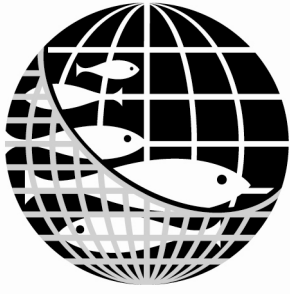


ISSN 1198-6727

**Ecological and Economic Impact
Assessment of Sablefish Aquaculture
in British Columbia**

*Fisheries Centre Research Reports
2005 Volume 13 Number 3*

ISSN 1198-6727



Fisheries Centre Research Reports

2005 Volume 13 Number 3

ECOLOGICAL AND ECONOMIC IMPACT ASSESSMENT OF SABLEFISH AQUACULTURE IN BRITISH COLUMBIA



Fisheries Centre, University of British Columbia, Canada

ECOLOGICAL AND ECONOMIC IMPACT ASSESSMENT OF SABLEFISH AQUACULTURE IN BRITISH
COLUMBIA

by

U.R. Sumaila, J.P. Volpe and Y. Liu

Fisheries Centre Research Reports 13(3)
33 pages © published 2005 by

The Fisheries Centre,
University of British Columbia

2259 Lower Mall
Vancouver, B.C., Canada, V6T 1Z4

ISSN 1198-6727

FISHERIES CENTRE RESEARCH REPORTS 13(3)
2005

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Ussif Rashid Sumaila, John Paul Volpe and Yajie Liu

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DIRECTOR'S FOREWORD

Once upon a time, there was a happy kingdom, ruled by a wise king with a merciful queen, and they had a beautiful daughter – which usually sets the stage for a story in which the kingdom is invaded by ruffians, the king and his queen die, and the daughter is taken captive – at least until the hero comes and re-establishes harmony.

British Columbia has a successful, well-managed fishery for blackcod. It is a fishery that is largely self-managed, i.e., the fishers are in charge, and though there is no king, there is harmony, at least as far as such things go in the real world.

Now there is talk of blackcod farming. If successful, this would increase supply and hence reduce prices – but only Japanese buyers would benefit, not their Canadian suppliers. But more importantly, farming blackcod would generate a high risk of parasite infection, and disease, something that is not needed along the BC coast, where salmon farming has already generated a parasite problem the extent of which we are only beginning to uncover – as it already did in Europe and everywhere else they are farmed.

Hopefully this report and the lessons it builds upon will help convince federal and provincial officials that in this case progress is served by not doing something – by not encouraging the emergence of blackcod farming in British Columbia.

So that, in our kingdom, there will be, for once, a happy ending.

Daniel Pauly
Director, Fisheries Centre UBC

ABSTRACT

The goal of this study is to undertake an assessment of the potential ecological and economic effects of sablefish *Anoplopoma fimbria* farming in British Columbia (BC). Sablefish aquaculture is a topical issue in BC due to the prospect of a major sablefish hatchery planned for Salt Spring Island, which would produce juveniles for the intended BC industry. This report analyzes available information in an effort to inform policy makers and the general public if and how development should proceed. If a common thread can be found in the published works on this issue so far, it is that empirical data are in short supply. Ecological data regarding wild sablefish are rudimentary at best, and of course aquaculture data are non-existent. As a result, authors, us included, rely to a great extent on the BC salmon aquaculture experience to frame the sablefish issues. While there will be many similarities, both economic and ecological, this is clearly not adequate to confidently flag the full array of emergent issues nor predict how they will manifest themselves. But clearly this is the sensible way to proceed in the given situation.

The following are some of the key findings of this study:

From an ecological perspective, the potential for negative interactions between wild and farm stocks is high. Further, because the sablefish knowledge base is narrow relative to that of salmon aquaculture, itself plagued with serious challenges, it is clear that timely diagnoses and successful remediation of the inevitable emergent problems is unlikely. We conclude that sablefish aquaculture development in BC is destined to proceed on a trial and error basis with coastal communities and BC's marine environment exposed to undeterminable risk.

A decrease in wild salmon landings followed the increase in salmon aquaculture. There was no corresponding decrease in wild salmon landings in Alaska, where a ban on salmon farming exists.

A decrease in the price of sablefish will ultimately follow an increase in sablefish supply to the market from aquaculture. This decrease will be at the expense of both sablefish farmers and fishers in Canada but beneficial to sablefish fish consumers, which in this case are mainly Japanese. Thus, benefits are exported while costs are entirely absorbed within Canada.

At low aquaculture production levels, small economic gains are possible if BC engages in sablefish farming under different ecological externality (impact) assumptions compared to salmon. However, gains quickly disappear as production increases towards anticipated levels.

Rather surprisingly, our study shows that a sablefish farming ban in BC would actually be beneficial to the province, if BC wild sablefish landings can be marketed in a way that would allow the province's landings to command a price premium of about 20-25%.

From the experience of salmon farming in BC, it appears that sablefish farming is unlikely to add to (i) BC and Canada's GDP, (ii) export earnings, and (iii) number of people employed in the sablefish sector of BC's economy.

PREFACE

Sablefish *Anoplopoma fimbria* (Pallas, 1814) aquaculture increased in profile dramatically in 2003-2004 largely due to the prospect of a major hatchery planned for Salt Spring Island, which would produce juveniles for the intended grow-out sablefish aquaculture industry in BC. This report reviews available information in an effort to inform policy makers and the general public if and how development should proceed. Ecological data regarding wild sablefish are rudimentary at best, and of course aquaculture data are non-existent. As a result, authors, us included, rely to a great extent on the BC salmon aquaculture experience to frame the sablefish issues. While there will be many similarities, both economic and ecological, this is clearly not adequate to confidently flag the full array of emergent issues, nor to predict how they will manifest themselves. For instance, the issue of sea lice was virtually absent in discussions regarding the BC salmon farming industry until after farms were implicated in the 2001 Broughton Archipelago pink salmon collapse, in spite of lice being a major ecological issue for European farms for over a decade. This serves to underscore a recurring theme in this and other examinations of the sablefish aquaculture issue: aquaculture development in BC has been fraught with unforeseen challenges – both economic and ecological. Some of these can fairly be called ‘catastrophic’. Such events have occurred in spite of salmon being arguably the most extensively studied fish in the world. In other words, voluminous a priori knowledge has not prevented dramatic, perhaps insurmountable challenges to industry. In contrast, the current state of knowledge regarding sablefish life-history, population biology and parasite or pathogen epidemiology is, relative to salmon, limited.

This report was written from the position that the overarching motivation driving sablefish aquaculture in BC is economic and not aimed at adding a net surplus of protein (the so called *Blue Revolution* argument) to local or foreign supplies. The Blue Revolution argument is often used to defend intensive culture of high-order carnivorous species but it appears indefensible. To date this has not played a prominent role in the BC sablefish aquaculture development debate and therefore is not considered here. Given the introduction of sablefish aquaculture is exclusively built on the premise of exploiting unrealized economic opportunities, we set forth to test the foundation on which this argument is built. In the first section, we discuss the ecological issues of farm escapees; this is followed by the second section on disease/parasite epidemiology. Of the many ecological issues associated with sablefish aquaculture, our discussions are limited to these two because they are the most prominent for informing the third section, which is the heart of this report - the economic analysis of sablefish aquaculture.

INTRODUCTION

Sablefish *Anoplopoma fimbria* (Pallas, 1814) are sleek, black-skinned fish from the cold, deep waters of the North Pacific, harvested mainly on the west coast of Canada and the United States. They belong to the family Anoplopomatidae (Sablefishes). Also known as blackcod or butterfish, sablefish reach a maximum size of 120 cm TL (Frimodt 1995), and maximum weight of 57 kg (Eschmeyer *et al.*, 1983). The fish has a long life span with a reported maximum age of 114 years. It is a marine species found in depths ranging to over 2700 m. In terms of its distribution, sablefish is found between 60° N – 28° N. It is found in the North Pacific, from the Bering Sea coasts of Kamchatka, Russia and Alaska southward to Hatsu Shima Island, southern Japan and Cedros Island, central Baja California, Mexico (www.fishbase.org).

Adult sablefish are found over mud bottoms, from about 300 to over 2700 m (Eschmeyer *et al.* 1983). Young-of-the-year juveniles are pelagic and found on the surface and near-shore waters (Armstrong 1996). The fish is generally sedentary, even though juveniles have been found to migrate over 2000 miles in 6 to 7 years (Armstrong 1996). Sablefish feed on crustaceans, worms and small fishes (Clemens and Wilby 1961).

Nearly all Canadian sablefish is harvested live in traps, ensuring a top quality product as well as virtually eliminating bycatch. A small portion of the Canadian harvest is caught by long-line gear. Sablefish is harvested offshore where virtually all the catch is bled, cleaned and frozen on board within minutes of coming aboard.

Wild sablefish have been harvested off the west coast of British Columbia, Canada, for more than 40 years. Before this, the Japanese distant water fishing fleet targeted Pacific sablefish for over a decade until 1977 when Canada declared a 200 mile Exclusive Economic Zone (EEZ). With increased market demand and increasing trap and longline fishing effort, the Canadian Department of Fisheries and Oceans (DFO) took steps, in 1981, to limit entry to the sablefish fishery. A limited entry scheme was implemented, which resulted in 48 vessels receiving sablefish licenses issued annually by DFO. The fishery was managed by opening on a specified date and then closing the fishery when the Department estimated that the TAC (Total Allowable Catch) was taken. Under this management approach, the fishery became shorter and shorter, shrinking to a mere 14 days in 1989 from 245 days in 1981, despite a 42% increase in the TAC. As the openings became shorter and shorter, the biological and economic waste that they entailed became apparent to all involved. In an effort to mitigate this waste, Individual Vessel Quota (IVQ) management was implemented in 1990. Stable annual catches since have led many to credit the IVQ system and identify the Canadian wild sablefish fishery as among the best-managed in the world. Wickham (2003) provides a lively discussion of what has been described as “a fishery that works”.

Against the backdrop of a sablefish fishery that is well managed, with stable catches, profitable fishing enterprises and healthy sablefish biomass, the big question is: what are the potential ecological and economic consequences of the introduction of sablefish farming in BC? This report reviews available information in an effort to inform policy makers and the general public if and how development should proceed; its major sources are: Auditor General of British Columbia (2000, 2004), Huppert and Best (2004), Leggatt (2001), PFRCC (2003), Robichaud *et al.* (2004), Sonu (1996), Steven and Fraser (2004). If a common thread can be found among these sources, it is that empirical data are in short supply. Ecological data regarding wild sablefish are rudimentary at best, and of course aquaculture data are non-existent. As a result all authors, us included, rely to a great extent on the BC salmon aquaculture experience to frame the sablefish issues. While there will be many similarities, both economic and ecological, this is clearly not adequate to confidently flag the full array of emergent issues nor predict how they will manifest themselves. But clearly this is the sensible way to proceed in the given situation.

The approach of the current report is to ask and address the following questions: What are the potential ecological impacts of sablefish aquaculture? What will happen to BC wild sablefish landings with the introduction of sablefish farming in BC? What will happen to the price of sablefish with the introduction of sablefish aquaculture in BC? Will BC achieve a net economic gain by engaging in sablefish farming? What will happen to BC employment in the sablefish sector with the introduction of sablefish farming? How will BC do with a ban on sablefish farming?

In the next section, we discuss the ecological issues related to farm escapees. This is followed by a discussion of the potential impacts from disease/parasite epidemiology. The final section, which contains the heart of this report, presents the economic analysis of sablefish aquaculture.

ECOLOGICAL ANALYSIS OF SABLEFISH AQUACULTURE

RISK AND POTENTIAL IMPACTS OF FARM ESCAPEES

The discussion in this section is based on the BC salmon farming experience and information quality control. Current expectations are that sablefish will be grown out in open net-pens very similar in type to those currently used for salmon. Further, it is anticipated that management and regulatory regime will also be very similar to that already in place for salmon. It is widely accepted that open marine net-pens do not afford complete containment and escape events do occur. The frequency and magnitude of escapes events on BC salmon farms is a matter of considerable debate. Despite the public profile and perceived importance of the issue, there are only two published reports in the scientific literature assessing the issue. Over a 214- to 260-day test period, losses in a Puget Sound chinook farm ranged from 8.4 percent to 38 percent of the net-pen population, averaging approximately 22 percent (Moring 1989). These data are nearly two decades old and it has been argued the evolution of net-pen technology in the interim would significantly lower these figures.

In 2000, independent scientist Alexandra Morton conducted an active survey of Atlantic salmon commercial captures in Area 12 (Broughton Archipelago). Her one-month active survey (August, 2000) showed 10,841 escaped Atlantic salmon were captured by commercial fishers (Morton and Volpe 2002). In contrast, the 'official' DFO Atlantic salmon capture tally for the entire year in 2000, across the entire BC coast, stands at 7,834 (DFO, 2003). Therefore the active survey of one small portion of the coast over a brief time period resulted in 41% more reported captures than DFO's coast-wide passive Atlantic Salmon Watch Program for the entire year. The implications are clear; passive surveys are not reliable instruments to assess farm escapes and, given this is the only effort to assess abundance and distribution of farm-escaped Atlantic salmon in BC's marine environment, it is impossible to infer how many Atlantic salmon are currently loose in coastal waters and therefore what associated impacts may be unfolding.

USEFULNESS OF PASSIVE SURVEYS

Shortcomings of passive surveys are particularly evident when reports of escapees from farms in BC are assessed (Table 1). Timely reporting of escape events is a required condition of all farm tenure agreements in BC. However this has not always been the case. A major escape of approximately 32,000 salmon from a farm in the Broughton Archipelago in 2000 went unreported until thousands of Atlantic salmon inexplicably turned up in commercial nets, prompting a subsequent report from the offending farm (Morton and Volpe 2002). Further, unlike farms in other jurisdictions, e.g. Washington State, farms in BC are located for the most part adjacent to wilderness coastlines. As a result farms operate largely in isolation, away from third party corroboration of reports.

Be that as it may, recent reporting trends of escape events on BC farms are out of place with those data from other jurisdictions. Table 1 summarizes escape data available from a variety of verifiable sources for major salmon farming jurisdictions. The apparent efficacy of BC farms in reducing escapes has grown from being consistent with the rest of the world (2001 and previous) to an order of magnitude more efficient (2002) to a resounding three orders of magnitude more efficient in 2003! This is curious given that the majority of farms in BC are operated in similar physical habitats and by the same companies dominating operations in the other countries – eliminating superior BC tenure location and operating procedures as an explanation.

Obviously, the most parsimonious explanation - like Atlantic salmon capture data - is that the reporting structure of escape events is inaccurate, lacking any mechanism for verification and/or evaluation of accuracy and precision. An independent assessment of the BC situation was jointly conducted by the World Wildlife Fund and the Atlantic Salmon Federation, which assessed the regulatory regimes and industry compliance in some major farm salmon producing countries (Porter 2003). On a 0 to 10 scale (0 being worst, 10 best) for adequacy of requirements for escape prevention and response plans and management systems, Canada ranked a '1' (Norway 9; Scotland 2). In adequacy for monitoring and enforcement of aquaculture systems and escape prevention and response plans, Canada ranked a '0.5' (Norway 5; Scotland 3). Chile was not included in the assessment.

Table 1. Comparison of recent production, reported escapes and estimated escape ratios for major salmon farming jurisdictions. Recent reporting in BC is very significantly out of step with other salmon farming jurisdictions despite similar environments and infrastructure. Note: BC is the only jurisdiction with publicly accessible time series escape data (to 2002). Escape ratio is Calculated by dividing estimated annual number of salmon in production by the reported number of escapees (e.g. 1 in 124 salmon escaped in BC in 1998). Number of fish in production is conservatively estimated by dividing annual production (tonnes) by 3 kg - this representing a mean size class of the 0+, 1+ and 2+ sea winter fish in marine net-pens during a given year. The actual figure would vary as market-ready adults (~4 kg) are harvested and replaced by a greater number of smolts (~70 g). A 3kg average is a conservative net-pen standing stock estimator, resulting in a conservative estimate of proportional escapes. † Chile production and escape figures include Atlantic salmon and coho salmon (all other jurisdictions are Atlantic salmon only). 2002 Chile figures also include marine production and escapes of rainbow trout.

Country	Year	Production (t)	Reported escapees	Escape ratio
BC	1998	33,100 ¹	89,286 ²	1:124
	2000	39,300 ¹	37,392 ²	1:350
	2001	58,000 ¹	57,890 ²	1:333
	2002	71,600 ¹	9,282 ²	1:2,571
	2003	72,700 ¹	34 ^{2,3}	1:712,745
Chile	1994	68699 ¹	2,204,789 ⁵	1:10
	1995	98,287 ⁴	315,133 ⁵	1:104
	1996	144,315 ⁴	111,706 ⁵	1:431
	2002	476,349 ⁴	900,000 ⁶	1:176
Norway	1997	332,58 ¹⁴	586,000 ⁷	1:189
	2000	440,06 ¹⁴	1,300,000 ⁸	1:112
	2003	500,000 ⁹	550,000 ¹⁰	1:303
Scotland	1997	99,200 ¹¹	78,480 ¹²	1:421
	2000	129,000 ¹¹	440,000 ¹³	1:97

¹ BC Ministry Agriculture, Fisheries and Food http://www.agf.gov.bc.ca/fish_stats/aqua-salmon.htm

² Atlantic Salmon Watch Program http://www.pac.dfo-mpo.gc.ca/sci/aqua/ASWP_e.htm

³ Andy Thompson, DFO, Atlantic Salmon Watch Program. Printed in the Victoria Times-Colonist June 15 2004 Page: C1 / Front Section: Business Byline: Carla Wilson

⁴ Fishstat Database, FAO, Rome, Italy. <http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp>

⁵ Soto et al. 2001. *Ecological Applications*. 11(6): 1750-1762

⁶ IntraFish <http://www.intrafish.com/>

⁷ Norwegian Directorate of Fisheries. Printed in the *Norway Post*, December 30 1998, Byline: Don Pyle. http://www.norwaypost.no/content.asp?cluster_id=29&folder_id=8

⁸ CNN <http://cnnstudentnews.cnn.com/2000/NATURE/06/22/salmon.enn/>

⁹ IntraFish <http://www.intrafish.com/pdf/download/4210879ea2de9223e9705937db0aa039/2004/3/05.pdf>

¹⁰ Newhouse News Service, December 3 2003 Byline: Michael Milstein

<http://www.newhousenews.com/archive/milstein120503.html>

¹¹ Scottish Executive <http://www.scotland.gov.uk/stats/bulletins/sfs02-03.asp>

¹² Scottish Executive as reported by Friends of the Earth Scotland <http://www.foe-scotland.org.uk/press/pr20000604.html>

¹³ Scottish Executive as reported by the Scottish Green Party <http://www.scotland.gov.uk/cru/kdo1/green/reia.pdf>

The astonishingly low escape report figures for BC are explained by the assessment of Porter (2003), particularly the latter criteria pertaining to monitoring and escape prevention, in which Canada registered only barely above 'non-existent'. In other words, the complete absence of capacity to independently assess precision and accuracy of the reporting mechanism enables any figure – regardless of how incredible it is – to be presented as fact. Thus, any figure emerging from this severely flawed system must be viewed with deep skepticism.

It is worrying that not only do managers in BC accept these figures as fact (see Thompson, 2004, p. C1) but that the putative sablefish aquaculture industry will be modeled on the same programs. This is made even more difficult given that farmed sablefish will be indistinguishable from wild con-specifics once released. At present, there are no plans for physical or genetic tagging of farm stock. This effectively removes any opportunity for post-hoc escape analyses (e.g. Morton and Volpe 2002). If a sablefish aquaculture industry were to establish in BC, the only measure likely to be available to assess the number of farm-escaped sablefish will be reports from the farms – which is clearly insufficient to meet even the most provisional precautionary management objective.

Even when farms report escapes, it appears such information does not necessarily become public. In May 2004 a large number of farmed Atlantic salmon escaped from their Muchalet Inlet farm in Nootka Sound on the west coast of Vancouver Island. Report of the incident was made to government agencies within 48 hours of detection. Six months later when the nets were emptied during the following November, the estimated number of escapees was pegged at 33,000. As of printing of this report, there remains no trace of this escape in provincial and federal databases, even though these agencies have apparently been in receipt of this knowledge for months. Provincial and federal representatives are on public record making statements alledging the number of escapees for the entire year for the entire coast to be ~ 30 individuals. Accountability within the system is seems lacking.

CAN SABLEFISH ESCAPES BE EFFECTIVELY MONITORED?

Given the discussion above, one must assume the establishment of a sablefish aquaculture industry in BC will result in the escape of substantial numbers of farm fish. This marks a major divergence from the majority of BC salmon farms in terms of potential impacts. The majority of salmon cultured in BC are Atlantic salmon (*Salmo salar*), an exotic species and therefore clearly identifiable in the wild as an escapee or progeny thereof. Further, being a foreign species, post-escape performance (foraging success, competitive interactions, etc.) of an Atlantic salmon would, at least initially, be lower than what one would expect of native species. Therefore in terms of using the salmon industry as a tool to forecast potential escape-related issues, attention should be focused on the North Atlantic drainage where Atlantic salmon are farmed within the native range of wild Atlantic salmon populations. This introduces a number of elements that are not part of discussions around the BC farm salmon debate.

The potential for direct genetic introgression is possible through hybridization of farm and wild individuals. Indirect impact from con-specific competition is possible (niche overlap will naturally be higher among con-specifics e.g. wild and farmed Atlantic salmon off New Brunswick, than among species belonging to different genera, e.g. Atlantic salmon and Pacific salmon, i.e. genus *Oncorhynchus*, in BC). The greater level of physical interaction between farm and wild con-specifics will also increase the potential for disease/parasite transfer between the two groups. These types of farm-wild interactions have all been documented in North Atlantic drainages. Over 80% of returning salmon in some Norwegian rivers are of farm origin (Lund *et al.* 1991; Fiske and Lund 1999) leading to significant declines in viability of introgressed populations (Fleming *et al.* 2000; McGinnity *et al.* 2003). The freshwater ectoparasite *Gyrodactylus salaris* first appeared in Norway in 1975 on Atlantic salmon in a west coast farm. The parasite quickly spread to 41 rivers through stocking of infected fish and via farm escapees subsequently entering adjacent rivers. *G. salaris* cannot swim so transfer is via direct fish to fish contact – suggesting high transfer rates among individuals likely to come into direct contact, e.g. conspecifics.

Genetic interactions

Thus the salmon experience in BC is only partially informative with respect to predicting potential impacts of farm sablefish. Rearing a species on an industrial scale within its native range introduces an additional layer of complexity not captured by issues surrounding Atlantic salmon farming in BC. Perhaps the most obvious ecological threat that escaped sablefish would pose to wild sablefish populations is that of genetic pollution. Genetic impacts can manifest in two ways: (i) introduction of locally maladaptive traits, and (ii) introduction of universally maladaptive (eg. domestic) traits.

The introduction of locally maladaptive traits would be significant if sablefish exhibited significant reproductive isolation resulting in genetic substructure across the species range. For instance salmon are reproductively philopatric to their natal streams. Straying of adult salmon is rare enough that each drainage supports a demonstrably unique population. For sablefish, the data are not nearly as clear. Given the variety of coastal marine habitats sablefish are known to frequent (estuaries, offshore seamounts, deep ocean canyons, oceanic plains), some degree of reproductive isolation among ecotypes might be expected. However, genetic analyses to date have been inconclusive as to whether sablefish exhibit reproductive substructure (Beamish and McFarlane 1988; Gary Winans, US NMFS, Seattle, WA. *pers. comm.*), largely because samples were collected outside of the spawning season (location at time of sampling may not correspond to location during spawning). Interpretation of these data has resulted in sablefish along the Pacific coast to be managed as a single panmictic population.

This conclusion has recently been challenged by stable isotope analysis of sablefish otoliths. Oxygen and carbon signatures from 90 sablefish sampled from the southwest coast of Vancouver Island to Cape Blanco in southern Oregon suggest there are three reproductive subpopulations in the region (Goa *et al.* 2004). The use of stable isotopes to discern reproductive stock structure is novel but has been shown to be a powerful tool in other pelagic marine species such as Pacific herring (Gao *et al.* 2001). How widespread such philopatry may be (consistent pattern across BC and Alaska?) and to what extent reproductive philopatry translates to local adaptation and associated increases in fitness has not been addressed. However, Gao *et al.* (2004) suggest the assumption of a panmictic population may be premature.

The introduction of universally maladaptive domestic traits via hybridization events is perhaps a greater threat if only because negative impacts would manifest irregardless of the genetic structure of the wild population. In general, the more complex the life history of the wild population, the stronger the selection pressure (direct and indirect) will be during the domestication of the species. Sablefish and salmon exhibit analogous (but not homologous) life history complexities. Most notably both are characterized by discrete spawning, juvenile rearing and adult feeding habitats. Selection pressures in the wild differ among these habitats and successful reproductive adults are the product of the intense multifaceted screening process. In contrast, the aquaculture environment is largely invariable and characters associated with high performance in the wild will be maladaptive in a net-pen. Unfortunately, the converse is also true; high performance in captivity will result in poor performance in the wild. If a genetic component to such traits exists (and voluminous literature attests that, in varying degrees, it does), maladaptive traits developed in captivity can be transferred to wild populations if escapees survive to spawn.

Faster growth, larger body size but smaller fins accompanying more aggressive and risk prone behaviour has been documented in farm strains of Atlantic salmon in comparison with wild counterparts (Fleming and Einum 1997; Fleming *et al.* 2002). Introgression of such traits into wild populations has been demonstrated to represent a significant threat to long-term viability of affected populations (McGinnity *et al.* 2003). If and how genetic introgression of maladaptive traits into wild sablefish populations occurs will depend on a number of factors; post escape performance and survivorship, capacity to migrate to spawning grounds, appropriate physical and behavioral reproductive development – all of which are virtually unknown currently. Often such considerations, in the absence of empirical data, are framed in the context of risk. A straightforward approach to assessing risk helps put issues in perspective. If the probability (P) of an event in a given period - say a year - is non-zero, then to calculate the probability of the event over n years is

$$1-(1-P)^n \quad (1)$$

which converges towards 1 (certainty) in the limit of large n . A wide array of issues can be assessed using this relationship as a first cut. For instance, given the likelihood of a farm-derived parasite epidemic event in any given year ranges, hypothetically, from 1% - 4%, the probability of such an event occurring over the next two decades is 18% - 44%. This probability calculation is retrospective as well as prospective. In other words, since farmed Atlantic salmon have been escaping in BC for over 16 years, the probability that they have already colonized is $1-(1-P)^{16}$. For example, if the probability (P) of colonization is 1%, the chance that Atlantic salmon have already colonized in BC is 15%, and if P is 2%, the chance that they have already colonized is 28% (Dr. Neil Frazer, University of Hawaii, *pers. comm.*). Of course the hurdle to applying this calculation is deriving P with an appropriate level of confidence that includes, among other considerations, temporal variability. For instance, in the first example P is proportional to the local abundances of wild and farm sablefish – reflecting temporally variable environmental and industry dynamics, respectively. What is of interest here is that if the probability of an event is non-zero, regardless of how unlikely, given enough time the event will occur. Unfortunately, given the current dearth of information regarding molecular ecology, epidemiology, and life history of sablefish populations, P of any substantial event in the current context is very difficult to estimate. This supports a conservative approach to the development of a sablefish aquaculture industry.

Disease and parasite issues

Parasites can regulate host populations (Anderson and May 1978; May and Anderson 1978; Grenfell and Dobson 1995; Hudson *et al.* 2002), and consequently, understanding how human activities affect the ecology of infectious diseases and parasites has become a central problem in conservation biology (May 1988; Scott 1988; McCallum and Dobson 1995; Daszak *et al.* 2000; Deem *et al.* 2001; Dobson and

Foufopoulos 2001) and human health (Daszak *et al.* 2000). A threat occurs with the creation of 'reservoirs', typically domesticated animals, from which diseases can 'spill-over' into threatened populations (McCallum and Dobson 1995; Daszak *et al.* 2000). Sablefish farms located within the native range of wild sablefish represent novel, spatially concentrated host populations that may perturb the dynamics of the extant sablefish host-parasite systems.

Much of the recent debate surrounding ecological sustainability of industrial salmon farming in BC has focused on disease and parasite-related impacts on wild salmonids. Not surprisingly, how industrial scale sablefish farms may likewise alter epidemiological processes is a major concern. Unfortunately published literature available on this issue is neither abundant nor recent. In contrast, consider the current salmon-sea lice situation in BC. This host-parasite system has been among the most intensively studied epidemiological system in all of aquaculture for over two decades - relevant life history, ecological and epidemiological parameters of both species are well understood. And yet, all attempts to evaluate the role of farms in sea lice infestations of wild salmonids remain inconclusive due to a lack of baseline data and variation of confounding variables (McVicar 1997; Mackenzie *et al.* 1998; Tully *et al.* 1999; Marshall 2003). The failure to demonstrate causal relationships underlies the contentious decade-old scientific and political debate, delaying government interventions to mitigate this threat. The recent application of probabilistic spatial models to disentangle farm-produced infection from natural sources and quantify the relative contribution of these infection sources to parasitism of out-migrating salmon smolts looks promising (Krkosek *et al.* 2005). Unfortunately, a major drawback of such *post-hoc* analyses (the only way cause and effect relationships can be demonstrated empirically) is that major disease or parasite outbreaks are pre-requisite to quantifying processes and impacts.

This is not a satisfying template on which to build policy for disease or parasite management in emerging industrial aquaculture species such as sablefish and halibut.

Despite intense, decades-long effort, understanding of the salmon-sea lice relationship has only recently developed. With this in mind there are some salmon-sablefish life history analogues that are informative for assessing potential issues arising from the establishment of a sablefish aquaculture industry.

Juvenile-Adult Interaction: Adult sablefish are generally found between 200-1500m depth along the continental shelf but have been found as deep as 2740m in the Astoria and Cascadia abyssal plains (Kendall and Matarese 1987). Juveniles on the other hand reside in inshore nursery habitats until they migrate offshore as adults. Therefore there is strict spatial separation of young and adult stages of wild sablefish.

Sablefish in BC waters spawn from January to March near the edge of the continental shelf in water deeper than 300m (McFarlane and Beamish 1983, Kendall and Matarese 1987). Fertilized eggs sink to depths of approximately 1000 m before hatching (Kendall and Matarese, 1987). Post-hatch, the larvae may sink as far as 1200 m (Alderice *et al.* 1988) but changes in buoyancy accompany ontogeny and larvae begin to rise towards the surface concurrently with development of eye pigmentation (~6.5 mm SL; Kendall and Matarese 1987), but are as much as 370 km from shore (Kendall and Matarese 1987). As larvae approach surface waters, their distribution becomes dependent on surface oceanographic conditions (McFarlane and Saunders 1997; McFarlane *et al.* 1997) setting up the potential for widespread distribution via onshore-offshore transport in relatively fast surface currents. By mid-summer juvenile sablefish engage in an active migration to inshore nursery habitats in fjords and inlets (King *et al.* 2000). Following two to five years in these inshore habitats offshore migration ensues to the continental slope or seamounts (ADFG 1985; Kendall and Matarese 1987; King *et al.* 2000).

It is during the two-five-year inshore residency that farm-wild pathogenic relationships are likely to manifest themselves. Sablefish farms are expected to follow the salmon template: open, near-shore net-pens, clustered near terrestrial access points to minimize marine transport costs of materials, labour, and product. The inshore presence of high densities of adult sablefish (farms) in direct contact (open net-pens) with wild juveniles represents a completely novel epidemiological regime. Never throughout the known history of this species have significant densities of juveniles and adults spatially and temporally co-occurred.

Thus from an epidemiological perspective, sablefish farms introduce two very substantial issues with respect to risk to wild populations:

EPIDEMIOLOGICAL RISK I – HIGH DENSITY AGGREGATES OF ADULTS

Net-pens functionally operate as ‘reservoirs’ of hosts for naturally occurring pathogens and parasites (McCallum and Dobson 1995; Daszak *et al.* 2000; Kent 2000). Following the initial infection of farm individuals, the ready availability of additional hosts enables pathogen or parasite populations to become highly successful and to grow exponentially. This is further aggravated by stress associated with crowding and handling, making otherwise robust hosts further susceptible to infection. Once infected, compromised individuals in net-pens are protected from predators and so live longer than would be expected in the wild, in turn increasing *per capita* reproductive output of the pathogen or parasite. Together, these factors if left unchecked can quickly lead to epidemic events. Impact of such an event cannot be assessed until a critical question is addressed: how large is the spatial and temporal pathogen or parasite distribution around the farm? In other words, for how long and how far does a farm increase infection pressure on wild fish? Unfortunately the answer will be to some extent unique for each farm, being a product of the interactions of each pathogen or parasite in question, and because of the dynamic nature of the environment, will likely vary over time. Among the key considerations are:

- Direct or indirect (i.e. intermediate hosts) transmission;
- Alternative hosts or reservoirs;
- Sessile or motile (active or passive);
- Dormancy potential;
- Virulence;
- Intrinsic rate of increase (r);
- Diagnosis / treatment efficacy;
- Differential susceptibility of other species on-site (e.g. salmon);
- Husbandry practices.

Vaccines have been developed for two of the most common sablefish pathogens, vibriosis (*Vibrio anguillarum*) and furunculosis (*Aeromonas salmonicida*). However, numerous other parasites, bacteria, viruses and fungi are likely to occur in any high-intensity sablefish farm. Appendix 1 lists major species of concern along with pertinent life history, diagnosis and treatment information [See Tables 1 and 2 in Robichaud *et al.* (2004) for an additional synthesis of described sablefish parasites and pathogens, respectively]. At present epidemiological information for these numerous parasites and pathogens is not sufficient to confidently bound the parameters listed above nor is there understanding how such factors are likely to vary in response to temporal and spatial environmental variability. Therefore, risk to wild populations (sablefish and others) from known pathogens and parasites cannot be quantified at this time.

An issue that has become associated with the introduction of new species into industrial-scale aquaculture is the appearance of heretofore undescribed pathogenic or parasitic organisms. As outlined above, open net-pens fundamentally alter distribution and abundance of potential hosts to a state not seen in nature. This has in the past lead to the emergence of organisms never seen before. For instance infectious salmon anemia (ISA), a contagious viral disease, was unknown to science until it appeared in the Norwegian salmon farming industry in 1984. Subsequently, the disease has been detected on farms in Canada (1996), Scotland (1999) and Chile (2000). There is no known cure for ISA, which led to an epidemic in 1998 in New Brunswick farms, forcing the slaughter of 1.2 million fish and a C\$10 million government bailout. More recently, a similar scenario played out in Scotland ending with a £9 million (about C\$23.4 million) government package to farmers. The experience of the global salmon farming industry with ISA serves as a cautionary tale for sablefish aquaculture. Not only is there an utter absence of epidemiological data for wild sablefish, the establishment of high-density farms introduces the potential for pathogens/parasites that are not yet known to science. How industry will deal with the emergence of novel diseases and parasites while safeguarding wild populations is a fundamental consideration in the development of effective pathology screening and safeguards.

Even when pathology of the relationship between host and pathogen or parasite is thought to be understood, additional complexities can arise to frustrate mitigation efforts. *Gyrodactylus salaris* is a fresh and brackish water ectoparasitic flatworm known in Sweden since the 1970s. *G. salaris* was controlled by pesticides and not considered a major threat since no significant harm to Baltic stocks of Atlantic salmon was observed. In 1975, *G. salaris* was found in a Norwegian hatchery and within a month had spread to the wild population in the adjacent river. Over the subsequent years, *G. salaris* spread across much of coastal Norway, with disastrous results. In 1984 alone, *G. salaris* was estimated to be

responsible for a loss of 250-500 tonnes to the commercial fishing fleet. Once established in a river, the only sure means of removing *G. salaris* is to kill all potential hosts. In an unprecedented move, the Norwegian government has purposely sterilized (poisoned) 27 rivers with rotenone since the mid-1980s. Whether this will prove ultimately effective is yet to be seen.

Wild Swedish Atlantic salmon stocks are known to be genetically distinct from Norwegian stocks. The likely explanation why *G. salaris* is so devastating for Norwegian stocks but not so for Baltic salmon is that the Baltic strains, having evolved with the parasite, seem to have developed a natural resistance. Norwegian Atlantic salmon, having never been exposed to *G. salaris* until its arrival in 1970s, lacked a defense system, leading to the dramatic losses.

What, if any, pathological substructure may exist among wild sablefish populations is unknown. Therefore issues of differential disease or parasite resistance among broodstocks and adjacent wild populations need to be addressed prior to transfer of fish to marine grow-out facilities. This is particularly relevant given the current intention of a single large hatchery, with as yet undefined broodstock profile, seeding widely dispersed grow-out facilities.

EPIDEMIOLOGICAL RISK II – HIGH DENSITY AGGREGATES OF ADULTS SYMPATRIC WITH JUVENILES

High density aggregates of sablefish adults inshore will alter pathogen or parasite abundance and distributions. However, the ramifications of this will be further complicated by these static adult assemblages being sympatric with migratory juvenile assemblages. Juvenile sablefish spend two to five years in inshore nursery habitat, typically bays and fjords – the same habitat preferred for net-pen tenures, which benefit from the physical protection afforded by such habitats. Thus, juvenile sablefish would now be exposed to pathogens or parasites to which heretofore only adult sablefish were exposed, and vice versa. The depauperate literature available regarding age-specific susceptibility and virulence of most common diseases and parasites is a major knowledge gap. A precautionary approach would accept the inevitability of horizontal transfer between wild and farm populations of those parasites and pathogens either directly or via intermediates with appropriate exposure to farm and wild individuals. The impact of such events can manifest themselves in two ways: (i) increased mortality of wild juveniles because of farm-mediated increases in infection pressure, negatively affecting recruitment to adult stages, and (ii) increased mortality of wild offshore adults via exposure to infected migratory juveniles. The two scenarios are not mutually exclusive; indeed each could potentially be characterized by significant interaction with the other.

One could make the assumption that sablefish transplanted to net-pen grow-out sites are clean of pathogens and parasites - an assumption that has been called into question given the apparent disease-related mortality of 70% of recent juvenile transfers to BC net-pens and anecdotal reports of illegally caught wild sablefish being 'laundered' via transfer from commercial vessels to farms, and sold as farm product. Nonetheless, assuming farm sablefish are initially clean, subsequent documentation of increased, farm-mediated infection in con-specifics would not only constitute strong evidence of farm to wild transmission but also subsequent wild juvenile to wild adult transmission is likely should the infected juveniles survive the offshore migration. The potential must be considered given that the cycle was likely initiated by (wild) juvenile to (farm) adult transmission in the first place and therefore the same scenario can be repeated offshore on the adult feeding grounds.

The potentially complicating effect of having migratory juveniles sympatric with confined farm adults has recently been revealed by farmed Atlantic salmon sympatric with juvenile Pacific salmon, both susceptible to sea lice in coastal BC. In a recently published study, Krkosek *et al.* (2005) demonstrate sea lice infection pressure adjacent to a salmon farm reaches 73 times above ambient levels. Further, farm-mediated infection decays slowly with distance and remains greater than ambient levels for 15.6-56.1 km along the wild Pacific salmon migration route studied. This unexpectedly large spatial lice distribution is the result of heavily-infected migratory juveniles acting as lice vectors. Particularly worrisome is the evidence Krkosek *et al.* (2005) present in support of secondary infection along the migratory route mediated by migrating infected cohorts of wild juveniles. For many juveniles initially infected at or near a farm, the lice load is lethal. However, a sub-group survives and continues along the migration route. Lice on these fish continue to develop and eventually reproduce, creating an explosion in abundance of infective lice larvae; however, the infected fish are by now dozens of kilometers from the farm that initiated the original infection. Local outbound salmon smolts dozens of kilometers from a salmon farm are exposed to the

amplified lice infection pressure mediated by their infected associates. Infected cohorts of migrating juveniles act as a moving ‘farm proxy’ with respect to transmission dynamics of sea lice. Therefore predicting rates and magnitude of transmission on any relevant spatial scale would be very difficult given most relevant parameters are subject to variation correlated to local environmental and ecological conditions. What is clear is that these data confirm the potential for infected migratory juveniles to act as parasite vectors, greatly amplifying the spatial footprint of the farm with regard to disease/parasite transfer.

The work of Krkosek *et al.* (2005) emphasizes the need to understand spatial dynamics of pathogen and parasite transmission and argues for a conservative approach to the consolidation of net-pens along the BC coast. Unfortunately the economic realities of the global salmon market and ecological realities of disease transmission are at odds. Again, the experience of the salmon farming industry in BC should serve as a cautionary tale to inform the development of a sablefish aquaculture industry in British Columbia. An important step in minimizing farm-mediated impacts on wild populations and their environment is to isolate farms from each other. In other words, separate farms enough to ensure the footprint (in terms of disease, parasite, wastes, toxins, bioactive therapeutants, even escapees) of one farm does not overlap that of another (eliminating farm-to-farm interaction and amplification). To do so, though, comes at a cost to the industry in terms of greater expense of transport of materials, product and labour in and out of the farm.

Transport costs are particularly acute in BC where most of the coast is not serviced by roadways resulting in existing farms being reliant on relatively expensive marine transport. This is an expense that does not burden BC’s global competitors to the same degree, particularly Chile, Norway and Scotland. As global production continues to increase and profit margins shrink in response, the motivation to minimize the distance between BC farms – thereby minimizing transport costs – grows. In response, farms are located closer together in an attempt to minimize marine transport costs (one ship can service more farms, faster, the closer they are to each other). The risk and magnitude of farm-mediated impacts, particularly, with regard to disease and pathogens increase with the degree of farm footprint overlap. The early stages of a sablefish aquaculture industry will be the most profitable and thus there will be minimal economic pressure on the sector. As time passes and supply of products increase, the price will drop (see economic forecasts in the following section), forcing offloading of production costs resulting in increasing spatial consolidation, as has been seen in the evolution of the salmon industry. As farm footprints overlap, the incidence of “ecological issues” will grow. The unavoidable economic realities of industrial aquaculture combined with the logistic challenges of operating on the BC coast present an insurmountable challenge to risk adverse development of a sablefish aquaculture industry in the absence of novel mitigation strategies.

In conclusion, the weight of evidence supports an expectation of significant epidemiological disruption to accompany the establishment of industrial scale open net-pen sablefish farming on the BC coast. Given the apparent overwhelming uncertainty surrounding pathogen and/or parasite mediated impacts on wild populations, strict observation of and adherence to precautionary principles is warranted. In the case of the DFO, the precautionary approach is legislatively mandated. This is particularly important given the admitted lack of oversight that DFO can bring to bear on the issue as underscored by the following quote from Dr. Dorothy Kieser (DFO fish health pathobiologist Nanaimo; Feb 17 2004) in an internal memo:

“Because there are no reportable fish diseases, DFO has no regulatory capacity for requiring farms to report disease outbreaks. Nor does the department have a routine monitoring program to check on the status of disease outbreaks on farms. While such monitoring is done by the provincial agency, DFO has no regulatory capacity for requiring farms to report disease outbreaks. Nor does the department have a routine monitoring program to check on the status of disease outbreaks on farms.

The department also does not maintain a surveillance program to detect pathogens/parasites in wild stocks or detect a change in the rate of infection/infestation. Hence there is no ability to state whether diseases in wild stocks are 'new' or whether there is a greater prevalence of pathogens in wild stocks.”

ECONOMIC ANALYSIS OF SABLEFISH AQUACULTURE

BACKGROUND

Earlier parts of this report discussed the possible ecological consequences of sablefish aquaculture in BC in a qualitative manner. It has profiled and characterized the potential for the spread of disease or parasites from wild-farm-wild transfers and the potential impacts of escapees on wild stock genetic structure.

Using this as background, we develop a discussion on the potential economic effects of introducing sablefish farming in BC. Much as we would like to conduct our analysis using wild and farmed sablefish ecological impact data, there is currently no such data available. What we decided to do, instead, is to use the lessons we can draw from salmon farming to support our discussion. Of course, this is not perfect since sablefish farming is unlikely to follow exactly the same pattern that salmon farming took. We expect, however, that this approach is better than making up an ecological impact model based on speculative data and relationships to back up our analysis.

ECONOMICS OF POTENTIAL IMPACTS OF SABLEFISH FARMING: LESSONS FROM SALMON AQUACULTURE

WILD SALMON FISHERIES AND SALMON AQUACULTURE IN BC

We present the profile of landings of BC wild and farmed salmon in Figure 1 and 2. We see from the figures that as farmed salmon production increased the landings of wild salmon dramatically declined.

A key question to ask here is, why did wild salmon landings rapidly decline as farmed salmon increased? Is it because of a wild biomass decline or because wild salmon fishing effort was diverted as a result of the introduction of salmon farming in BC? To help us attempt to answer this question, we searched for data on the total biomass of wild salmon in B.C. Unfortunately we could not find such data, and therefore, we had to resort to using either biomass or escapement data for coho, sockeye and pink salmon available for some BC rivers. The biomass profiles are plotted in Figure 2.

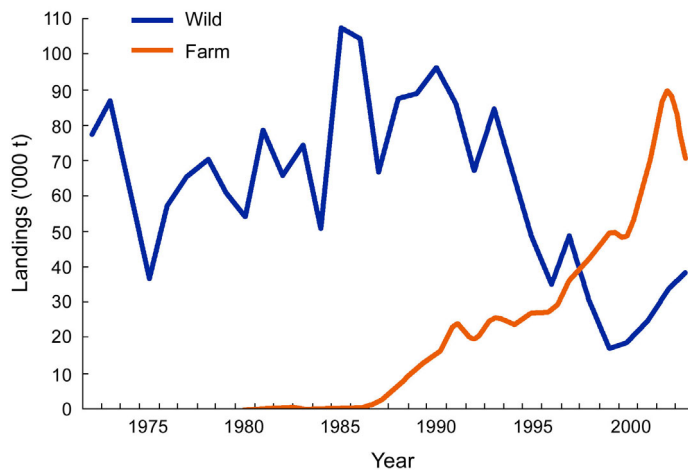


Figure 1: Landings of wild and farmed BC salmon from 1972 to 2002. Source: Statistical Service, Fisheries and Oceans Canada. (http://www.dfo-mpo.gc.ca/communic/statistics/main_e.htm).

Figure 2 shows that between 1990 and 2000, a period of rapid expansion of salmon farming in BC, there was a clear decline in the abundance of coho. Also, there was a decline in pink salmon between 1990 to 1994, and even though the abundance of sockeye varied considerably, it trended upwards during this period. Given these trends, it is not clear that the decline in wild salmon landings is attributable to a diversion of fishing effort from wild salmon. A more likely explanation is a decline in wild salmon abundance.

Wild salmon fisheries in Alaska

The next question to ask is can the decline in wild salmon landings be attributed to the expansion of salmon farming? Clearly, this is a difficult question, as there are many potential reasons for the biomass decline observed (e.g., regime shifts). To help shed some light on this, we examine the landings and biomass data of wild salmon in the US State of Alaska, which provides a good control because salmon farming is banned in this state's waters.

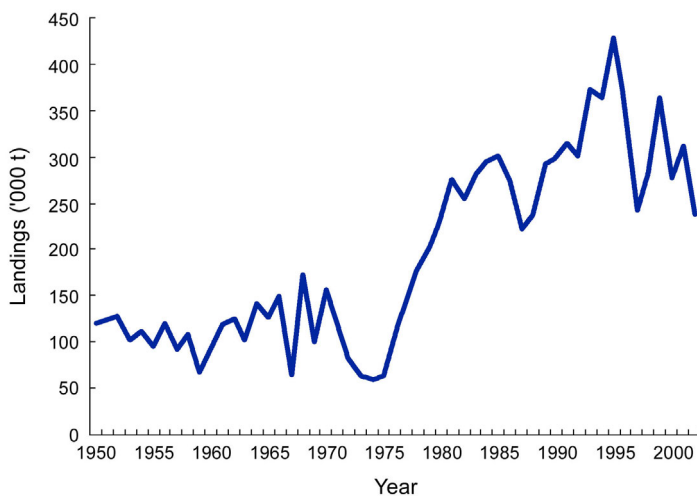


Figure 3: Landings of Alaskan wild salmon, 1950-2002. Source: Fisheries Statistics and Economic Division, National Marine Fisheries Service, National Oceanic and Atmospheric Administration (NOAA) (<http://www.st.nmfs.gov/st1/index.html>).

These data show that with the advent of salmon farming in BC came a sharp decline in the landings of BC wild salmon. Meanwhile, during the same period salmon landings in Alaska, which has a ban on salmon farming in its waters, actually increased. From the abundance data at hand, it appears that BC wild salmon abundance also trended downwards during this period, while the opposite was the case for Alaskan salmon abundance. Does all of this indicate that the drop in landings of BC wild salmon is due to the rise of salmon aquaculture in BC? One cannot answer this question in the affirmative with any certainty, but,

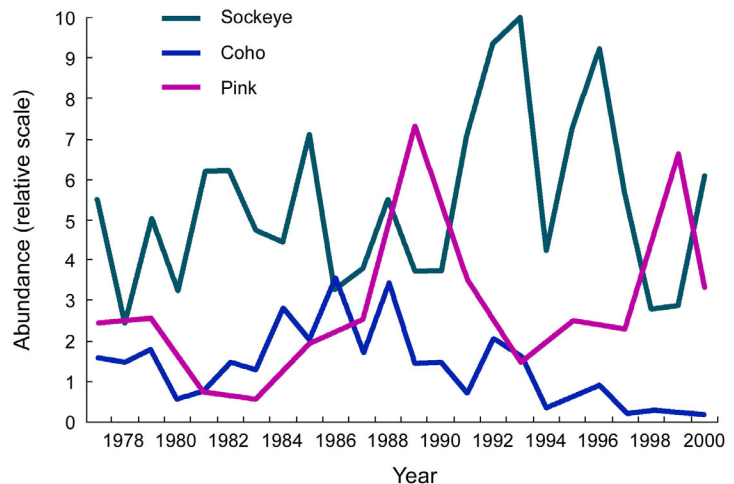


Figure 2: Abundance of Sockeye, Coho and Pink salmon in British Columbia waters from 1977-2000. Abundance of sockeye salmon (x million nos.) is made up of stocks in Area 3 of the Nass River, the Skeena River stocks in Area 4, the Barkley Bound stocks, the Meziadin and Cultus stocks. The abundance of coho salmon (x 100,000 nos.) refers to the stocks in the interior Fraser River. Finally, the abundance of pink salmon (x 1,000,000 nos.) is based on the stocks in Management Area 5 & 6. Sources: Bocking *et al.* (2002); Schubert *et al.* (2002); Cox-Rogers *et al.* (2004); Cox-Rogers (2004); Hyatt *et al.*, (2003); Simpson *et al.* (2003).

Contrasting Alaskan landings with BC wild salmon landings, we see a stark difference - while the landings of BC wild salmon dropped significantly during the period of aquaculture growth, Alaskan landings actually trended upward during the same period.

Turning to wild salmon biomass in Alaskan waters, we plot biomass indicators (that is, escapement or biomass) in Figure 3.

The relative abundance plots in Figure 4 show that just when salmon farming began to grow in 1986, chinook, coho, and sockeye trended up until 1996. Even after this year we did not see the kind of declines in abundance as in the case of BC coho and pink salmon (Fig. 2).

while precise mechanisms of interaction are not clear, the coincidence in the data is too great to be discounted out off hand. What we see in these data tells us that, at the least, salmon aquaculture may have played some role in the observed decline in BC wild salmon landings.

SUPPLY AND DEMAND EFFECTS OF SABLEFISH AQUACULTURE

Sablefish market

Sablefish is harvested year-round and is mostly processed onboard: headed, gutted and frozen at sea mainly for export. The balance is either smoked or processed as fillets or steaks for local consumption (e.g., in restaurants). On average, 86% of sablefish processed is currently exported to Japan. In recent years exports to other Asian countries (e.g., China, Hong Kong, Singapore) and Europe (e.g., UK, France and Spain) have increased (NMFS, 2004). At the same time,

consumption in Canada and the U.S. is increasing as well. Japan is the world’s largest importer and consumer of sablefish, and the sablefish supply to the Japanese market is currently entirely dependent on imports. The US is the primary supplier of sablefish to the Japanese market, followed by Canada. The US exports up to 80% of its total sablefish landings, and Canada exports up to 70% of its total landings (Cascorbi, 2004).

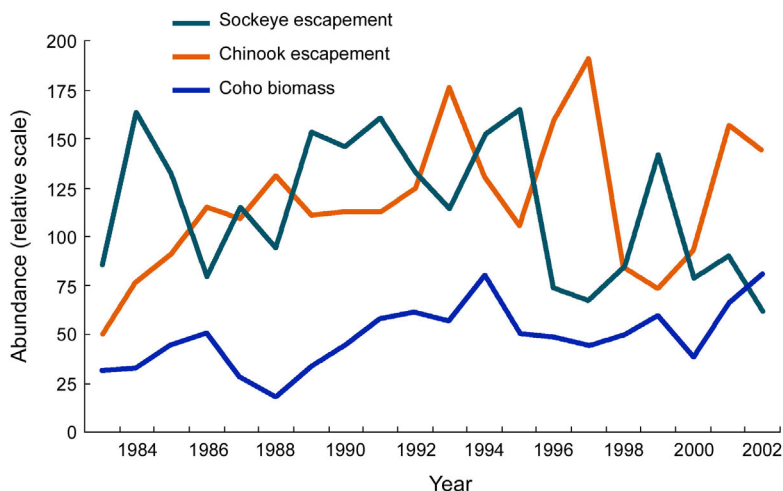


Figure 4: Abundance for chinook, coho and sockeye salmon in the Alaska area. The total escapement of chinook salmon (in thousands of individuals) include data for 11 indicator systems (Alek, Taku, Stikine, Situk, Chilkat, Andrew, Unuk, Chickamin, Blossom, Keta, King Salmon) in Southern Alaska and transboundary rivers; the total escapement of sockeye salmon (x 100,000 individuals) refers to the Bristol Bay of the Central Alaska region; the total biomass of coho salmon (x 100,000 individuals) is based on the exploitation rate of four indicator stocks (Auke lake, Berners River, Ford Arm lake and Hugh Smith Lake) and the total harvest of coho salmon in the southeast Alaska/Yakutat. Source: Lynch and Skannes (2004), ADF&G (2004a) and ADF&G (2004b).

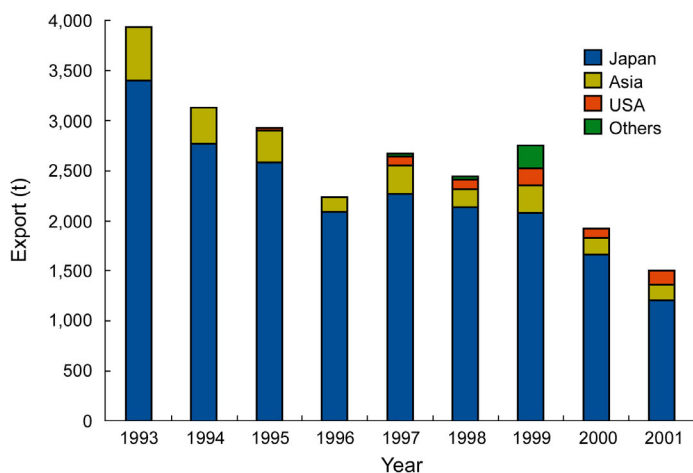


Figure 5: Export quantities of Canadian sablefish to Japan and other countries/regions. Source: Canadian International Trade. External/International Trade Division, Statistics Canada, Ottawa (<http://data.library.ubc.ca>).

Before 1993, sablefish trade data were combined with that of other ground fish species in Canada; thus, we present figures for the period from 1993 to 2001 only (Figure 5).

Over the last 20 years, the supply side of the sablefish market has witnessed major structural changes along with a general decrease in the total allowable catch (TAC) and a general increase in sablefish prices. For instance, before 1977, Japan’s demand for sablefish was met by Japanese catch in the waters of the Pacific Northwest. This changed dramatically with the implementation of Exclusive Economic Zones (EEZs), when Japan, because it could not fish freely in other countries’ EEZs, had to resort to imports to meet demand for sablefish (Huppert and Best, 2004).

Price effects and their potential economic impacts in the face of sablefish aquaculture

If sablefish aquaculture is successfully operated in BC and other parts of the world on a commercial scale, the total supply of sablefish will increase. Basic economics of supply and demand dictates that increasing sablefish supply without a corresponding increase in demand will drive sablefish prices down, as happened in the case of salmon (Figure 6). As a result, per unit weight revenues from the wild sablefish fishery will decrease, with the implication that, *ceteris paribus*, the economic rent from the fishery will drop. Huppert and Best (2004) developed two quantitative demand models to help predict the price effects of sablefish farming. *Model 1* is a standard demand model that simply represents a relationship between overall sablefish supply and market prices, while *Model 2* is an extension of *Model 1*, incorporating Japanese macroeconomic variables (e.g., the exchange rate, GNP).¹

In order to estimate the models, this study makes two critical assumptions: (1) sablefish products will continue to be sold mainly in the Japanese market, implying that there will be no change in sablefish demand in other countries; and (2) sablefish products from wild and farmed sablefish are identical and therefore will command the same price in the market. The predictions from these two models from Huppert and Best (2004) are similar, but the predictions from Model 2 show more severe impacts on market prices. For instance, when an additional 20,000 and 50,000 tonnes of farmed sablefish from aquaculture is supplied to the market, Model 1 predicts that ex-vessel prices will drop by 19% and 47%, respectively, while Model 2 forecasts that ex-vessel prices will drop by 25% and 62%, respectively.

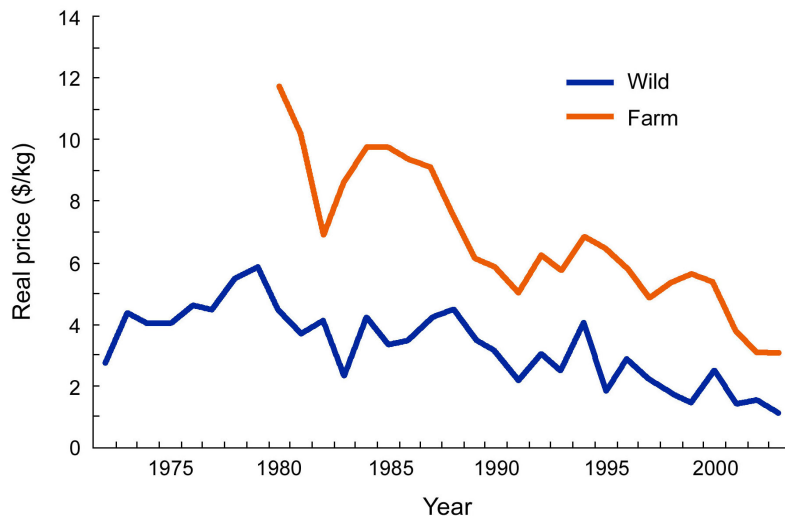


Figure 6: Real price of wild and farmed BC salmon from 1980 to 2002. Prices are estimated based on the total landings and landed values, of the sum of all the wild salmon species in BC. Farmgate prices for aquaculture and ex-vessel prices for wild sablefish. Source: Statistical Service, Fisheries and Oceans Canada (http://www.dfo-mpo.gc.ca/communic/statistics/main_e.htm).

GSGislason & Associates (2001) demonstrated that even though there should potentially be a strong market demand for farmed sablefish², they came to the conclusion that increasing supply of sablefish by 8,000 tonnes from aquaculture will drive sablefish price down by 40%, and that the declining price will result in correspondingly low returns for commercial sablefish fishers.

The bottom line from these studies is that an increase in the supply of sablefish on the market due to sablefish farming in BC or elsewhere will result in a drop in the price of sablefish overall, and that the magnitude of this drop will depend on whether the demand for sablefish decreases, stays the same or increases due to future changes in market conditions. We now turn to the assessment of the evolution of the BC salmon market post-introduction of salmon farming for additional insight.

Figure 6 shows the following: (1) the price per kg of farmed salmon are consistently higher than the price of wild salmon because of its year-round availability, value-added processing, product consistency, and because the average prices of wild salmon include the low price of pink salmon; (2) the gap between the

¹ Readers are advised to consult Huppert and Best (2004) for details of these models.

² Because: (1) sablefish aquaculture can fill the shortfall of supply to Japan from wild sablefish and Patagonian toothfish fisheries, (2) demand for sablefish in North America and other parts of the world beside Japan would be increasing in the long run, and (3) sablefish aquaculture can target niche markets.

two prices has been shrinking over time; and (3) before the introduction of salmon farming, the price was in an increasing trend, which reversed with the introduction of salmon farming.

The trend shown in the figure supports the assertions in the two studies cited earlier, that prices will fall with the increase in supply from sablefish aquaculture. From Figure 6, it appears that the assumption that farmed and wild sablefish are identical in the market has not proven to be the case for salmon. However, this assumption may yet be correct for sablefish for two reasons. First, Figure 6 seems to suggest that with time the prices of the two salmon products may converge. Second, farmed Atlantic salmon and wild Pacific salmon are so different, for example in terms of their fat content, that the price differential depicted in the figure may not be applicable to sablefish, where such marked differences between wild and farmed may not occur.

Net social benefits versus private profits from sablefish aquaculture

In this section, we examine the potential net benefits, that is, the benefits less the costs, to suppliers (producers) and consumers of sablefish farming in BC. In other words, we will determine changes in added values under different scenarios, and their distribution to the wild and farmed sablefish sectors. To carry out this analysis, we will apply cost and price information from Huppert and Best (2004).

The base case scenario for our analysis is developed around the assumption that there will be sablefish farming globally with BC producing 10% of global farmed and wild sablefish production. The 10% figure is based on the current contribution to the global wild sablefish landings by BC. This assumption is later removed to determine net benefits when sablefish farming is carried out in other countries, but not in BC, i.e., assuming a ban on sablefish farming in BC.

Prices

For the computations, we use demand Model 1 in Huppert and Best (2004), which is the more conservative of the two models reported in terms of the predicted drop in sablefish price, in response to the increase from sablefish farming. We calculated the impact of different quantities of sablefish supply to the market from farming globally under three assumptions: (1) sablefish farming in BC waters does not cause any ecological externalities, and therefore does not reduce current BC wild sablefish landings (that is, the 'No externalities' scenario); (2) sablefish farming in BC waters causes ecological externalities,

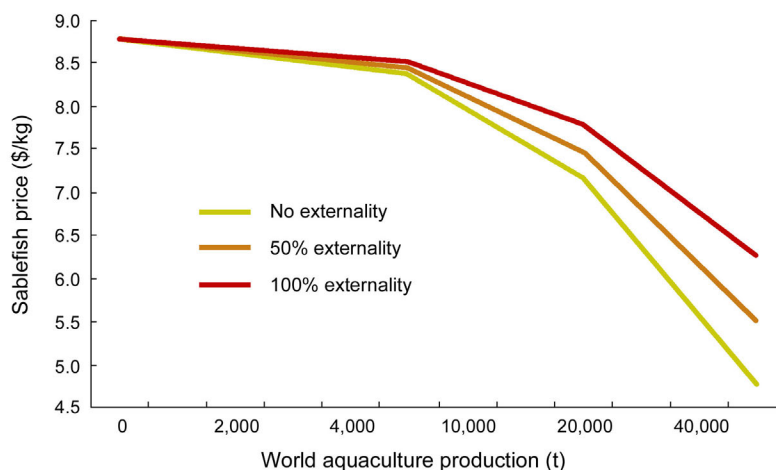


Figure 7. Global sablefish prices under different scenarios.

with impacts on wild sablefish landings at only about 50% of the rate of decline observed in BC wild salmon landings, with the introduction of salmon farming (the '50% externalities' scenario); and (3) sablefish farming in BC waters comes with ecological externalities, with impacts on wild sablefish landings at the same rate of decline observed in the case of BC wild salmon landings ('100% externalities' scenario).

We observe from Figure 7 that the price faced by BC and the rest of the world drops more when there is no ecological externality reducing landings from wild sablefish. As would be expected, the price decreases depicted in Figure 7 will impact on the net benefits to BC and the rest of the world as will be shown in later sections of the report.

Costs

The operating cost for sablefish aquaculture is estimated based on salmon aquaculture operating costs. The operating cost includes direct farm costs (e.g., stock, feed, additives, labor, insurance, maintenance, transportation, etc.) and processing and packaging costs. This operating cost for sablefish aquaculture is estimated at about C\$4.51 per kg (Huppert and Best, 2004). The operating cost for sablefish fishing is estimated at about C\$3.62 per kg (Wickham, Canadian Sablefish Association; pers. comm.). This cost is direct fishing costs, including fuel, labor, maintenance, etc.

Net social benefits

Scenario 1: Sablefish farming everywhere, with BC contributing 10% of total production

We report in Table 2 the assumed global farmed sablefish production¹, BC farmed sablefish production, and BC wild sablefish landings under the assumptions of 50% and 100% externality. Under the 'no externalities' scenario, total BC sablefish production increases by the quantity of sablefish produced from farming. In physical terms this is a positive outcome, as more sablefish is made available for consumption. Under the other two scenarios where externalities do occur, as more sablefish is produced in farms, the landings of wild BC sablefish decrease.

Table 2. Global farmed sablefish production, BC farmed sablefish production and BC wild sablefish landings under the assumptions of 50% and 100% externalities (t).

Global farmed	BC farmed	Wild landings (50% externality)	Wild landings (100% externality)
–	–	2,796	2,796
1,000	100	2,778	2,759
2,000	200	2,759	2,722
3,000	300	2,741	2,685
4,000	400	2,722	2,648
5,000	500	2,704	2,611
10,000	1,000	2,611	2,426
20,000	2,000	2,426	2,056
30,000	3,000	2,241	1,686
40,000	4,000	2,056	1,316
50,000	5,000	1,871	946

Combining the predicted prices and costs, BC farmed sablefish production, BC wild sablefish landings, we plot the total predicted BC added values from sablefish in Figures 8.

We see from Figure 8a that under the no ecological impact (externality) scenario, the sum of added value to BC increases marginally initially and stays relatively stable until BC production of farmed sablefish exceeds 1,000 t. (total world production at 10000 t.). Then we witness a sharp decline in values mainly as a result of a sharp drop in prices. Surprisingly, the sablefish farmers do badly under this scenario. This is partly because of the higher cost of production they face relative to the wild sablefish fisheries.

Under the mild ecological effect scenario, we see a similar trend in the aggregate, but with regards to the two sectors, there is a marked difference in added values as sablefish farming grows. We see the wild sablefish sector taking a major economic hit as BC sablefish production exceeds 1,000 t., while values to the farming sector increase. This is because the ecological impacts imply less supply coming from the wild sector thereby mitigating against the kind of steep price decline experienced under the no externality scenario. It should also be noted that after the supply from farming has exceeded about 3,000 t. the total added value to BC starts to fall.

¹ In scenarios that assume large world sablefish aquaculture, we are making room for the possibility that countries that do not have wild sablefish in their waters may take to sablefish farming, as it happened in the case of salmon aquaculture in Chile.

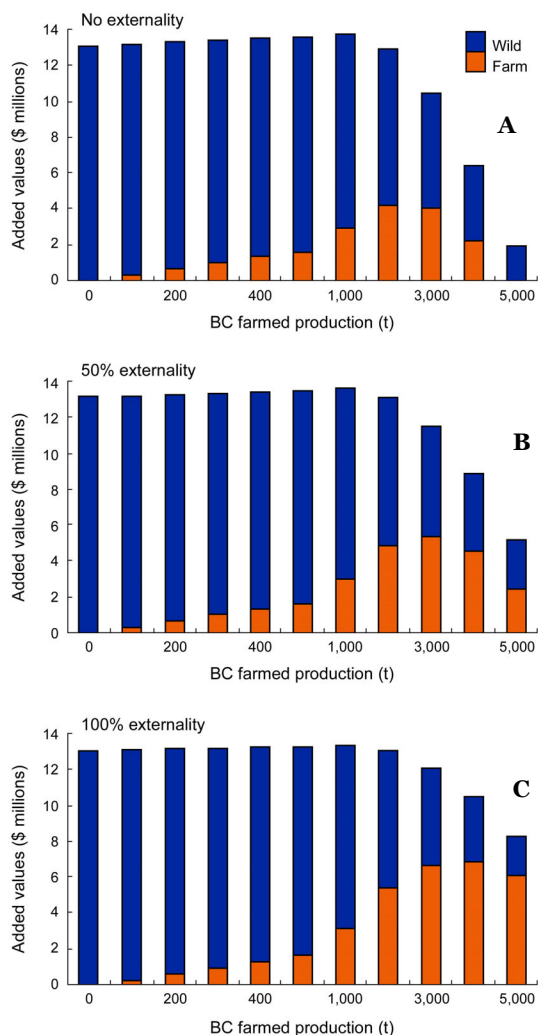


Figure 8: Net values from sablefish aquaculture and wild sablefish fishery to BC under assumptions of: (A) no externality; (B) 50% externality; (C) 100% externality.

From Figure 9 we see that the added value from the BC wild sablefish sector declines with increasing global aquaculture production. The added values are very close at low levels of aquaculture production, except for the ‘BC ban with price premium’ scenario. This scenario does increasingly better than the farming scenarios as more supply comes from farming. At all production levels, economic return of the ban with a price premium scenario exceeds all the scenarios with sablefish aquaculture, regardless of the assumed magnitude of ecological externalities.

We see from Figure 10 that, if BC is able to obtain a price premium of up to 25%, then a ban on sablefish farming will result in the highest added value for the province from the sablefish sector. Indeed, even lower price premiums will still make a ban with price premium an economically reasonable decision until total global production becomes large. On the other hand, a BC ban without price premium scenario does

Finally, Figure 8c, which depicts the outcome under the assumption of a 100% externality, demonstrates how the negative outcome under the mild ecological impact (externality) scenario is aggravated under this scenario.

As to which of the three scenarios is more likely to happen in reality, given the evolving case of salmon, and the discussion of the potential ecological problems that can arise with the introduction of sablefish farming in BC, the no externality scenario appears to be unrealistic. Hence, we are left with the scenarios depicted in Figures 8b and 8c, with significant negative economic consequences to the BC wild sablefish sector.

Scenario 2: Sablefish farming everywhere, except BC. What if BC bans sablefish farming, while other countries allow it, supplying their production to the market? Wouldn't BC pay a price for refusing to join the race to engage in sablefish farming? With a ban, it is safe to assume that the scenarios with ecological impacts will cease to be a problem in BC, and therefore the wild sablefish sector will not likely suffer the drops in landings possible under these scenarios. What BC will not be able to escape is the impact of increased supply of farmed sablefish from other countries on the price the province receives for its wild sablefish. However, it may be possible for BC to market its supply of wild sablefish as an ‘Eco-sablefish’ and/or ‘Organic sablefish’, and thereby enjoy a price premium for its supply to the world market.¹ We plot in Figures 9 and 10, respectively, the added values that would accrue to BC from the wild fishery, and the wild and farmed fisheries taken together. This is done under the following scenarios (i) a BC ban without price premium, (ii) a BC ban with price premium of 25%; (iii) aquaculture with no externality; (iv) aquaculture with 50% externality; and (v) aquaculture with 100% externality.

¹ This is quite possible, given that current buyers of BC wild sablefish are very happy with the quality of the fish because it meets the high quality standards of the Japanese market. Even now some buyers prefer Canadian sablefish fish because the fishery operates in an environmentally sustainable manner (GSGislason & Associates 2001). BC can for instance, benefit by obtaining certification of its sablefish products as being environmentally produced.

worst in terms of added value, until at large production levels when the ‘farmed with no externality’ takes over as the worst.

Net benefits from wild and farmed sablefish to BC: evidence from BC salmon

We will focus on four key measures of net benefits to BC, namely, (i) contribution to GDP, (ii) export earnings, (iii) benefits to consumers, and (iv) employment and income from the wild and farmed sectors. As data on these variables are not available for sablefish, we will draw lessons from the BC salmon industry.

Contribution to GDP

Figure 11 below shows that, at least currently, the sum of the contribution to GDP from wild and farmed BC salmon is below or about the same as the contribution to GDP from wild salmon alone, indicating that farmed salmon is currently not adding to the GDP of BC (Canada).

Export earnings from wild and farmed BC salmon

Export earnings from wild and farmed BC salmon demonstrate that the sum of farmed and wild salmon export values has not increased significantly with the introduction of salmon farming (Figure 12). This is due in large part to the overall price erosion of both products reflecting a global salmon glut from aquaculture overproduction.

Potential benefits to consumers from sablefish farming

Huppert and Best (2004), GSGislason & Associates (2001) and the salmon story all show that the price of sablefish will drop with the introduction of sablefish farming. We have also demonstrated earlier in this report that the effect of this is to reduce the added values from wild sablefish even if the landings of wild sablefish remain stable. This will result in a drop in added value from wild sablefish, especially if, as in the case of salmon, the introduction of sablefish farming is followed by a drop in landings from wild sablefish. An interesting question at this juncture is, how does the consumer figure in all of this? In general a drop in price, *ceteris paribus*, will benefit consumers at the

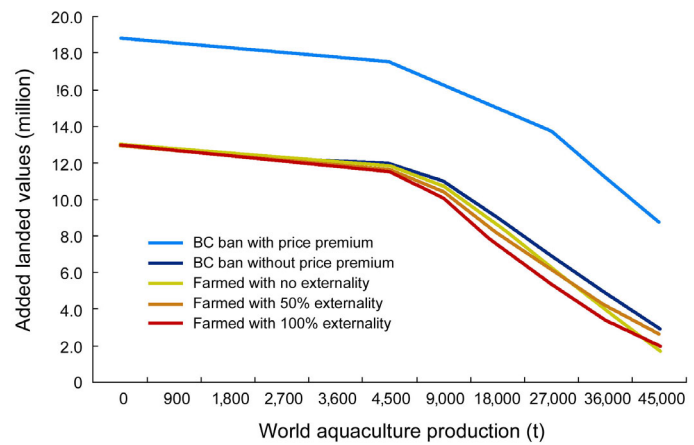


Figure 9: Added landed values from wild sablefish fishery with BC aquaculture ban, aquaculture with and without ecological impacts.

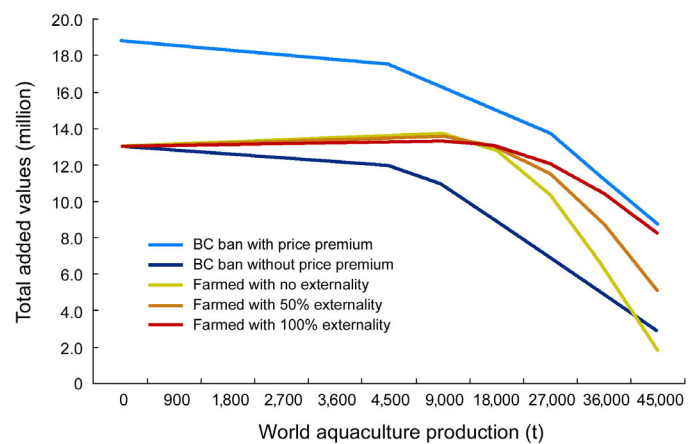


Figure 10: Added landed values from wild and farmed sablefish fishery with BC aquaculture ban, aquaculture with and without ecological impacts.

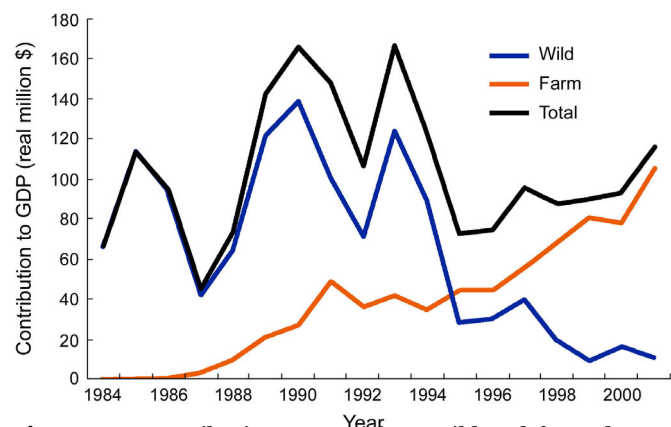


Figure 11: Contribution to GDP from wild and farmed BC salmon from 1980 to 2001. Source: British Columbia Fisheries and Aquaculture (2002).

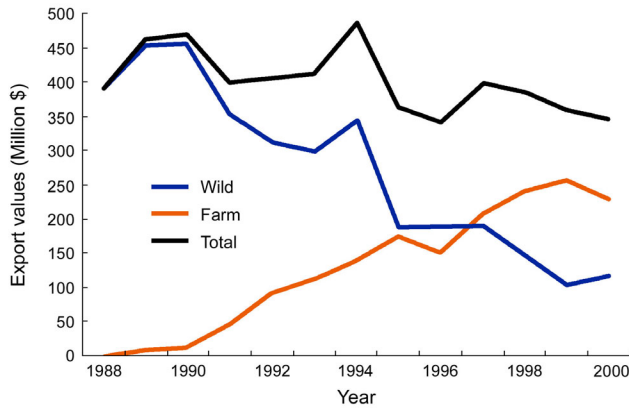


Figure 12. Export earnings from wild and farmed BC salmon. Source: British Columbia Fisheries and Aquaculture (2002).

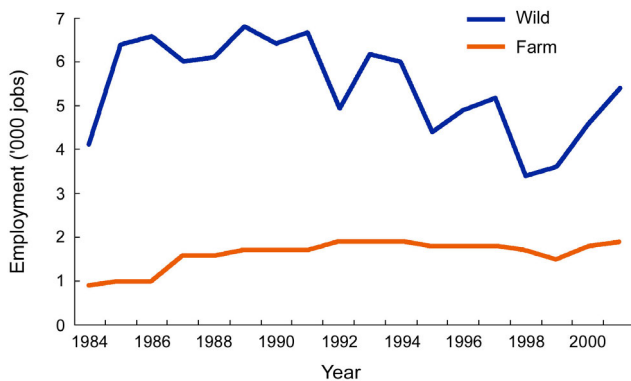


Figure 13: Employment from commercial fishing ('wild') and aquaculture ('farm') sectors. Source: British Columbia Fisheries and Aquaculture (2002).

expense of the producers. In terms of BC and Canada, such a drop in price could actually be beneficial if the benefits consumers receive as a result exceed the loss to producers. The only problem in the case of sablefish is that the consumers are mainly Japanese while the producers are Canadians. Hence, BC (Canada) suffers a loss (lower revenues) while Japanese consumers enjoy the benefits (lower prices) that are likely to result from the introduction of sablefish farming.

Employment and income from commercial fishing and aquaculture

Figure 13 below shows the number of jobs in the commercial fishing and aquaculture sectors of BC. It is clear that the wild sector has consistently provided more jobs in BC than has the farmed sector. This is not surprising given that aquaculture, in particular salmon farming, is in general a more mechanized and controlled activity than wild salmon fishing. Table 3 below reports the average annual (i) number of jobs, (ii) total income, (iii) revenue per capita, and (iv) productivity per capita from commercial fishing and aquaculture sectors. We see from this table that the two sectors provided nearly the same amount of wages and salaries (C\$21.83 and 19.97 million, respectively). The average number of jobs from commercial fishing is over three times that from the aquaculture sector, while the wages and salaries per worker from the latter is just under three times those from the commercial fishing sector. The major difference between commercial fishing and aquaculture income per employee is probably partly due to the fact that commercial fishing crews are often compensated with shares of their catch.

Figure 14 reports the annual wages and salaries earned by workers in the two sectors. We see from this figure that initially wages and salaries from both sectors increased, but then within a few years wages and salaries from commercial fishing began to decline while the rate of increase from aquaculture tapered off.

The employment data analyzed above are taken from the BC Government's website published in 2002. A report prepared by AXYS Environmental Consulting Ltd (2002) for the BC Ministry of Sustainable Resource Management states that 3-5 on-site full-time positions are required on a typical farm. Since there are about 80 operating salmon farms in BC, this gives an estimated 320 full-time on-site jobs in BC – a remarkable difference from the 1622 jobs reported on the BC government website, which includes off-site indirect and induced jobs.

Finally, data from Norway, a country with a longer track record and more accessible data than BC, shows that as aquaculture production increases, employment per tonne produced decreases (Directorate of Fisheries, 2000), this being a result of the pressure to increase economic efficiency in an ever-competitive business facing declining world market prices.

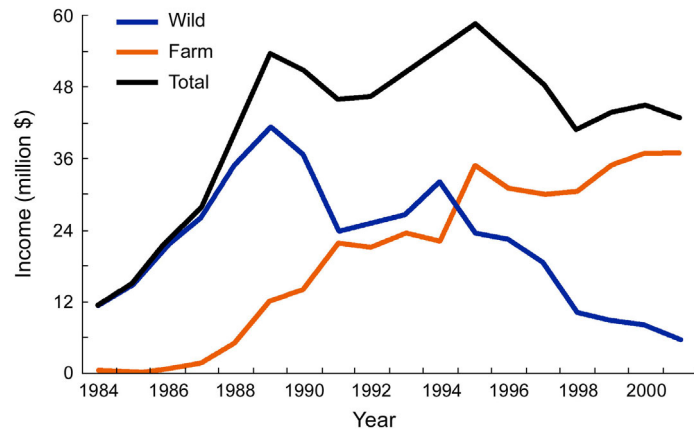


Figure 14: Wages and salaries from commercial, ‘wild,’ fishing and aquaculture, ‘farm,’ sectors (British Columbia Fisheries and Aquaculture, 2002).

Table 3. Total employment and total wages, and revenue per capita and productivity per capita from commercial fishing and aquaculture sectors. Source: British Columbia Fisheries and Aquaculture, 2002.

	Number of jobs	Total wages (million\$)	Revenue per job (\$/job)	Productivity per job (t/job)
Commercial fishing	5,428	21.8	3,920	46
Aquaculture	1,622	20.0	11,356	18

SUMMARY AND CONCLUSIONS

The following are some of the key findings of this study:

- From an ecological perspective, the potential for negative interactions between wild and farm stocks is high. Further, because the sablefish knowledge base is narrow relative to that of salmon aquaculture, itself plagued with serious challenges, it is clear that timely diagnoses and successful remediation of the inevitable emergent problems is unlikely. We conclude that sablefish aquaculture development in BC is destined to proceed on a trial and error basis with coastal communities and BC's marine environment exposed to some risk.
- A decrease in wild salmon landings followed the increase in salmon aquaculture. There was no corresponding decrease in wild salmon landings in Alaska where a ban on salmon farming exists.;
- A decrease in the price of sablefish will ultimately follow an increase in sablefish supply to the market from aquaculture. This decrease will be at the expense of both sablefish farmers and fishers in Canada but beneficial to sablefish fish consumers, which in this case are mainly Japanese. Thus, benefits are exported while costs are entirely absorbed within Canada.
- At low aquaculture production levels, small economic gains are possible if BC engages in sablefish farming under different ecological externality (impact) assumptions compared to salmon. However, gains quickly disappear as production increases towards anticipated levels.
- Rather surprisingly, our study shows that a sablefish farming ban in BC would actually be beneficial to the province, if BC wild sablefish landings can be marketed in a way that would allow it to command a price premium of about 20-25%.
- From the experience of salmon farming in BC, it appears that sablefish farming is unlikely to add to (i) BC and Canada's GDP, (ii) export earnings, and (iii) number of people employed, in the sablefish sector of BC's economy.

Arguments in support of sablefish aquaculture could have merit only if rewards in the offing exceeded the potential risks. The economic analysis in this report demonstrates that the chances of BC achieving significant gains from sablefish farming is very low. There is currently a push by some key decision makers for the establishment of an industrial sablefish aquaculture industry in BC. The message from this study is that policy makers need to tread gently because while the risks may be high the potential gains are not large. In fact, our economic analysis may have understated the potential risks of sablefish farming by focusing only on the interaction between farm and wild sablefish, as there may be potential risks to other species and the marine habitat as a whole, whose costs are not factored into the analysis. The information vacuum in which this issue unfolds is characterized by something as fundamental as sablefish stock structure which remains ambiguous. Tagging data indicate extensive sablefish movement and a single large stock from Washington through Alaska (Dr. Carl Walters, UBC; *pers. comm.*) suggesting that it is the whole North American stock that is at risk. Whereas isotope data suggest three or more reproductively isolated populations reside within the BC-Oregon corridor alone. Pattern and magnitude of effect are nearly impossible to meaningfully address given the general dearth of data – even at this most fundamental level.

Global aquaculture over-production (largely from Norway and Chile) has driven the price of all salmon to all-time lows. BC producers must offload production costs to remain competitive, which manifests itself as 'ecological problems'. For instance, we have outlined that the need to minimize transport costs is at the root of the salmon- sea lice issue and that 'escape-proof' net-pen systems are feasible but at current low salmon prices, are worth more than the salmon they contain. Land-based closed containment is out of the question – economically, not technically. Sourcing "clean" feed to reduce bioaccumulation and bioamplification issues is possible, just not economically viable. BC salmon producers are not the authors of their fate, but are at the mercy of global markets. The collective answer of the BC industry is the need to expand, to adopt greater economies of scale, to remain competitive with other global producers. The question is to what end? And at what risk and cost?

ACKNOWLEDGEMENTS

The financial support for research assistance by the Canadian Sablefish Association is gratefully acknowledged. Rashid Sumaila also acknowledges the *Sea Around Us* Project initiated and funded by the Pew Charitable Trusts. We thank Jennifer Gee for research assistance and Dale Marsden, Steve Martell, M.L. Deng Palomares, Daniel Pauly, Carl Walters and Dirk Zeller for their comments on an earlier draft. Finally, we thank Janice Doyle for proof-reading the report and Rachel C. Atanacio for helping out with the figures and frontpage design.

REFERENCES

- Alaska Department of Fish and Game (ADF&G) 1985. Sablefish, *Anoplopoma fimbria*. In: Alaska habitat management guide, south central region, Volume 1: Life histories and habitat requirements of fish and wildlife. 1: 353-357.
- Alaska Department of Fish and Game (ADF&G) 2004 (a). Commercial, personal use and subsistence salmon fisheries, region I: Southeast Alaska–Yakutat. Commercial Fisheries Division, Alaska Department of Fish and Game, Juneau, Alaska. Regional information report No. 1J04-01. 34p.
- Alaska Department of Fish and Game (ADF&G) 2004 (b). Annual management report 2003. Division of Commercial Fisheries --- Bristol Bay Area, Alaska Department of Fish and Game. Regional Information Report 1 No. 2A04-16, 149p.
- Alderice, D.F., Jensen, J.O.T., Velsen, F.P.J. 1988. Preliminary trials on incubation of sablefish (*Anoplopoma fimbria*) eggs. *Aquaculture* 69: 271-290.
- Anderson, R. M., May, R. M. 1978. Regulation and stability of host-parasite population interactions. I. Regulatory processes. *J. Anim. Ecol.* 47:219-247.
- Armstrong, R.H. 1996. Alaska's Fish: A Guide to Selected Species. Alaska Northwest Books. 94 p.
- Auditor General of British Columbia 2004. Salmon Forever: An Assessment of the Provincial Role in Sustaining Wild Salmon. 107p. <http://bcauditor.com/AuditorGeneral.htm>.
- Auditor General of Canada. 2000. The Effects of Salmon Farming in British Columbia on the Management of Wild Salmon Stocks. [http://www.oag-bvg.gc.ca/domino/reports.nsf/html/0030ce.html/\\$file/0030ce.pdf](http://www.oag-bvg.gc.ca/domino/reports.nsf/html/0030ce.html/$file/0030ce.pdf).
- AXYS Environmental Consulting Ltd 2002. Net Pen Finfish Aquaculture in British Columbia. Report prepared for Economic Development Branch, BC Ministry of Sustainable Resource Management, 10p.
- Beamish, R. J., McFarlane, G. A. 1988. Resident and dispersal behavior of adult sablefish (*Anaplopoma fimbria*) in the slope waters off Canada's west coast. *Can. J. Fish. Aquat. Sci.* 45: 152-164.
- Bocking, R.C., Link, M.R., Baxter, B., Nass, B., Jantz, L, 2002. Meziadin Lake Biological Escapement Goal and Considerations for Increasing Yield of Sockeye Salmon (*Oncorhynchus nerka*), DFO Canadian Science Advisory Secretariat Research Document 124, 56p.
- British Columbia Fisheries and Aquaculture (BCF&A) 2002. British Columbia's Fisheries & Aquaculture Sectors, Ministry of Management Services of British Columbia, 107p.
- Cascorbi, A. 2004. Seafood Watch - Seafood Report: Sablefish. Monterey Bay Aquarium, 22p.
- Clemens, W.A., Wilby, G.V. 1961. Fishes of the Pacific Coast of Canada (2nd ed). Fish. Res. Bd. Canada Bull. (68):1-443 .
- Cox-Rogers, S. 2004. Pre-Season 2003 Stock Size Forecasts For Skeena River and Nass River Sockeye Salmon, Canadian Science Advisory Secretariat Research Document 020, Fisheries and Oceans Canada, 22p.
- Cox-Rogers, S., Hume, J.M.B., Shortreed, K.S. 2004. Stock Status and Lake-Based Production Relationships for Wild Skeena River Sockeye Salmon, Canadian Science Advisory Secretariat Research Document 010, Fisheries and Oceans Canada, 60p.
- Daszak, P., Cunningham, A., Hyatt, A. 2000. Emerging infectious diseases of wildlife: threats to biodiversity and human health. *Science* 287:443-449.
- Deem, S., Karesh, W., Weisman, W. 2001. Putting theory into practice: wildlife health in conservation. *Cons. Biol.* 15:1224-1233.
- Fisheries and Oceans Canada (DFO) 2003. BC Marine Atlantic Salmon Captures. Available at http://www.pac.dfo-mpo.gc.ca/sci/aqua/aswp/bc_ad_marine.pdf.
- Directorate of Fisheries 2000. Key Figures from Norwegian Aquaculture Industry. Department of Aquaculture, Norway, 15pp.
- Dobson, A. P., Foufopoulos, J. 2001. Emerging infectious pathogens of wildlife. *Phil. Trans. R. Soc. Lond. B.* 356:1001-1012.
- Eschmeyer, W.N., Herald, E.S., Hammann, H. 1983. A Field Guide to Pacific Coast Fishes of North America. Houghton Mifflin Company, Boston, U.S.A. 336p.
- Fiske, P., Lund, R.A. 1999. Escapes of reared salmon in coastal and riverine fisheries in the period 1989-1998. NINA Oppdragsmelding 603: 1-23 (Norwegian with English abstract).
- Fleming, I. A., Einum, S. 1997. Experimental tests of genetic divergence of farmed from wild Atlantic salmon due to domestication. *ICES J. Mar. Sci.* 54:1051-1063.
- Fleming, I.A., Hindar, K., Mjølnerød, I.B., Jonsson, B., Balstad, T., Lamberg, A. 2000. Lifetime success and interactions of farm salmon invading a native population. *Proceedings Royal Society of London (B)* 267:1517-1523.
- Fleming, I. A., Agustsson, T., Finstad, B., Johnsson, J. I., Björnsson, B. T. 2002. Effects of domestication on growth physiology and endocrinology of Atlantic salmon (*Salmo salar*). *Can. J. Fish. Aquat. Sci.* 59:1323-1330.
- Frimodt, C., 1995. Multilingual illustrated guide to the world's commercial coldwater fish. Fishing News Books, Osney Mead, Oxford, England. 215p.

- Gao, Y., Joner, S.H., Bargmann, G.G. 2001. Stable isotopic composition of otoliths in identification of spawning stocks of Pacific herring (*Clupea pallasii*) in Puget Sound. *Can. J. Fish. Aquat. Sci.* 58:2113-2120.
- Gao, Y., Joner, S.H., Svec, R.A., Weinberg, K.L. 2004. Stable isotopic comparison of otoliths of juvenile sablefish (*Anoplopoma fimbria*) from waters off the Washington and Oregon coasts. *Fisheries Research* 68:351-360.
- Grenfell, B. T., Dobson, A. P. 1995. *Ecology of Infectious Diseases in Natural Populations*. Cambridge: Cambridge University Press. 521p.
- GSGislason & Associates Ltd, 2001. Halibut and Sablefish Aquaculture in Bc: Economic Potential. BC Ministry of Agriculture, Food & Fisheries, Victoria, BC, 32p.
- Hudson, P. J., Rizzoli, A., Grenfell, B. T., Heesterbeek, H., Dobson, A. P. 2002 *The Ecology of Wildlife Diseases*. New York: Oxford University Press. 197p.
- Huppert, D.D., Best, B. 2004. Study of Supply Effects on Sablefish Market Price. School of Marine Affairs, University of Washington, 46p.
- Hyatt, K., Luedke, W., Rankin, P., Till, J., Lewis, D. 2003. Review of the Year 2002 Return of Barkley Sound Sockeye Salmon and Forecasts for 2003, Canadian Science Advisory Secretariat Research Document 033, Fisheries and Oceans Canada. 39p.
- Johnsen, B.O. Jensen, A.J.. 1986. Infections of Atlantic salmon, *Salmo salar*, by *Gyrodactylus salaris* in Norwegian salmon rivers. *Journal of Fish Biology*. 29:233-241.
- Kendall, A.W., Matarese, A.C. 1987. Biology of eggs, larvae and epipelagic juveniles of sablefish, *Anoplopoma fimbria*, in relation to their potential use in management. *Marine Fisheries Review* 49(1): 1-13.
- Kent, M. L. 2000. Marine netpen farming leads to infections with some unusual parasites. *International Journal of Parasitology* 30: 321-326.
- King, J.R., McFarlane, G.A., Beamish, R.J. 2000. Decadal scale-patterns in the relative success of sablefish (*Anoplopoma fimbria*). *Fish. Oceangr.* 9:62-70.
- Krkosek, M., Lewis, M.A., Volpe, J.P. 2005. Fish Farms, Sea Lice, and Infestations of Wild Salmonids. *Proceedings of the Royal Society of London Series B. In press*.
- Leggatt, S.M. 2001. Clear Choices, Clean Waters: The Leggatt inquiry into salmon farming in British Columbia. 35p. http://www.davidsuzuki.org/files/Leggatt_reportfinal.pdf
- Lund, R.A., Økland, F., Hansen, L.P. 1991. Farmed Atlantic salmon (*Salmo salar*) in fisheries and rivers in Norway. *Aquaculture* 98:143-150.
- Lynch, B., Skannes, P. 2004. Report to the board of fisheries, summary of the 2003 --- Southeast Alaska/Yakutat --- salmon troll fisheries. Regional information report No. 1J04-01. Division of Commercial Fisheries Douglas, Alaska Department of Fish and Game, Alaska, 78p.
- Mackenzie, K., Longshaw, M., Begg, G. S., Mcvicar, A. H. 1998. Sea lice (Copepoda: Caligidae) on wild sea trout (*Salmo trutta* L.) in Scotland. *ICES J. Mar. Sci.* 55:151-162.
- Marshall, S. 2003. The incidence of sea lice infestations on wild sea trout compared to farmed salmon. *Bull. Europ. Assoc. Fish. Path.* 23:72-79.
- May, R. M. 1988. Conservation and disease. *Cons. Biol.* 2:28-30.
- May, R. M., Anderson, R. M. 1978. Regulation and stability of host-parasite population interactions. II. Destabilizing processes. *J. Anim. Ecol.* 47:249-267.
- McCallum, H., Dobson, A.P. 1995. Detecting disease and parasite threats to endangered species and ecosystems. *Trends Ecol. Evol.* 10:190-194.
- McFarlane, G. A., Saunders, M.W. 1997. Dispersion of Juvenile sablefish, *Anoplopoma fimbria*, as indicated by tagging in Canadian waters. NOAA Technical Report NMFS 130. p137-150.
- McFarlane, G.A., Saunders, M.W., Thomson, R.E., Perry, R.I. 1997. Distribution and abundance of larval sablefish, *Anoplopoma fimbria*, off the west coast of Vancouver Island, and linkages to physical oceanography. NOAA Technical Report, NMFS 130 Biology and Management of Sablefish, *Anoplopoma fimbria*: 27-38.
- McGinnity, P., Prodöhl, P., Ferguson, A., Hynes, R., Maoiléidigh, N. Ó., Baker, N., Cotter, D., O'Hea, B., Cook, D., Rogan, G., Taggart, J., Cross, T. 2003. Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proceedings Royal Society of London (B)* 270:2443-2450.
- McVicar, A. H. 1997. Disease and parasite implications of the coexistence of wild and cultured Atlantic salmon populations. *ICES J.Mar. Sci.* 54:1093-1103.
- Moring, J.R. 1989. Documentation of unaccounted-for losses of chinook salmon from saltwater cages. *The Progressive Fish Culturist*. 51:173-176.
- Morton, A., Volpe, J.P. 2002. A description of Atlantic salmon *Salmo salar* in the Pacific salmon fishery in British Columbia, Canada, in 2000. *Alaska Fishery Research Bulletin* 9:102-110.
- National Marine Fisheries Service (NMFS) 2004. Database of Foreign Trade for Fisheries Products from Jan. 1975 to April 2004. Fisheries Statistics and Economics Division, National Marine Fisheries Services., available at accessed at July 12, 2004.

- Pacific Fisheries Resource Conservation Council (PFRCC) 2003. Wild Salmon and Aquaculture in British Columbia. 13p. http://www.fish.bc.ca/reports/pfrcc_wild_salmon_and_aquaculture_2.pdf.
- Porter, G. 2003. Protecting wild Atlantic salmon from impacts of salmon aquaculture. World Wildlife Fund, Washington DC and Atlantic Salmon Federation, St. Andrews NB. 72p.
- Robichaud, D., Labelle, M., English, K.K. 2004. A preliminary assessment of the issues associated with sablefish aquaculture. LGL Ltd., Sidney, British Columbia, 25p. <http://www.canadiansablefish.com/news20.htm>
- Schubert, N.D., Beacham, T.D., Cass, A.J., Cone, T.E., Fanos, B.P., Foy, M., Gable, J.H., Grout, J.A., Hume, J.M.B., Johnson, M., Morton, K.F., Shortreed, K.S., Staley M.J., Withler, R.E. 2002. Status of Cultus Lake Sockeye Salmon (*Oncorhynchus nerka*), Canadian Science Advisory Secretariat Research Document 064, Fisheries and Oceans Canada. 119p.
- Scott, M. E. 1988. The impact of infection and disease on animal populations: Implications for conservation biology. *Cons. Biol.* 2:40-56.
- Simpson, K., Chamberlain, M., Fagan, J., Holtby, B., Sweeting, R., Tanasichuk, R.W., 2003. Forecast for southern and central British Columbia coho salmon in 2003, Canadian Science Advisory Secretariat Research Document 102, Fisheries and Oceans Canada. 76p.
- Sonu, S.C. 1996. The Japanese Sablefish Market. NOAA Technical Memorandum – NMFS. NOAA-TMNMFS-SWR-031. 52p.
- Steven, C., Fraser, E. 2004. British Columbia Sablefish Aquaculture Risk Assessment Based on the National Codes of Introductions and Transfers. 78p. <http://web.mala.bc.ca/cch>.
- Thompson, A. 2004. Atlantic Salmon Watch Program, Victoria Times-Colonist June 15, page C1.
- Tully, O., Gargan, P., Poole, W. R., Whelan, K. F. 1999 Spatial and temporal variation in the infestation of sea trout (*Salmo trutta* L.) by the Caligid Copepod *Lepeophtheirus salmonis* (Kroyer) in relation to sources of infection in Ireland. *Parasitology* 119: 41-51.
- Wickham, E. 2003. Dead fish and fat cats. Granville Island Pub., Vancouver, British Columbia, Canada, 167p.

APPENDICES

APPENDIX 1: SURVEY OF SOME DISEASES AND PARASITES RELEVANT TO SABLEFISH AQUACULTURE

Disease/Parasite	<i>Anisakis</i>	<i>Flavobacterium branchiophila</i>	<i>Renibacterium salmonarium</i>
Common Name	Cod Worm	Bacterial Gill Disease	Bacterial Kidney Disease (BKD)
Type of Pathogen	Nematode	Myxobacteria	Bacteria
Distribution	World-wide	Environmental microflora	World-wide
Intermediate Host(s)/Transmission	Crustaceans	None/ Horizontal spread-water to fish in early stages and then fish-fish as disease spreads	None/ Egg and fish transmitted
Vulnerable Life History Stage	Juvenile and older (wild populations)	Juveniles usually more susceptible	Possibly juveniles as salmonid smolts show immunological suppression
Pathology	Only if host consumed-not fatal	Will result in fish death if allowed to progress	Chronic-often fatal-Vertical and horizontal spread
Appearance/Diagnosis	White coils on abdominal organs	Swollen, clubbed or fused gill filaments, sudden cessation of feeding, sluggish behavior	White nodular lesions on kidney and spleen. Body cavity filled with fluid in late stages
Treatment		External disinfectants-Prophylactic treatment and responsive treatment: Quaternary ammonium (e.g. Benzalkonium Chloride) followed by Chloramine-T. Also, immersion baths of chloramines, blue vitrol, malachite green, sulphonamides or chinolone chemotherapeutics	No vaccine available. Antibiotics only temporary control as bacteria tendency for resistant strains. Use Erythromycin.
Potential Effects on Aquaculture		Can result from environmental stresses such as overcrowding. May cause excessive mortality in fish under stress	Outbreaks possible-particularly of antibiotic resistant strains. Potential to cause high mortality if outbreak in intensively cultured fish (fish vaccine)
Reference:	1,6,22	1,5,10,22,24	4,10,18,22,27

Disease/Parasite Common Name	<i>Epitheliocystis</i>	<i>Aeromonas salmonicida</i> Furunculosis	Leech Leech
Type of Pathogen	Chlamydia-like bacteria	Bacteria	Macro-Parasite
Distribution	World-wide	World-wide	World-wide
Intermediate Host(s)/ Transmission	Transmission method unknown-obligate intracellular parasite	Lateral transmission-via infected fish and contaminated solid surfaces and water.	None/ Not transmitted
Vulnerable Life History Stage	Juvenile and larval salmonids mortality rates of 4-100%	All	
Pathology Appearance/Diagnosis	Gills and skin- hypertrophied cells with fine basophilic granular inclusions. Show respiratory distress	High Appetite loss, hemorrhagic gills, enlarged spleen, intestines engorged with blood, muscle lesions. When allowed to advance always results in death	Externally apparent; skin &/or fins most commonly affected
Treatment		Vaccine or antibiotics including terramycin, romcin, and oxytetracycline-Antibiotic treatment often only inhibit growth of bacteria-not kill it-so treated fish remain carriers. Vaccines do not offer complete protection	
Potential Effects on Aquaculture	More prevalent in cultured fish stocks. Likelihood of occurrence increased with environmental stress	Bacteria adhere to solid surfaces-particularly plastics-and stainless steel to a lesser extent. Potential concern-dead and dying fish contain large quantities of bacteria- Loss of appetite can make treatment difficult when antibiotics in feed used. More likely to occur when conditions induce stress e.g. elevated water temperatures	
Reference:	6,17	4,5,9,10,12,22,27	20,22,23
Disease/Parasite Common Name	Microsporidae	Viral Hemorrhagic Septicemia (VHS)	Myxobacterial fin infection
Type of Pathogen	Assemblage of related bacteria	Rhabdovirus	Bacteria
Distribution	Affects a widely distributed variety vertebrates and invertebrates	World wide	
Intermediate Host(s)/ Transmission	Release of spores from infected fish	Horizontal transmission-direct or vector infection-including water	Water borne- enter fish via abraded areas
Vulnerable Life History Stage		Young fish-vaccine	
Pathology		Infection usually results in death	
Appearance/Diagnosis	Degeneration of muscle tissues-muscle cells may contain cysts with necrosis of overlying skin	Hemorrhaging in external and internal organs, necrosis of liver, spleen, hematopoietic tissue and pancreatic acini	
Treatment		No known therapeutic treatment available to control virus	
Potential Effects on Aquaculture	Release of spores into water would increase spread of infection	Severe disease with high mortality. Once VHS established in a farm site it becomes endemic due to carrier fish	Infection most likely when fish have broken skin-occurs frequently in net pens
Reference:	13	11,12,15,22,27	22

Disease/Parasite		<i>Pseudomonas</i> sp.	<i>Dactylogyrus</i>
Common Name	Papillomatosis		Fluke
Type of Pathogen	Retrovirus	Bacteria	Trematode
Distribution	widespread	widespread	North America
Intermediate Host(s)/ Transmission	None	None / transmission from water, concentrations of organic matter or within the fish	None
Life history stage			Juvenile
Sablefish vulnerable at Pathology		High	
Appearance/Diagnosis	Epidermal tumours on skin and scales-up to 5 mm thick and 4 cm in diameter	Toxins released from bacteria affect the fish	Opaque mucus covering gills, increased respiratory rate, gill tissue destroyed eventually
Treatment	None known	Resistant to most antibiotics	Can treat with formalin, NaCl, methyl blue or metriphonate
Potential Effects on Aquaculture	Leaves fish susceptible to secondary infections	Stressed fish are particularly vulnerable to infection	
Reference:	2,16	22,26	7,22
Disease/Parasite	<i>Caligus clemensi</i>	<i>Loma salmonae</i>	<i>Cryptocotyl</i>
Common Name	Sea lice (Lepeophtherius salmonis)	Microsporidial Gill Disease (MGD)	Fluke
Type of Pathogen	Copepod	Protozoan parasite	Trematode
Distribution	Wide spread		
Intermediate Host(s)/ Transmission	Broad host range	Through water or by ingestion of infected viscera	littoral snails
Vulnerable Life History Stage	All-particularly juveniles		
Pathology	High in areas of dense host population	High	
Appearance /Diagnosis	Visible on body of fish	Spores form white-colored cyst in gills or muscles	black dots on skin
Treatment	Emamectin benzoate (Slice)	Acridflavin (trypaflavin)	
Potential Effects on Aquaculture	Similar to outbreaks with other aquaculture operations part. salmon farms	Causes high mortality	
Reference:	22	1,6,8,22	24,21

Disease/Parasite	<i>Diplostomum</i>	<i>Trichoina</i> sp.	<i>Vibrio anguillarum</i>
Common Name	Eye Fluke		Vibriosis
Type of Pathogen	Trematode	Protozoa	Bacteria
Distribution			Marine and freshwater fish world wide
Intermediate Host(s)/ Transmission	Snails/ Feeding on infected snails		Always part of aquatic microflora. Transmission via ingestion of infected materials or via wounds. Can survive in organic material- e.g. fouling on nets or debris accumulations below net pens
Vulnerable Life History Stage	Once begin feeding off bottom- ~ >3y.		Protection from vaccine only found to occur in fish > 1.0-2.5 g.
Pathology Appearance/Diagnosis	Changes fish behaviour to increase chance of avian predation. May cause blindness.	Feeds on and damages the gills	High Toxins produced by bacteria result in severe anemia- fish appear dark and hemorrhagic, swollen spleen, liquefying kidneys, muscle erosion due to ulcers, white eyes, loss of vision and pale gills
Treatment		Therapeutic bath partially effective-using malachite green or malachite green and formaldehyde	Antibiotics such as tetracycline, sulphonamides, quinolines-treatment results in variable success due to development of drug resistances by the bacteria. Vaccines available and well established
Potential Effects on Aquaculture			Stress related disease- occurrence has been linked to overstocking, over handling, rapid changes in water temperature. Net damage to fish may increase infection rate.
Reference:	3,11,22	22,27	10,12,19,20,22

APPENDIX 2: LITERATURE CITED IN APPENDIX 1

- Anonymous, 1992. Bad Bug Book. US Food and Drug Administration Center for Food Safety and Applied Nutrition. <http://vm.cfsan.fda.gov/~mow/chap25.html>. Updated January 2003.
- Anonymous, 2000a. Atlantic salmon papillomatosis (retrovirus). Fish Health Issues 2(11). <http://www.maine.gov.ifw/fishing/fishlab/vol2issue11.htm>. Updated November, 2002.
- Anonymous, 2000b. Aquaculture Dictionary. <http://www.aquatext.com/dicframe.htm>. Updated 2000.
- Anonymous, 2003a. Diplostomum. Parasitology Section, University Erlangen. <http://www.biologie.uni-erlangen.de/parasit/index.htm>. Updated March 2003.
- Anonymous, 2003b. Fish Diseases. Department of Natural Resources-Michigan. <http://www.michigan.gov>. Updated 2003.
- Anonymous, 2004a. Bacterial Diseases. DBWS-Aquaworld Network. <http://www.aquaworldnet.com/dbws/bacterial.htm>. Updated 2004.
- Bates, K., 2004. Dactylogyrus spp. Biology Department, Winona State University. <http://bio-winona.msus.edu/bates/Parasitology/Dactylogyrus%20spp.htm>. Update January 2004.
- Becker, J., Speare, D., Daley, J., 2001. Future directions on the control of microsporidial gill disease in salmonids. Fish Health I Abstracts, Aquaculture Canada. <http://www.aquacultureassociation.ca/ac02/abstracts/health1.htm#Becker> Updated 2002.
- Carbello, J., Seoane, R.M., Nieto, T.P. 2000. Adhesion of *Aeromonas salmonicida* to materials used in aquaculture. Bull. Eur. Fish Pathol. 20(2): 77-82.
- Crosa, J.H. (ed.), 1983. Bacterial and viral diseases of fish: molecular studies. Washington Sea Grant Program, Seattle W.A. 86p.
- Elkan E., Reichenbach-Klinke, H., 1974. Color atlas of the diseases of fishes, amphibians and reptiles. TFH Publications, Inc. Ltd. Toronto, Ontario.
- Ellis, A.E. (ed.), 1988. Fish Vaccination. Academic Press. Harcourt Brace Jovanovich, Publishers Toronto, Ontario. 255p.
- Ferguson, H.W., 1989. Systematic Pathology of Fish. Iowa State University Press, Ames, IA. 263 p.
- Gores, K.X., Prentice E.F., 1984. Growth of sablefish (*Anoplopoma fimbria*) in marine net-pens. Aquaculture. 36:379-386.
- Ishiki, T., Nishizawa, T., Kobayashi, T., Nagano, T., Miyazaki, T., 2001. An outbreak of VHSV (viral hemorrhagic septicemia virus) infection in farmed Japanese flounder *Paralichthys olivaceus* in Japan. Dis. Aquat. Org. 47:87-99.
- Kortet, T., Vainikka, A., Taskinen, J., 2003. Effect of epidermal papillomatosis on survival of the freshwater fish *Rutilus rutilus*. Dis. Aquat. Org. 57:163-165.
- Nowak, B.F., Clark, A. 1999. Prevalence of epitheliocystis in Atlantic salmon, *Salmo salar* L., farmed in Tasmania, Australia. J. Fish. Dis. 22:73-78.
- O'Flynn, F., Friars, G.W., Griffiths, S.G., Mellville, K.J., 2002. Studies on bacterial kidney disease resistance. The Atlantic Salmon Federation: Research. <http://www.asf.ca/Research/resrcho5.htm>. Updated 2002.
- Olsson, J.C., Joborn, A., Westerdahl, A., Blomberg, L., Kjelleberg, S., Conway, P.L., 1998. Survival, persistence, and proliferation of *Vibrio anguillarum* in juvenile turbot, *Scophthalmus maximus* (L.), intestines and faeces. J. Fish. Dis. 21:1-9.
- Qin, Q., Wu, Z., Pan, J., 2000. Immunization against vibriosis in maricultured grouper, *Epinephelus awoara* in China. p.132-133. In : The Third World Fisheries Congress Abstracts. Beijing, P.R. China.
- Ramsay, J.M., Speare, D.J., Sanchez, J.G., Daley, J. 2001. The transmission potential of *Loma salmonae* (Microspora) in the rainbow trout, *Oncorhynchus mykiss* (Walbaum), is dependent upon the method and timing of exposure. J. Fish. Dis. 24:453-460.
- Roberts, R.J., Shepherd, C.J., 1986. Handbook of Trout and Salmon Diseases. 2nd edition. Fishing News Books Ltd., Farnham, Surrey, England. 222p.
- Roberts, R.J. (ed.), 1978. Fish Pathology. University Press, Aberdeen. Cassell ltd. 318p.
- Snieszko, S.F., Axelrod, H.R. (eds), 1970. Diseases of Fishes. TFH Publications, Inc. Ltd. Toronto, Ontario.
- Steimle, F.W., Shaheen, P.A., 1999. Tautog (*Tautoga onitis*) Life History and Habitat Requirements. NOAA Technical Memorandum NMFS-NE-118: 23p. <http://www.nefsc.noaa.gov/nefsc/publications/tm/tm118/tm118index.htm>. Updated May 2004.
- Stover, K.C., Pham, X.Q., Erwin, A.L., Mizoguchi, S.D., Warrener, P., Hickey, M.J., Brinkman, F.S.L., Hufnagle, W. O., Kowalik, D.J., Lagrou, M., Garber, R.L., Goltry, L., Tolentino, E., Westbrook-Wadman, S., Yuan, Y., Brody, L.L., Coulter, S.N., Folger, K.R., Kas, A., Larbig, K., Lim, R., Smith, K., Spencer, D., Wong, G.K.-S., Wu, Z., Paulsen, I., Reizer, J., Saier, M.H., Hancock, R.E.W., Lory, S., Olson, M.V., 2000. Complete genome sequence of *Pseudomonas aeruginosa* PAO1: an opportunistic pathogen. Nature. 406: 959-964.
- Tesarcik, J., Svobodova, Z. (eds.), 1991. Fish Diseases in Manual for international training course on fresh-water fish diseases and intoxicants: diagnostics, prophylaxis and therapy. <http://www.fao.org/docrep/field/003/AC160E/AC160>.



1993 Volume 1(1) – 2005 Volume 13(3)

Pitcher, T. and Chuenpagdee, R. (eds) (1993) Commercial Whaling - The Issues Reconsidered. Fisheries Centre Research Reports 1(1):36pp.

Pitcher, T. and Chuenpagdee, R. (eds) (1993) Decision Making by Commercial Fishermen: a missing component in fisheries management? Fisheries Centre Research Reports 1(2):75pp.

Pitcher, T. and Chuenpagdee, R. (eds) (1994) Bycatch in Fisheries and their Impact on the Ecosystem. Fisheries Centre Research Reports 2(1):86pp.

Bundy, A. and Babcock, E. (eds) (1995) Graduate Student Symposium on Fish Population Dynamics and Management. Fisheries Centre Research Reports 3(2):33pp.

Pitcher, T. and Chuenpagdee, R. (eds) (1995) Harvesting Krill: Ecological Impact, Assessment, Products and Markets. Fisheries Centre Research Reports 3(3):82pp.

Pauly, D., Christensen, V. and Haggan, N. (eds) (1996) Mass-Balance Models of North-eastern Pacific Ecosystems. Fisheries Centre Research Reports 4(1):131pp.

Pitcher, T. (ed) (1996) Reinventing Fisheries Management. Fisheries Centre Research Reports 4(2):84pp.

Pitcher, T. (ed) (1997) The Design & Monitoring of Marine Reserves. Fisheries Centre Research Reports 5(1), 47pp.

Dalsgaard, J. and Pauly, D. (1997) Preliminary Mass-Balance Models of North-eastern Pacific Ecosystems. Fisheries Centre Research Reports 5(2), 33pp.

Pitcher, T., Watson, R., Courtney, A. and Pauly, D. (1998) Assessment of Hong Kong's Inshore Fishery Resources. Fisheries Centre Research Reports 6(1):148pp.

Pauly, D. and Weingartner, G. (eds) (1998) Use of Ecopath with Ecosim to Evaluate Strategies for Sustainable Exploitation of Multi-Species Resources. Fisheries Centre Research Reports 6(2):49pp.

Vasconcellos, M. and Preikshot, D. (eds) (1998) Graduate Student Symposium on Fish Population Dynamics and Management. Fisheries Centre Research Reports 6(3):40pp.

Okey, T. and Pauly, D. (eds) (1998) Trophic Mass-Balance Model of Alaska's Prince William Sound Ecosystem for the Post-Spill Period 1994-1996. Fisheries Centre Research Reports 6(4):143pp. [n/a; superceded by 7(4), 1999]

Pauly, D., Pitcher, T., Preikshot, D. and Hearne, J. (eds) (1998) Back to the Future: Reconstructing the Strait of Georgia Ecosystem. Fisheries Centre Research Reports 6(5):99pp.

Bonfil, R., Munro, G., Sumaila, U., Valtysson, H., Wright, M., Pitcher, T., Preikshot, D., Haggan, N. and Pauly, D. (eds) (1998) Distant Water Fleets: An Ecological, Economic and Social Assessment. Fisheries Centre Research Reports 6(6):111pp.

Trites, A., Livingston, P., Mackinson, S., Vasconcellos, M., Springer, A. and Pauly, D. (1999) Ecosystem Change and the Decline of Marine Mammals in the Eastern Bering Sea. Fisheries Centre Research Reports 7(1):106pp.

Pitcher, T. (ed.) (1999) Evaluating the Benefits of Recreational Fisheries. Fisheries Centre Research Reports 7(2):169pp.

Haggan, N., Beattie, A. and Pauly, D. (eds) (1999) Back to the Future: Reconstructing the Hecate Strait Ecosystem. Fisheries Centre Research Reports 7(3):65pp.

Okey, T. and Pauly, D. (eds) (1999) A Trophic Mass-Balance Model of Alaska's Prince William Sound Ecosystem for the Post-Spill Period 1994-1996, 2nd Edition. Fisheries Centre Research Reports 7(4):137pp.

Guénette, S., Chuenpagdee, R. and Jones, R. (2000) Marine Protected Areas with an Emphasis on Local Communities and Indigenous Peoples: A Review. Fisheries Centre Research Reports 8(1):56pp.

Pauly, D. and Pitcher, T. (eds) (2000) Methods for Evaluating the Impacts of Fisheries on North Atlantic Ecosystems. Fisheries Centre Research Reports 8(2):195pp.

Hunter, A. and Trites, A. (2001) An Annotated Bibliography of Scientific Literature (1751-2000) Pertaining to Steller Sea Lions (*Eumetopias jubatus*) in Alaska. Fisheries Centre Research Reports 9(1):45pp.

Watson, R., Pang, L and Pauly, D. (2001) The Marine Fisheries of China: Development and Reported Catches. Fisheries Centre Research Reports 9(2):50pp.

Zeller, D., Watson, R. and Pauly, D. (eds) (2001) Fisheries Impacts on North Atlantic Ecosystems: Catch, Effort and National/Regional Data Sets. Fisheries Centre Research Reports 9(3):254pp.

Guénette, S., Christensen, V. and Pauly, D. (eds) (2001) Fisheries Impacts on North Atlantic Ecosystems: Models and Analyses. Fisheries Centre Research Reports 9(4):344pp.

Pitcher, T., Sumaila, R. and Pauly, D. (eds) (2001) Fisheries Impacts on North Atlantic Ecosystems: Evaluations and Policy Exploration. (2001) Fisheries Centre Research Reports 9(5):94pp.

Preikshot, D. and Beattie, A. (eds) (2001) Fishing for Answers: analysis of ecosystem dynamics, trophic shifts and salmonid population changes in Puget Sound, 1970-1999. Fisheries Centre Research Reports 9(6):35pp.

Tyedmers, P. and Ward, B. (2001) A Review of the Impacts of Climate Change on BC's Freshwater Fish Resources and Possible Management Responses. Fisheries Centre Research Reports 9(7):12pp.

Sumaila, U. and Alder, J. (eds) (2001) Economics of Marine Protected Areas. Fisheries Centre Research Reports 9(8):250pp.

- Pitcher, T., Vasconcellos, M., Heymans, S., Brignall, C. and Haggan, N. (eds) (2002) Information Supporting Past and Present Ecosystem Models of Northern British Columbia and the Newfoundland Shelf. Fisheries Centre Research Reports 10(1):116pp.
- Pitcher, T. and Cochrane, K. (2002) The Use of Ecosystem Models to Investigate Multispecies Management Strategies for Capture Fisheries. Fisheries Centre Research Reports 10(2):156pp.
- Pitcher, T., Buchary, E. and Trujillo, P. (eds) (2002) Spatial Simulations of Hong Kong's Marine Ecosystem: Ecological and Economic Forecasting of Marine Protected Areas With Human-Made Reefs. Fisheries Centre Research Reports 10(3):169pp.
- Ainsworth, C., Heymans, J., Pitcher, T. and Vasconcellos, M. (2002) Ecosystem Models of Northern British Columbia for the Time Periods 2000, 1950, 1900 & 1750. Fisheries Centre Research Reports 10(4):41pp.
- Pitcher, T., Heymans, J. and Vasconcellos, J. (eds) (2002) Ecosystem Models of Newfoundland for the Time Periods 1995, 1985, 1900 and 1450. Fisheries Centre Research Reports 10(5):74pp.
- Haggan, N., Brignall, C., Peacock, B., and Daniel, R. (eds) (2002) Education for Aboriginal Fisheries Science and Ecosystem Management. Fisheries Centre Research Reports 10(6):49pp.
- Pitcher, T., Power, M., and Wood, L. (eds) (2002) Restoring the Past to Salvage the Future: report on a community participation workshop in Prince Rupert, BC. Fisheries Centre Research Reports 10(7): 55pp.
- Pauly, D. and Palomares, M.L.D. (eds) (2002) Production Systems in Fishery Management. Fisheries Centre Research Reports 10(8):28pp.
- Haggan, N., Brignall, C., and Wood, L. (eds) (2003) Putting Fishers' Knowledge to Work Conference Proceedings. Fisheries Centre Research Reports 11(1):504pp.
- Seaman, W., Smiley, B., Pitcher, T., and Wood, L. (eds) (2003) Research and Monitoring of Marine Reefs Using Volunteer Divers. Fisheries Centre Research Reports 11(2):107pp.
- Sumaila, U.R. (ed) (2003) Three Essays on the Economics of Fishing. Fisheries Centre Research reports 11(3):33pp.
- Burek, K.A., Gulland, F.M.D., Sheffield, G., Keyes, E., Spraker, T.R., Smith, A.W., Skilling, D.E., Evermann, J., Stott, J.L., and Trites, A.W. (2003) Disease Agents in Steller Sea Lions in Alaska: A Review and Analysis of Serology Data From 1975-2000. Fisheries Centre Research Reports 11(4):26pp.
- Heymans, J.J. (ed) (2003) Ecosystem Models of Newfoundland and Southeastern Labrador: Additional Information and Analyses for 'Back to the Future'. Fisheries Centre Research Reports 11(5):79pp.
- Zeller, D., Booth, S., Mohammed, E. and Pauly D. (eds) (2003) From Mexico to Brazil: Central Atlantic Fisheries Catch Trends and Ecosystem Models. Fisheries Centre Research Reports 11(6):264pp.
- Pitcher, T. (ed) (2004) Back to the Future: Advances in Methodology for Modelling and Evaluating Past Ecosystems as Future Policy Goals. Fisheries Centre Research Reports 12(1):158pp.
- Kavanagh, P. and Pitcher, T. (2004) Implementing Microsoft Excel Software for *RAPFISH*: A Technique for the Rapid Appraisal of Fisheries Status. Fisheries Centre Research Reports 12(2):75pp.
- Stanford, R. and Pitcher, T. (2004) Ecosystem Simulations of the English Channel: Climate and Trade-offs. Fisheries Centre Research Reports 12(3):103pp.
- Christensen, V., Walters, C. and Pauly, D. (2004) Ecopath with Ecosim: A User's Guide. Fisheries Centre Research Reports 12(4) (in press).
- Morato, T. and Pauly, D. (2004) Seamounts: Biodiversity and Fisheries. Fisheries Centre Research Reports 12(5):78pp.
- Watson, R., Hoshino, E., Beblow, J., Revenga, C., Kura, Y. and Kitchingman, A. (2004) Fishing Gear Associated With Global Marine Catches. Fisheries Centre Research Reports 12(6):32pp.
- Palomares, M.L.D. and Pauly, D. (2004) West African Marine Ecosystems: models and fisheries impacts. Fisheries Centre Research Reports 12(7):209pp.
- Sumaila, U.R., Volpe, J., and Liu, Y. (2005) Ecological and Economic Impact Assessment of Sablefish Aquaculture in British Columbia. Fisheries Centre Research Reports 13(3):33pp.

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