada, and widely around the world. Though malachite green is banned in Chili, it was found repeatedly in their farm-raised salmon between 2002 to 2004. In June 2005, in two separate incidents, malachite green turned up in farm-raised Chinook salmon in British Columbia. It has also turned up in Slovakia and in wild British Columbia Chinook salmon (DiPietro and Fiorillo, 2005).

Fish farm antibiotic and pesticide use has also raised concerns about impacts to natural ecosystems and human health. (Goldburg *et al.* 2001). The Washington Fish Growers Association (2002) claims that antibiotics and pesticides play an essential role in the integrated management of fish health in aquaculture and that the extent of use in the industry is declining. They go on to say that the reduction in antibiotic use can be attributed to better husbandry and the targeted use of antibiotics and vaccines.

The Province of British Columbia's Salmon Aquaculture Review (1997) concludes the following on antimicrobial drugs and pesticides:

- No direct evidence of adverse human or fish health effects of antibiotic use in salmon farming could be found. The transference of antimicrobial drug resistance from marine or aquatic organisms to humans is a hypothetically possible yet an unproven concern.
- The risk of human exposure to antimicrobial drug residues in marketed farmed fish appears to be slightly higher than for terrestrial species. The probability of human exposure to tissue residues of antimicrobial drug residues in wild species captured near fish farms is low and exposure will be largely restricted to areas in close proximity to farms and within narrow time frames. However, drugs used by aquaculture operations could move beyond the immediate vicinity of treated farms if fish escape before the drug withdrawal period expires or if mobile species such as wild fish or crustaceans ingest sufficient drug to develop harmful tissue residues. The likelihood of a severe adverse human health effect resulting from the ingestion of seafood with residues of antimicrobials used in B.C. is also low.
- Some evidence supports the contention that pesticide use in marine and aquatic environments can have lethal and sub-lethal effects on individual animals.
- As B.C. has not allowed pesticide use in its salmon farms, the negative effects of pesticide use remains a potential, yet unrealized risk. There are reports of non-target effects associated with ivermectin use [for sea lice], but no reports were found regarding ecological impacts. Data regarding the extent of use of ivermectin in B.C. was unavailable, thus preventing an evaluation of the risks its use presents in B.C.

The publication "Fishy Business" (Marshall 2003) says the following about antibiotics and pesticides:

> Since water can flow freely from net cage fish farms to the marine environment and vice versa, these chemicals [antibiotics, pesticides] accumulate beneath fish farms and are distributed

more widely into the marine environment due to ocean currents. This is of particular concern with respect to pesticides intended to kill sea lice (like ivermectin and emamectin benzoate, also called SLICE). These chemicals are toxic to lobsters, a relative of the sea lice (both are crustaceans). Other crustaceans—including commercially important species such as prawns, crab, and shrimp—are also at risk from these chemicals. Not surprisingly, shellfish harvesters in both BC and Scotland oppose the application of these pesticides.

IX. Colorants

The carotenoids, astaxanthin and canthaxanthin, are needed by salmon for healthy growth, metabolism and reproduction, but they cannot produce them in the body. In the wild, salmon consume small algae-eating crustaceans, such as shrimp to obtain their pink flesh color. Farm-raised fish are supplied with carentoids in their feed to obtain the flesh pink color. Federal law requires farmed salmon to be labeled "color added" if they contain carotenoids. Since this is a food additive, concerns have been raised on its impacts to human health. A link has been found between high canthaxanthin intake and eyesight problems (deposition on the retina). The European Commission (2003) adopted a directive to reduce the authorized level of canthaxanthin in animal feed due to the health risk to human consumers of the animal products. According to the National Fisheries Institute (2003), some literature indicate that humans would need to ingest "large" quantities of canthaxanthin – 3 .3 lbs of raw salmon [or its equivalent] a week in order to have adverse affects (NFI 2003).

X. Ecosystem – Fish Feed

Aquaculturally-raised fin fish are primarily fed fish meal composed of "bait fish", such as anchovy anchoveta, herring, menhaden, capelin, and sand eels. These small pelagic species are important to the marine ecosystem, as they are prey for fish, birds and mammals. There have been concerns raised that overexploitation of these lower trophic species is occurring and could result in an "ecological time bomb" (Tuominen and Esmark 2003).

The Food and Agriculture Organization (FAO) (2004) reports that seven of the top ten species, accounting for about 30 percent of the world capture fisheries production (quantity), are either fully exploited or overexploited. Four of those seven species are anchoveta, Japanese anchovy (*Engraulis japonicus*), capelin and Atlantic herring (*Clupea harengus*), all of which are used to produce fish meal and oil. Major increases in catch cannot be expected from these species. In addition, Zaldivar (2004) estimates that fish meal demand for aquaculture will increase to 48 percent of total demand, up from the current 34 percent, and that fish oil demand will grow from the current 54 percent to 97 percent by 2010[4]. Nash (2004) points out that the likelihood of success in the development of alternative fish feeds is considerable, given ongoing research. Tacon (2004) asserts that the long term usage of fish meal and fish oil by the aquaculture industry will actually decrease by 20.2 percent and 6.9 percent respectively by 2010 given the following:

> The main reason why the use of fish meal and fish oil by the aquaculture sector is expected to decrease in the long term is a combination of increasing economic/market pressures placed on the fish meal and fish oil manufacturing industry and animal feed compounder

[4] All the above-mentioned figures consider a partial substitution of these products by rape seed and soy meals for fishmeal, and by linen oil and rapeseed oil for fish oil.

on the one hand, and the consequent search, development and use of lower cost and more sustainable alternative dietary protein and lipid sources by the commercial aquafeed manufacturing sector on the other hand, so as to maintain profitability and sustain the growth of the feed-dependent aquaculture sector.

As mentioned earlier, fish farmers are beginning to incorporate plant proteins such as wheat, soy meal and corn gluten meal into commercial trout and salmon diets. Feed producers say that the plant protein ingredients reduce the cost of feed and pressure on wild stock small pelagic fish species (Sabaut 2002). To that end, in July (2005) Norway, the National Institution of Nutrition and Seafood Research announced a project called "Aquamax" that aims to develop a plant based "sustainable" aquaculture feed. Partners in the venture include China, and the European Union (Olsen 2005). At issue is whether reducing the dependence on fish meal and fish oil in combination with better feed conversion ratios[5] will result in a reduced need for small pelagic fish in an expanding industry. Also, will fish oil and meal not used by the aquaculture industry instead end up as livestock feed, resulting in continued fishing pressure?

Another option is to raise fish that are lower on the food chain and do not require high proportions of fish meal and oil in their diet (e.g. tilapia). Examples of FCRs can be found in Table 4 (Sabaut 2002 and National Aquaculture Council {No Date}).

Table 2. Feed conversion ratios for 2000 and 2010 (predicted) for various aquaculture species (Sabaut {2002}, National Aquaculture Council* {No Date}, and Ottolenghi et al. * {2004}).

Species	Food Conversion Ratio	
	2000	2010
Carp	2.00	1.50
Tilapia	2.00	1.50
Shrimp/Prawn	1.80	1.60
Salmon	1.40	1.10
Marine fish (1)	2.20	2.00
Trout	1.40	1.10
Catfish	1.60	1.40
Milkfish	2.00	1.60
Other marine fish (2)	2.20	2.00
Eel	2.00	1.20
Tuna*	10 – 30	ND

(1) Sea basses, breams, yellowtail, groupers, jacks and mullets (2) Flatfish, cod and hake

[5] Feed conversion ratio (FCR) is calculated from the number of kilos of feed that are used to produce one kilo of whole fish.

XI. Sablefish (Black cod)

Limited sablefish culture has started in British Columbia (Sablefish Farms Ltd.) and concerns have been raised that farmed sablefish operations and escapes (e.g., diseases and parasites) will impact wild sablefish stocks. In 2004, the Canadian Sablefish Association, a group representing commercial sablefish fishermen, failed in court to stop the net-pen sablefish operation. In August 2004, Senator Lisa Murkowski (R-AK) wrote a letter to the Canadian Ambassador to the United States urging the Canadian government to stop a proposed transfer of 30,000 juvenile black cod to Canadian fish farms for grow out, and to delay any future sales of juvenile black cod to B.C. fish farms pending more scientific studies. This appeal was unsuccessful. Only one sablefish farm is in operation as of May 2005 (DiPietro 2005c). Thirty-seven sablefish sites have been approved around Vancouver Island, and a hatchery is scaling up production on Salt Spring Island (one of the Gulf Islands) to provide juvenile sablefish for the developing B.C. industry. The goal of the company is to raise 2 million fingerlings within five years.

There are concerns that sablefish culture will negatively impact wild capture sablefish prices similar to what happened with wild and farmed salmon. According to Huppert and Best (2004):

> At the very least, we can expect a moderate level of sablefish culture to depress prices in the key Japanese market. At worst, the price of Alaskan sablefish will drop to between $1.39 and $1.15 per pound over the next 5 to10 years, a 45 percent to 33.5 percent drop. Canadian prices will drop to the range of $2.06 to $2.51 C$/lb. Whether the farming of sablefish presents a serious threat to the sablefish fishery depends upon the marketing and technical issues discussed [in this document]. To remain a vibrant and profitable enterprise, the fishing industry may need to develop a marketing strategy to sell its product as different and especially desirable. Finally, and most speculatively, if the sablefish farming sector expands in British Columbia, a coordinated effort between the fishing and farming interests to control that expansion and to expand marketing efforts could forestall the more dire predicted effects on market price.

XII. Tuna

Tuna culture, primarily bluefin tuna (*Thunnus thynnus*), has expanded significantly in the past 10 years. Tuna culture is a capture-based aquaculture operation[6], although efforts are underway to breed tuna in captivity (Garcia 2005). Impacts from tuna farming could include disease transmission, overfishing and habitat impacts. Tuna also have high food conversion ratios (15-30:1). The World Wildlife Fund (2005) raises concerns about imported feed fish for tuna grow out operations in the Mediterranean:

> During their captive period, which lasts for about 6 months, farmed tuna are fed on an exclusive basis, large quantities of whole bait fish (small and medium pelagic species). The systematic dumping of thousands of tonnes of exotic whole fish into the Mediterranean marine

[6] Capture-based aquaculture uses wild-caught stocks that are grown-out or fattened in captivity; examples include eels, groupers, tunas and yellowtails. Worldwide the production value of these 4 species in 2000 was $1.7 billion (US) (Ottolenghi et al. {2004}).

> ecosystems constitutes a first order environmental threat due to the significant risk of spreading new diseases to the native fish populations. The subsequent threat to local purse seine fishing fleets that target small pelagic fish is also obvious – as well as to the wider marine ecosystems – where small pelagic populations play a key functional role.

RubVita and Mar (2005) conducted a study to evaluate the particulate organic waste output originated by tuna farming and reported the following:

> The settling rate of particulate wastes was approximately 14 times the background level. The study suggests that particulate waste output from tuna fattening is qualitatively and quantitatively different from that produced in the culture of other Mediterranean species such as sparids [porgies]. The underlying sediments may become enriched under the net cages. This may have important consequences for sediment biogeochemistry with relatively local impacts. Another study was carried out to identify changes in sediment characteristics, macrofaunal assemblages and the spatial and temporal scale of environmental impact[s] due to tuna farming activities. The sediment analyses, analyses of benthic community and toxicity tests carried out in the present work indicated there was a lightly affected zone that extended approximately 220 m around the farm. Dramatic impact was only detected under the tuna cages. The fallow period produced partial remediation of the area affected, except in the sediment directly underneath the cages, where the succession towards unpolluted communities was incomplete.

The FAO (2004) raises concerns about capture based aquaculture:

> The siting and operation of Capture Based Aquaculture (CBA) farms can be problematic. Significant among the environmental and safety issues still to be addressed by the CBA sector is the lack of adequate, cost-effective environmental assessment systems that would ensure good site selection. The latter is essential in order to minimize sediment build-up, thereby preventing eutrophication and avoiding the risk of contaminating farmed products (e.g. with dioxins and PCBs).

Additional concerns have been raised about "uncontrolled" bluefin tuna ranching in the Mediterranean and its impact on Atlantic Ocean stocks. Atlantic bluefin are a wide ranging pelagic species which crisscross the Atlantic Ocean, making them exceedingly difficult to manage. After being harvested in the Eastern Atlantic, they are placed into net-pens for grow out. The fear is that countries, such as Morocco, Tunisia, and Libya, are underreporting their catch of their quota (e.g. overharvesting) as set by the International Commission for the Conservation of Tunas (ICAAT) (McGovern 2004).

XIII. Issues to be Addressed

1. Sea lice transmission from Atlantic salmon fish farms to wild stocks continues to be an issue that needs resolution.

2. The likelihood of Atlantic salmon escaping from fish farms and successfully breeding and establishing feral stocks on the West Coast is very low. Though escape events have trended downward in recent years, regulatory agencies in Washington and British Columbia need to revisit regulations so that farmers are held accountable, perhaps financially, for these escape events.

3. Technology aimed at development of alternative sources of protein (e.g., plant based) for fish meal and oil appears promising. Increased reliance on alternative sources of fish feed will be critical for continued global expansion of aquaculture, allaying concerns about both the overharvest of small pelagic species and contaminated farm raised product.

4. Cumulative ecosystem-wide water quality impacts from fish farming needs further study.

5. Concerns about capture based aquaculture, especially with regard to impacts to apex predators stock health (e.g. tuna), deserves further attention.

6. Further peer reviewed research of contaminant levels in farmed and wild fish is needed.

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Appendix 1: Levels of PBDEs and PCBs (in ng/g wet weight) for wild caught salmon, rockfish (*Morone saxatilis*), bluefish (*Pomatomus saltatrix*) and farm-raised Atlantic salmon*, from Hayward *et al.* (2004).

	PCBs	**PBDEs**	**Ratio (PCB/BDE)****
Wild Alaskan King salmon (MD)	5.8	0.71	8
Wild Alaskan King salmon (DC)	5.4	1.2	4.5
Wild Alaskan King salmon (MD)	5.8	0.71	8
Wild Alaskan King salmon (DC)	5.4	1.2	4.5
Wild Alaskan Coho salmon (MD)	0.35	0.04	9
Wild Alaskan Coho salmon (MD)	2.9	0.24	12
Farmed Atlantic salmon (DC)	1.8	0.21	8.6
Farmed Atlantic salmon (MD)	12	1.2	10
Farmed Atlantic salmon (MD)	12	1.5	8
Farmed Icelandic salmon (MD)	8.0	0.49	16
Rockfish (DC)	22	1.7	13
Rockfish (MD)	35	3.7	10
Rockfish (MD)	39	2.3	18
Rockfish (DC)	93	7.2	13
Rockfish (MD)	120	14	9
Bluefish (NC)	800	36	22
Bluefish (DC)	140	6.5	22
Bluefish (MD)	106	7.4	14
Bluefish (MD)	12	0.61	20
Bluefish (MD)	280	24	12

***Sample Size:** A single bluefish sample was collected representing a composite of 12 commercial fillets, of the four Individual farm-raised Salmon: four were wild caught salmon (as identified in market), three bluefish and four "rockfish" fillets were collected as fillets. (Purchased East Coast). **Region** where fish was purchased; DC=Washington, DC, MD=Maryland, NC=North Carolina.
****Ratio (PCB/BDE):** The ratio or the slope between the classes of persistent compounds in fish species could indicate trends for contamination in a given area providing useful information for environmental management.

Appendix 2. Studies of the degree of benthic 'halo' region impact associated with aquaculture operations (Costa-Pierce and Bridger 2002)[7].

Study	Benthic Impacts Reported
Mattsson and Linden (1983) Species: Mussel (*Mytilus edulis)*	Species composition changed up to 20 m away from mussel farm
Brown *et al*. (1987) Species: Atlantic salmon	Species composition changed up to 15 m away from cage edge
Gowen *et al*. (1988) Species: ?[8]	Species composition changed up to 30-40 m away from cages
Lumb (1989) Atlantic salmon	Impacts restricted to within 50 m of cage edges and dependent on seabed type
Ritz *et al*. (1989) Salmonid	Macrofaunal community under the farm adopted an undisturbed condition 7 wk post-harvest of farm stock
Kupka-Hansen *et al*. (1991) Salmon?	Species composition changed up to 25 m away from cages
Weston (1990) Salmon?	Farm effects on sediment chemistry evident up to 45 m from the farm; species composition changed at least to 150 m away from cages
Johannessen *et al*. (1994) ?	No influence of fish farming could be detected 250 m away from cages
Krost *et al*. (1994) Salmon?	Affected area extended 3-5 m from the fish farm margin
Wu *et al*. (1994) ?	Impacted area extended to 1000 m with industry using trash fish as feed and poor water flushing exists
McGhie *et al*. (2000) ?	Farm wastes largely restricted to area beneath sea cages; most of the sediment organic input from feces; and 12-month fallowing period sufficient to return site to pre-farm oxic conditions
Morrisey *et al*. (2000) Atlantic Salmon	Large temporal & spatial variabilities depending on water velocities; recovery times estimated between 3-12 years
Dominguez *et a*l. (2001) Seabream *(Sparus aurata)*	No affect on physical and chemical sediment characteristics due to fish farm operation in high average water current velocity (6 cm/s) site.

[7] For the citations used in this table please go to Riedel and Bridger (2004) http://www.masgc.org/oac/toc.html
[8] ? = we were unable to determine the fish species used in the study.

Appendix 3: Freshwater juvenile Atlantic salmon recoveries, Washington and British Columbia.

Freshwater Juvenile Atlantic Salmon Recoveries

	Washington (1)				**British Columbia (2)**
			Snorkel Survey		
Year	**Mayfield Trap (Cowlitz)**	**Chehalis River Trap**	**Cowlitz**	**Chehalis**	
1987		18			
1988		22			
1989					
1990					
1991					
1992	18				
1993	17	5			
1994	49	8			
1995	58	24			
1996	8	183			54
1997	2	5			26
1998	25	7			114
1999	59	9			150
2000	125	22			12
2001	18	0			3
2002	12	17			8
2003	n/a	3	3	1000-2000	
2004	N/D	6	0	1	
2005					
TOTAL	**391**	**329**	**3**		**367**

(1) Source: Washington Department of Fish and Wildlife. **Note:** It is impossible to estimate the number of juvenile Atlantic Salmon that have actually migrated out, because the scoop traps that are used only reach 2-3 feet into the water column and do not span the entire river. Juvenile Atlantics have also been reported in the Tilton River, in Cowlitz County, where there is another hatchery (Cinnabar Creek).

(2) Source: Department of Fisheries and Oceans, Canada

Appendix 4: List of all rivers and streams that have been surveyed by WDFW for Atlantic salmon juveniles and adults (2003-2005). Those with an asterisk (*) or a pound sign (#) have had one or more foot surveys or float boat surveys conducted seeking returning adults.

Black River	Hamm Creek	Salt Creek
Bogachiel	Hill Cr. *	Samish River
Boulder Creek	Hoko River	Satsop River (East Fork)
Buck Creek	Humptulips River	Satsop River (Middle fork)
Burley Creek	Independence Creek	Satsop River (West Fork)
Calwah River	Issaquah Cr	Sauk River
Canyon Creek	Jackman Creek	Scatter Creek
Canyon River(West Fork Satsop)	Johns River	Seiku River *
Carbon River	Kalama River * #	Sherman Creek
Cascade River	Kapowsin Creek	Skagit River
Cedar Creek *	Kennedy Creek *	Skokomish River *
Cedar River	Klickitat River	Skookumchuck River * #
Chambers creek	Lewis River * #	Skykomish River *
Chehalis River * #	Lilliwaup River	Snoqualmie River
Chehalis River (East Fork)	Lummi River	Solduc *
Chehalis River (West Fork)	Lyre River	South Prairie Creek
Cinebar Creek	Mashell River *	Spring Creek
Clark Cr *	Mccallister Creek	Stillaguamish River (North Fork *
Coal Mine Creek	McDonald Creek	Sultan River
Cornell Creek	Minter Creek	Sund Cr *
Coulter Creek	Morse Creek	Tahuya River
County Line Cr	Nemah River(North Fork)	Taylor Creek
Coweeman River	Newaukum River #	Tilton River *
Cowlitz River * #	Nisqually River *	Tolt River *
Decker Cr	Nooksack River	Union River *
Delezene *	Ohop Creek	Unnamed Creek
Deschutes River	Olequa Creek	Vesta Creek *
Dewatto River	Perry Cr	Voights Cr
Dry Bed Cr	Pilchuck River	Waddell Creek
Duckabush River *	Porter Creek *	Wildcat Cr
Dungeness River *	Puyallup River * #	Willipa River
Elk Creek	Queets River	Wishkah River *
Elwha River	Quilicene River	Woods Creek
Fennel Cr	Quinault River *	Workman Creek
Finch Cr *	Racehorse Creek	Wynoochee River * #
Garrard Creek	Rock Cr *	
Goble Creek *	Rock Creek	
Green River *	Rocky Creek	
Greenwater River *	Salmon River	