# Overview of Sea Lice Issues and Risks for Farmed and Wild Salmon in British Columbia

*Prepared for*

**CERMAQ ASA**

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January 2008

# MEMORANDUM

TO: Marit Thorsrud, Cermaq ASA

FROM: Sonja Saksida, BC Centre for Aquatic Health
Director of Epidemiology and Veterinary Medicine

DATE: January 31, 2008

SUBJECT: Report on issues and risks associated with sea lice infections on farmed and wild salmon in British Columbia (BC)

Attached is the report which was contracted by Cermaq ASA in the latter part of 2007. This report provides a background and overview on the farmed and wild salmon sea lice debate with a focus on Vancouver Island geographic areas where Mainstream Canada has salmon farming operations.

Over the last few years, I have found that a large percentage of my time and research efforts are spent responding to this debate which has become a vocal and often reoccurring topic in the media. While the negative news stories presented by the non-governmental organizations (NGOs) make great headlines, studies and responses that call into question the motives of and provide a critical analysis of the NGO research do not. Responding to the same repeated messages and faulty science has become a source of frustration for me and many others throughout the BC salmon farming industry. Research that disputes the NGO viewpoint remains largely unrecognized by the public.

As such, it is a pleasure to write this report on behalf of Cermaq ASA. Cermaq's interest in having a better understanding of the debate is not only admirable, but prudent since the sea lice issue affects public perception of all BC salmon farming companies. I hope this report helps Cermaq ASA respond to questions about sea lice concerns in British Columbia and, more specifically, at its own Mainstream Canada farming operations.

Some of the research presented in this report is not yet published. As a courtesy to these authors and their work, I would appreciate it if this report is not widely circulated prior to these papers becoming part of the public domain.

Thank you for the opportunity to provide a balanced view of the sea lice debate in British Columbia.

# *Table of Contents*

# EXECUTIVE SUMMARY

*Background*

The Pacific salmon is a symbol of the heritage, culture, natural wonder and spirit of British Columbia. As such, it is no wonder that any threat or perceived threat is taken very seriously by British Columbians. Salmon farming has been targeted as a threat and, in particular, farmed salmon as a source or reservoir of sea lice infection of Pacific salmon is a reoccurring headline news item. In addition to utilizing the news media to deliver their message, non-governmental organizations (NGOs) and their supporters have added credence to the anti-salmon farming message by backing up claims with published studies in peer-reviewed journals. These NGOs have a vested interest in presenting only one point of view; therefore, this research needs to be critically analyzed.

Responding to the sea lice debate, salmon farming companies and government agencies have increased monitoring efforts. Company policies, government regulations and regular auditing ensure that farm sea lice levels are controlled.

Even though salmon farming is a relative newcomer to BC's agricultural industry sector, it accounts for about 15% of BC's total agricultural production. This farm gate value was worth $228.1 million in 2004[1]. Currently, there are four major salmon farming companies operating in BC: down from fifty in 1989 and twelve in 2002. These four companies have operations in and around the northeast and west coasts of Vancouver Island. While there are approximately 135 farm tenures, only seventy to ninety are active and stocked with salmon. Over 85% of the salmon farmed in BC is Atlantic, the remaining 15% is farmed Pacific species –Chinook and coho.

[1] http://www.salmonfarmers.org/about_salmon_farming.php

*Pacific Salmon*

There are five species of wild salmon found in the Pacific Ocean of North America: Chinook, chum, coho, pink, and sockeye. Each species is unique in appearance and life history, but all are anadromous and single time spawners. In British Columbia, Fisheries and Oceans Canada (DFO, formerly called Department of Fisheries and Oceans) regulates fisheries for saltwater species. There are three Pacific salmon fisheries: First Nations, commercial and recreational.

Salmon survival and factors that contribute to this survival are topics of intense debate in BC. In the late 1970's the first salmon enhancement hatcheries were built on the BC coast and these hatcheries and their enhancement programs became a tool for rebuilding wild stocks of coho, Chinook, chum and pink salmon.

Of the Pacific salmon species, pink salmon are the most widely distributed and because of this species' characteristic two-year life cycle, it tends to be used as an indicator species for general ocean health and productivity. Even though pinks are the most abundant Pacific species, they still undergo a high mortality rate of up to 75% during the first six weeks in saltwater[2].

Chum are the second most abundant salmon and Chinook are the least abundant, though largest in size. Currently, Chinook stocks in the Pacific Northwest from Washington south to California are listed as threatened or endangered, stocks in BC, especially southern Strait of Georgia and West Coast of Vancouver Island are very low, while most stocks in Alaska are relatively stable. While stable for many years (1960's to 1990's, about twelve million fish), coho populations decreased to approximately six million fish between 1997 and 2003[3]. With regards to all Pacific salmon species, it is generally felt that while some stocks were low in abundance that the general trend is towards higher abundance. There has been a long term trend towards

[2] http://www-sci.pac.dfo-mpo.gc.ca/aquaculture/sok/pinkbiology_e.htm
[3] http://www.npafc.org/new/publications/Bulletin/Bulletin%20No.%204/093-104Shaul.pdf

decreasing individual size of returning salmon; however, this trend seems to be reversing as well.

Pacific salmon are able to adapt to habitat disturbances and readily re-colonize damaged areas. Salmon face a greater threat from people (industry and human settlement) than from nature. Balancing the needs of people and industry, while maintaining and enhancing stocks and habitat, poses a considerable challenge for the management and conservation of Pacific salmon stocks[4]. Further confusing the issue is the impact of global climate changes that ultimately affect fish populations as well.

*Sea Lice*

The two species of sea lice most commonly reported on salmonids in BC are: *Lepeophtheirus salmonis* (*L. salmonis*) and *Caligus clemensi* (*C. clemensi*). *L. salmonis* has a circumpolar distribution and is believed to have a limited host range, primarily salmonids. Outbreaks of disease caused by sea lice on farmed salmon are reported in many regions internationally, with the exception of Canada's west coast and Japan. The Pacific Ocean *L. salmonis* is genetically different from the copepod of the same name in the Atlantic Ocean (Todd et al., 2004). *L. salmonis* is known to infect all Pacific salmon species. Of the Pacific salmon species, pink salmon have the highest prevalence of adult *L. salmonis*. Chum have the second highest levels and sockeye have the lowest prevalence. Generally, in Pacific salmonids the prevalence and abundance of sea lice increases with increasing age and size of fish (Nagasawa, 1993). Sea lice reproduction and re-infestation appear to occur in the open-ocean as well as coastal waters.

*Sea Lice on Salmon Farms*

Enumeration of sea lice did not start until 2003 when BC provincial government instituted stringent sea lice monitoring systems and control measures. In March 2003, this plan started

[4] http://www.dfo-mpo.gc.ca/zone/underwater_sous-marin/salmon/salmon-saumon_e.htm

on Atlantic salmon farms in the Broughton Archipelago and expanded to include all salmon farms by October of the same year. Random audits of farm sea lice enumeration were initiated by BC Ministry of Agriculture and Lands (BCMAL) in January 2004. Even though companies farming Pacific salmon (coho and Chinook) were initially required to report numbers, by the end of 2004 these farm sites were no longer required to monitor and report sea lice numbers – this policy change was due to the low numbers of lice found on farmed Pacific salmon.

During the period of wild juvenile pink salmon out-migration, salmon farms are expected to maintain motile *L. salmonis* levels below three motile stages per fish. This is done either by treatment with SLICE® (emamectin benzoate) or immediate harvest. Sea lice treatments are only available under veterinary prescription and are administered via fish feed. Over the last few years, sea lice levels have decreased in many regions, including the Broughton, even though there is no indication that there has been an increase in treatments. There appears to be considerable differences in sea lice numbers between sea lice management zones and from year to year. Influences of sea lice levels may include: regional differences in salinity patterns and interaction with native fishes, especially wild adult Pacific salmon, which may carry high levels of *L. salmonis* when they return to spawn.

To date, the sea lice data reported on Atlantic salmon farms appear to indicate that patterns of infestation and pathogenicity are quite different to what has been commonly reported in Europe and the east coast of North America. In BC, the sea lice levels appear to be lower and require fewer treatments to maintain low levels. Through monitoring and management, sea lice do not appear to pose a significant health risk to farmed salmon in BC.

*Sea Lice on Pacific Salmon*

Until recently, very little research has been conducted on the effects of sea lice on juvenile Pacific salmon. The crux of the sea lice debate in BC revolves around the impact that sea lice (particularly *L. salmonis*) have on juvenile pink salmon and the resulting impact on adult pink salmon returns. A study by Krkosek et al. (2006) stated pink salmon mortality rates associated with sea lice varied from 9 to 95%. Even though there are major flaws in this study, it has been used to draw conclusions in subsequent research papers.

Sea lice exposure trials by Jones et al. (2008b) suggest that the innate resistance to *L. salmonis* displayed by pink salmon develops in fish heavier than 0.3g and appears to be functional by 0.7g. The development of resistance coincides with changes to the epidermis and dermis, including the formation of scales. Once 0.7g is attained, pinks appear to have incredible immunity to sea lice. Conversely, exposure trials (Ross et al., 2000) with larger Atlantic salmon showed a high infestation rate and resulting mortalities. A study of exposure rates of several fish species found that threespine stickleback (a non-salmonid) appear to possess the least innate immunity followed by chum then pink salmon. All three species had considerably lower infestation rates than those reported on Atlantic salmon (Jones et al., 2006a). The report provides evidence that stickleback may act as a temporary host for sea lice.

Ongoing studies are assessing the health of the wild juvenile pink salmon during their out-migration through the Broughton Archipelago to determine whether sea lice infections have any effect on health parameters and to examine for sea lice-caused lesions and secondary infections that may have health implications. Thus far, very few negative health outcomes are associated with sea lice infection of wild Pacific salmon.

Even so, there has been a tendency by NGOs and individuals who represent them to ascribe any low pink salmon returns to sea lice infections on juvenile pinks. Additionally, these media releases assume a causative relationship between farmed salmon (as a reservoir of sea lice) and sea lice infections of pink salmon.

There appears to be some discrepancy in sea lice data collected and reported in various studies conducted in the Broughton Archipelago. This was particularly evident during the 2004 sample period when reported abundance and prevalence differed by 30% or more. It is possible that this difference may be related to sampling methodology as well as sample area and size. Research conducted by DFO (Jones and Nemec, 2004) was far more extensive and more likely an accurate reflection of the sea lice abundance and prevalence in the regions. The findings from DFO reports suggest that there is an annual variation in sea lice abundance and intensity in pink and chum salmon and that during the last few years the levels are the lowest recorded in the region. The abundance of lice was higher on fish from the areas closest to the ocean and with the highest salinities. The sea louse *L. salmonis* was evident on non-salmonid species, particularly the threespine stickleback, with higher prevalence and intensity observed on this species than either pink or chum. It does not appear the lice reach maturity on this species.

A report by Morton et al. (2005b) assumes that a decrease in sea lice infections levels in 2003 was a direct consequence of farm site fallowing. This is not the case, as overall salmon production was not lower. The higher pink salmon return rates in 2004 may be attributed to other factors such as temperature, salinity and water dynamics.

Three potential sources of sea lice for wild juvenile pink and chum salmon have been proposed: farmed salmon, other wild salmonids (Gottesfeld et al., 2005) and wild non-salmonids, such as threespine sticklebacks which have a higher sea lice abundance than either pink or chum salmon (Jones et al., 2006c; Jones and Hargreaves, 2007b). The relative importance of each potential source would likely vary between locations and would be influenced by: relative abundance of the infective stages of lice; environmental factors such as salinity, temperature and current which would influence the success of settlement; and susceptibility of the host at the time of exposure as it appears that juvenile chum and pink salmon quickly develop an innate immunity to sea lice. Therefore, although the source of infection is a vital factor, the overall effect of the lice on the population is more important.

*Conclusion*

Balance in understanding has to be infused into the sea lice debate. Reasonable risks can be and are being mitigated. Regulations are in place to reduce the risks presented by a contained population. These regulations include regular monitoring, assessing and auditing as part of a complete sea lice management program. In fact, BC's salmon farming industry operates under some of the toughest fish health and operating practice regulations in the world. These regulations ensure that sea lice transfer from farmed to wild is negligible. Data from farms, government auditing programs and independent research indicate that wild populations are not substantially at risk from sea lice infections of farmed salmon. In fact, the current DFO monitoring program has provided data showing that sea lice on juvenile pink and chum salmon are on the decline. This valuable information allows sea lice management to move away from the precautionary principle to a science-based program that can be developed in BC for BC.

# INTRODUCTION

As a result of its legacy of food and ceremonial use by Native peoples, sustenance for early settlers and coastal employment and community development, the Pacific wild salmon has become a symbol of the heritage, culture, natural wonder, and spirit of British Columbia (BC). This symbolic nature has taken on almost mythical portions such that the health of the wild Pacific salmon populations is seen as a thermometer for the long term health of BC's natural environment, economy and cultural identity. Given this, it is no wonder that any threat or perceived threat to this symbol is taken not only seriously, but personally, by the majority of British Columbians.

The concerns surrounding sea lice spread from farmed to wild salmon and the possible negative effect on Pacific salmon is part of a greater debate on the effects of salmon farming on BC's coastal environment. However, of the issues affecting public perception of salmon farming, the sea lice debate is possibly the most vocal issue with a consistent production of negative press resulting in a damaged public perception of the industry. The repetition of simple messages that speak personally to British Columbians is a strength and cornerstone of the non-governmental organization (NGO) strategy. To support claims about the negative impact of sea lice, some NGO groups and individuals who represent them have published studies in peer-reviewed journals. These groups and individuals have vested interests in presenting one point of view and; therefore, the research produced needs to be analyzed critically.

Throughout the debate, the salmon farming industry and government agencies have responded with increased sea lice surveillance and more open policies regarding sea lice information sharing. Government regulations and agencies ensure the accuracy of sea lice information and the control of sea lice levels on farms. Data from government and industry as well as research –both independent and government or industry sponsored- is available to provide a better understanding of the complexities of the sea lice issue.

This report summarizes the state of knowledge regarding sea lice research in British Columbia. The report's objective is to provide a critical review of research, both past and present, on the effects of sea lice on farmed and wild salmonids in British Columbia. Minimal emphasis will be placed on research conducted in other salmon farming regions in either North America or internationally. A summary of current ongoing projects will be presented as well.

The report begins with a brief introduction to and background on salmon farming and wild Pacific salmon stocks in British Columbia. The main body of the report includes summaries and evaluations of current research on sea lice on farmed salmon, sea lice on wild salmon and the interaction of sea lice infections of wild and farmed salmon.

## SALMON FARMING IN BRITISH COLUMBIA

A relative newcomer among BC agriculture-based industries, the salmon-farming sector has grown rapidly and has become a vital part of the local economy in many coastal communities. Today, the industry accounts for about 15% of BC's total agricultural production and hundreds of millions of dollars in economic activity.[5] In the span of just over twenty years, the salmon farming industry in British Columbia has grown to be the province's largest agricultural

[5] http://www.salmonfarmers.org/files/farming_seas.html

exporter and an enormous contributor to the economies of coastal communities. In 2004, the farm gate value of the salmon, shellfish and trout sectors combined was $228.1 million.[6]

The first salmon farm began operation in 1971. The salmon aquaculture industry developed from ten operating farms in 1984 to a peak of 135 tenures in 1989. Through rationalization and consolidation, the number of companies has declined from fifty in 1989 to twelve in 2002 and there are now only four major salmon producers. A few small producers, which rear mainly Pacific salmon species, still remain. Farms are located primarily in and around the northeast and west coasts of Vancouver Island. The major farming areas include: Sunshine coast (zone 3.1), Campbell River area (zone 3.2 + southern farms in zone 3.3), Broughton Archipelago (most farms in zone 3.3 plus 2 farms in zone 3.4), Port Hardy area (most farms in zone 3.4), Nookta/Quatsino sounds (zone 2.4) and Tofino (zone 2.3) (Figure 1). Additionally, there are approximately six farms located on the mid-coast around the first nation community of Klemtu (zone 3.5). Currently, while there are approximately 135 farm tenures at any one time, only 70 to 90 are active and stocked with salmon.

In the industry's early days, mostly Pacific salmon (Chinook and coho salmon) were raised; however, over time there was a switch to Atlantic salmon which are more domesticated and better suited to being reared in a captive environment. Currently, over 85% of farmed salmon production is Atlantic salmon. Strict regulations limit the importation of genetic material and, as a consequence, almost all of the current Atlantic salmon produced in British Columbia is offspring of McConnell and Mowi stocks imported as eggs during the late 1980's and mid 1990's.

[6] http://www.al.gov.bc.ca/fisheries/index.htm

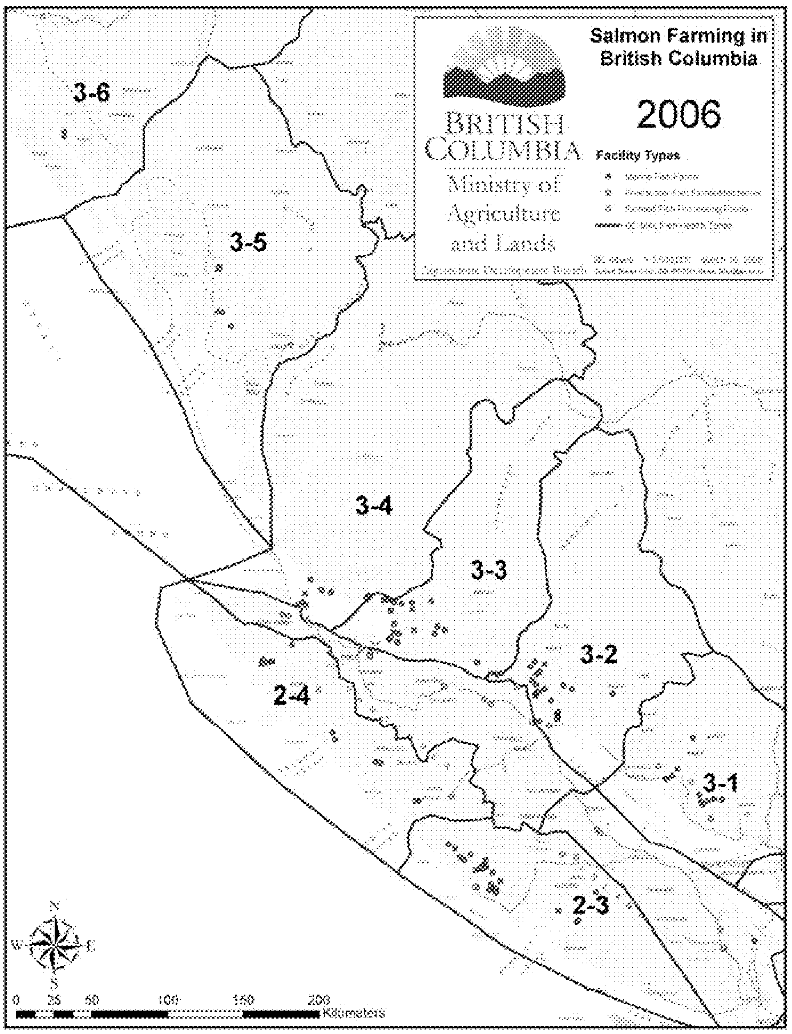



**Figure 1 - Salmon farm tenures in respective fish health zones**

## PACIFIC SALMON

### *Life Cycles of Pacific Salmon*

There are five species of wild salmon found in the Pacific Ocean of North America: Chinook, chum, coho, pink, and sockeye. Although each species has a unique appearance and different life history (Table 1), these salmonids share many characteristics. These salmon are anadromous - meaning eggs are laid and hatched in freshwater, and young spend at least some of their early lives in freshwater before swimming to the sea to grow and mature. The ability to return to their home river when it is time to reproduce is one of the most remarkable things about salmon. Pacific salmon are single time spawners and, as such, die post-spawning thereby providing nutrients to the streams where their lives started.

| Characteristic | Chinook | Chum | Coho | Pink | Sockeye |
|---|---|---|---|---|---|
| Time Rearing In Freshwater | 1 month to 1 year | hours to days | most 1-2 years | hours to days | 1 to 2 years |
| Primary Early Rearing, Habitats | stream, estuary | estuary | stream | estuary | lake |
| Time Spent At Sea | 1.5-4.5 years | 2.5-4.5 years | 0.5-1.5 years | 1.5 years | 1.5-3.5 years |
| Avg Age at Maturity | (range 2-8) | (range 2-7) | (range 2-4) | 2 | (range 3-8) |
| Avg Forklength & Weight at Maturity | 90 cm & 16 kg | 65 cm & 5.5 kg | 55 cm & 4.5 kg | 45 cm & 1.8 kg | 65 cm & 2.3 kg |

**Table 1 - Life histories of the major Pacific salmon species in North America**[7]

### *Saltwater Range of Pacific Salmon*

Each species of Pacific salmon has a characteristic distribution and range. Seasonal and year-to-year variation will occur based on climatic, geologic and ecological factors. These same factors affect the abundance and distribution of plankton and other salmon prey species and; therefore, further modify distributions and ranges. As these ranges are independent of political sovereignty, there is crossover of populations/runs from one political and/or management jurisdiction to another. Ultimately, this complicates the understanding and

[7] http://www.dfo-mpo.gc.ca/zone/underwater_sous-marin/salmon-saumon_e.htm

management of salmon populations and runs. The following figures (2a-e) give some idea of the range for each species and the inherent complexities.[8]

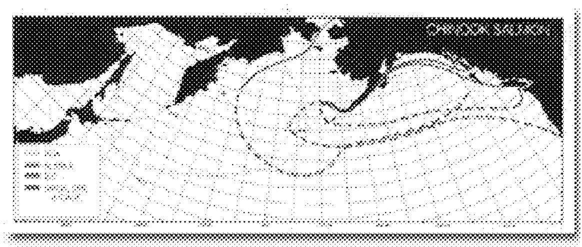


Figure 2a - Chinook: *Oncorhynchus tshawytscha*

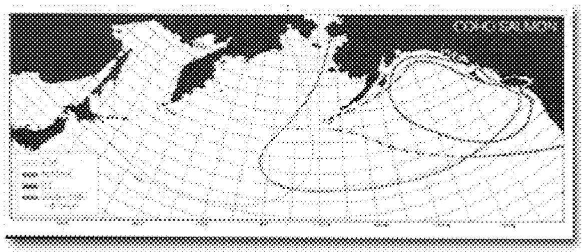


Figure 2b - Coho: *Oncorhynchus kisutch*

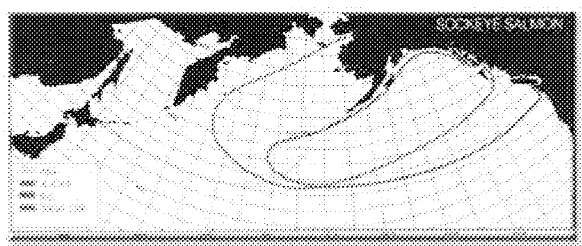


Figure 2c - Sockeye: *Oncorhynchus nerka*

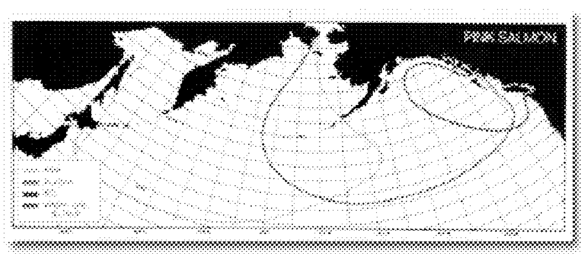


Figure 2d - Pink: *Oncorhynchus gorbuscha*

[8] http://www.pac.dfo-mpo.gc.ca/species/salmon/salmon_facts/default_e.htm

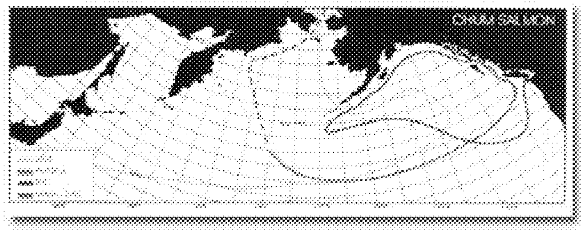


Figure 2e - Chum: *Oncorhynchus keta.*

## *Pacific Salmon Fisheries in British Columbia*

A thorough review of fisheries management (Knapp, 2007) in Canada, Alaska and the United States Pacific is provided in Appendix 2. Additionally, this report discusses the economic effects of farmed salmon on an ever-changing and less profitable commercial fishery – particularly in Alaska where commercial fishing still has strong economic and community ties. In BC, there are three main user groups for Pacific salmon resources: First Nations, commercial and recreational fishers. The fisheries and restrictions on use for each group in British Columbia are described below.

### *First Nations Fisheries*

In 1992 the Department of Fisheries and Oceans (DFO, now renamed Oceans and Fisheries Canada) initiated the Aboriginal Fisheries Strategy (AFS) in response to a Supreme Court ruling which affirmed the right of First Nations people to fish for food, social and ceremonial (FSC) purposes. Today, FSC fisheries have priority over all other fisheries. Harvest opportunities are developed through consultation with First Nation communities, and then authorized via a Communal License issued by Fisheries and Oceans Canada. The individual Band or Tribal Council in turn issues designations to individual members, authorizing them to fish for the group.

### *Commercial Fisheries*

Commercial fishing for salmon began shortly after the arrival of Europeans on the West Coast and has continued to the present. Commercial openings can occur anywhere along the coast depending on local run timing (May-October), distribution and stock strength. Information is gathered and salmon stock management is maintained by a number of policies and programs in place, including the New Direction series instituted in 1998.

### *Recreational Fisheries*

Fisheries and Oceans Canada regulates recreational fishing for Pacific salmon in both tidal and non-tidal waters. Unlike the commercial salmon fishery, entry to the recreational fishery is not limited, although all recreational fishers must possess a valid sport fishing license.
Salmon are the dominant group of fish in the waters of the north Pacific. Catches of Pacific salmon are at historical levels for all north Pacific coast countries. The highest catches occurred in 1995 and the second highest in 2005, the third highest was in 2003 (Figure 3). Pacific salmon are also an indicator of the health of the ocean ecosystem and a key species that is familiar to the general public. For this reason, ecosystem based management has become a focus for many marine stewardship studies and management agencies.

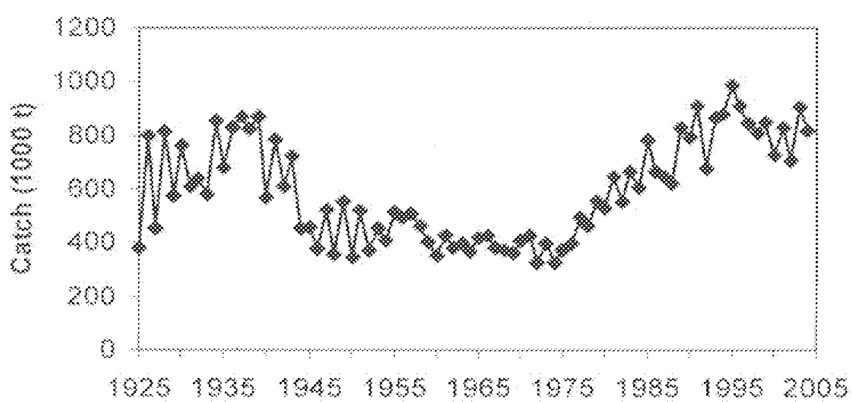



**Figure 3 - World wide Pacific salmon catch 1925-2005**[9]

[9] http://www.npafc.org/new/pub_bulletin4.html

Salmon survival and factors attributed to their survival are topics of intense debate in British Columbia. There are a wide range of factors that affect the mortality and survival of Pacific salmon. Variability in salmon returns from year to year is most likely caused by the oceanic conditions the salmon encounter once out of the river system, rather than influences in the freshwater environment.

Since the late 1970's, salmon enhancement has been used as a stock re-building tool for the purposes of maintaining and contributing to fishing opportunities of Pacific salmon stocks. BC has had a system of enhancement hatcheries up and down the coast that release artificially propagated salmon of various species. This 'enhancement' of native salmon has been a major tool used to increase freshwater survival of wild, native stocks of Coho, Chinook, chum, steelhead, sockeye and pink salmon. For the most part, the program was designed to enhance the productivity of native wild salmon stocks by not introducing other (non-native) stocks into a river system. As such, each stock maintains its own genetic adaptations to the home river/stream. Although hatcheries have successfully provided high survival environments in freshwater, once released, these fish are subject to the same environmental conditions and high mortality rates of naturally propagated fish. There are thirteen larger enhancement hatcheries and many smaller salmon enhancement program (SEP) operations. Figure 4 shows the locations of enhancement facilities and programs in BC.

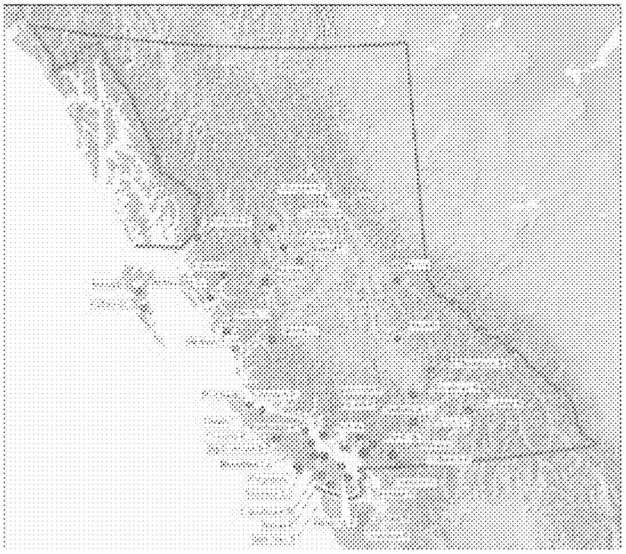


**Figure 4 - Location of major salmonid enhancement facilities in British Columbia** [10]

During the years 1975-1993, the abundance of Pacific salmon nearly doubled (Figure 5). Enhancement contributions, better ocean productivity, and management strategies all played a part in this increase.

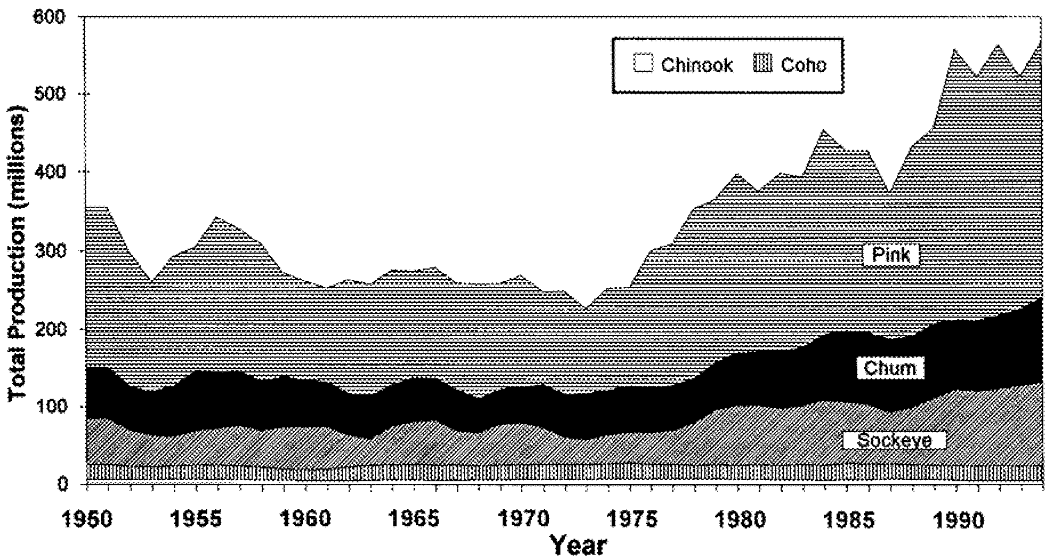



**Figure 5 - Total North Pacific Ocean salmon production, 1951–1994.**
Data from D. Rogers, Fisheries Research Institute, University of Washington, Seattle, WA 98195 (Bigler 1996).

[10] http://www-heb.pac.dfo-mpo.gc.ca/facilities/MacKinlaySalmonHatcheriesinCanada.pdf

Trends in pink salmon populations, the most abundant salmon species, are related to an odd and even-year cycle where abundance is high in the odd years and low in the even-years or visa-versa. These trends in odd-even year fluctuations may persist for many years while stocks in neighbouring regions show the opposite cycle. Regional trends in abundance vary more than large scale trends of the open-ocean. Figures 6a and b show the pink salmon's historical catch and escapement for Area 12 in BC (Broughton Archipelago).

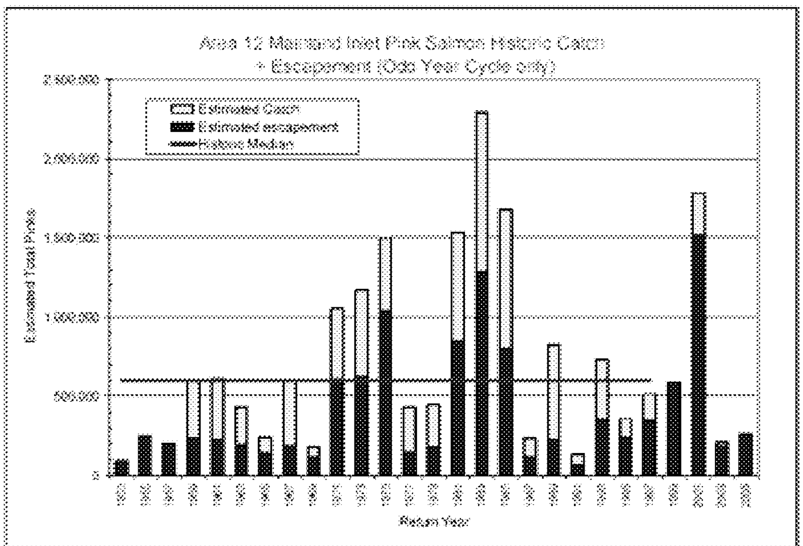



**Figure 6a - Historical odd-year returns of pink salmon to Area 12 Mainland Inlet Streams, 1953-2006**

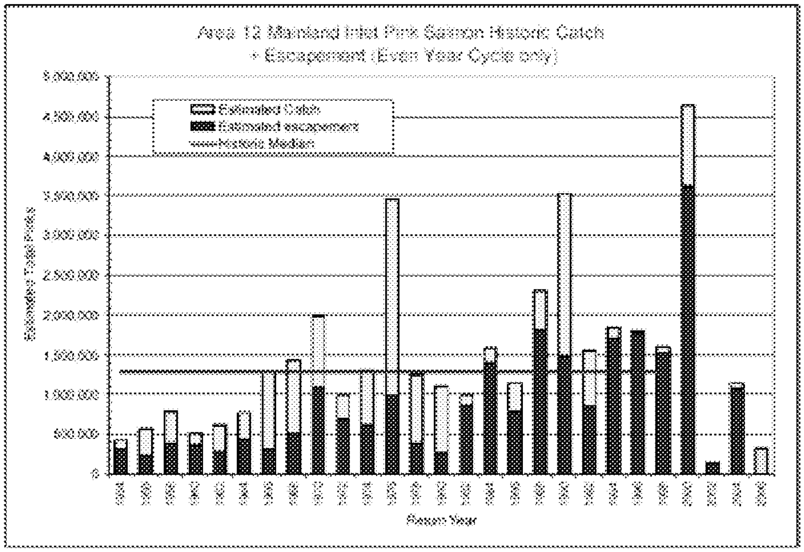



**Figure 6b - Historical even-year returns of pink salmon to Area 12 Mainland Inlet Streams, 1953-2006[11]**

Pink salmon are widely distributed and are the most abundant salmon species in BC. Because of this species' characteristic two-year life cycle, it tends to be used as an indicator species for the general health of the ocean and its productivity. This unique life cycle means that as a species, pink salmon populations are more prone to impact in ocean conditions.

A study by R. R. Parker[12] on pink salmon population dynamics in central BC showed a high mortality rate (from 59 to 77%) for pinks in the first 40 days of seawater. Figure 7 illustrates the range of natural mortality rates estimated by Parker over three pink salmon brood years on BC's central coast.

[11] http://www.pac.dfo-mpo.gc.ca/sci/aquaculture/sok/risk_e.htm#Figure_B

[12] http://www-sci.pac.dfo-mpo.gc.ca/aquaculture/sok/pinkbiology_e.htm

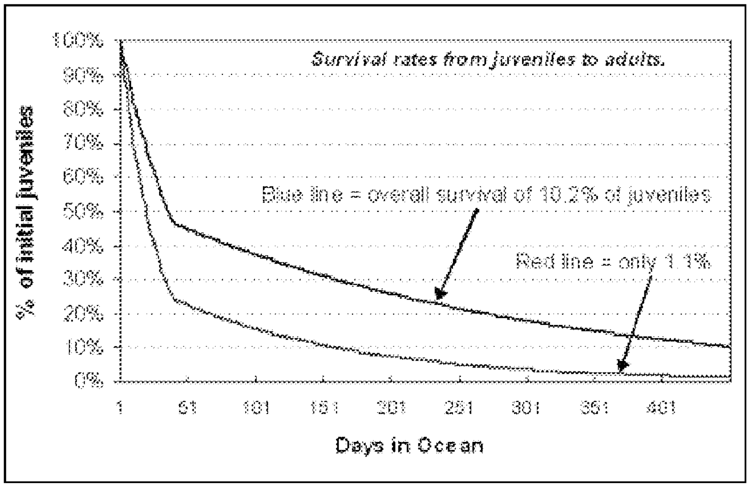



**Figure 7 - Range of natural mortality rates estimated by Parker over three brood years of pink salmon from the Bella Coola and Tanbark Rivers (1961-1963, returns in 1963-1965)**

Similar results were found by Karpenko in Alaska, where he estimated a 53.1 - 94.4% loss in the first few weeks (40-45 days) and from 55.4 to 95.8% in the last period of ocean life (360 days).[13]

Chum salmon are the second most abundant salmon in the north Pacific with historically high catch levels from the 1990's to the present[14] (Figure 8).

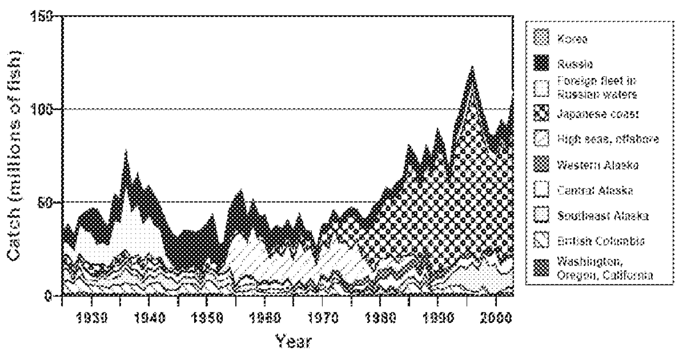



**Figure 8 - Catches of chum salmon by area around the North Pacific Ocean 1925-2003**

[13] http://www.npafc.org/new/publications/Bulletin/Bulletin%20No.%201/page%20251-261(Karpenko).PDF
[14] http://www.npafc.org/new/publications/Bulletin/Bulletin%20No.%204/035-043Fukuwaka.pdf

Chinook salmon are the least abundant salmon in the North Pacific Ocean but the largest in size of all the Pacific salmon species. Most stocks have only a small percentage of their historical numbers. Their life history is elastic with variable time spent in the open ocean resulting in multiple age groups, diverse temporal migration behavior, and divergent races with separate freshwater and ocean life-history behavior patterns. There are even distinctive red-fleshed and white-fleshed forms. Currently, Chinook stocks in the Pacific Northwest from Washington south to California are listed as threatened or endangered, stocks in BC, especially southern Strait of Georgia and West coast of Vancouver Island are very low, while most stocks in Alaska are relatively stable. Figure 9 illustrates commercial harvest of Chinook salmon by North Pacific countries.

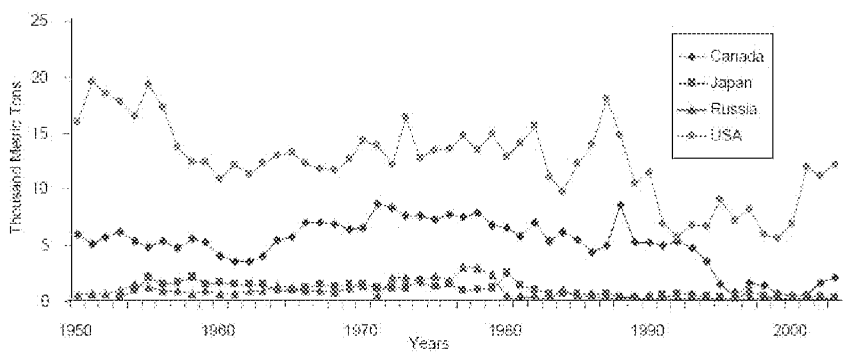



**Figure 9 - Commercial harvest of Chinook salmon by Canada, Japan, Russia, and United States.**[15]

Coho salmon reached a stable level of over twelve million for about thirty years from the 1960's into the 1990's. Between 1997 and 2003 populations decreased sharply to around six million as a result of reduced marine survival.[16] Marine survival is extremely variable with BC survival rates around 6-10%. Indications are that the localized marine environment is critical to marine survival. Figure 10 shows coho landings for North Pacific Ocean countries.

15 http://www.npafc.org/new/publications/Bulletin/Bulletin%20No.%204/077-091Heard.pdf

16 http://www.npafc.org/new/publications/Bulletin/Bulletin%20No.%204/093-104Shaul.pdf

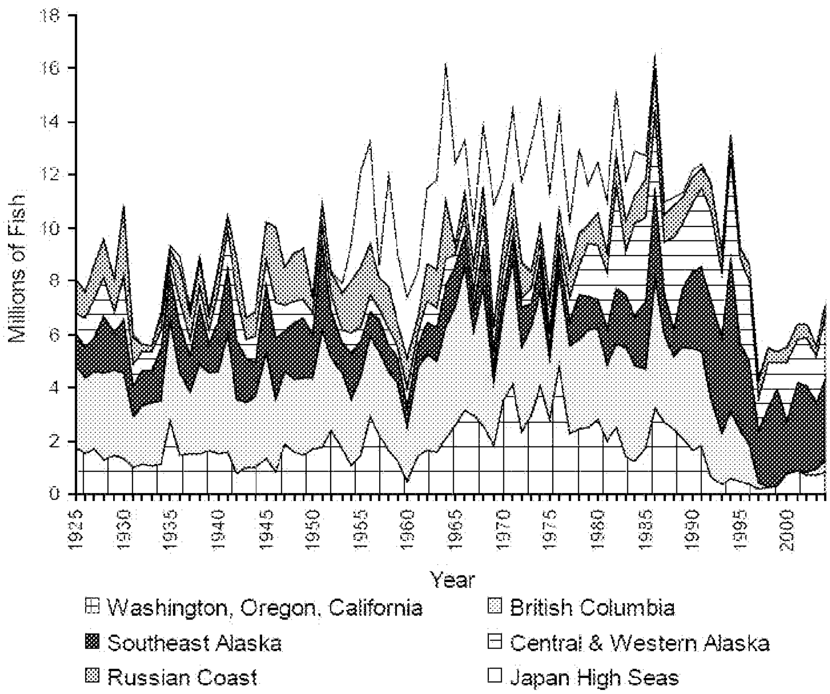



**Figure 10 - Commercial landings of Coho salmon in Pacific Rim, 1925-2004.**

In the proceedings of the 2005 NPAFC-PICES [North Pacific Anadromous Fish Commission (NPAFC) and North Pacific Marine Science Organization (PICES)] Joint Symposium on the Status of Pacific Salmon and Their Role in North Pacific Marine Ecosystems, papers presented gave strong evidence that Pacific salmon stocks are generally very healthy. Some stocks were low in abundance but the general trend was toward higher abundance. There has been a long term trend towards decreasing individual size of returning salmon, but this seems to be reversing.

### *Factors Affecting Wild Salmon Survival Rates and Run Sizes*

Salmon face both natural and manmade threats. Natural threats include extreme weather that can produce floods that wash away spawning gravels, landslides that can block rivers and even volcanic eruptions that destroy entire rivers. Pacific salmon are superbly adapted to such habitat disturbances and can quickly re-colonize damaged areas. In fact, when the glaciers retreated after the last ice age 11,000 years ago, salmon were confined to a few small refuge areas in the eastern Pacific. Since then they have re-colonized and adapted to nearly every stream, river and lake that can be accessed.

Salmon face more serious threats from people than from nature. Prior to European contact, the harvesting of salmon by First Nations people had minimal impact on population numbers – there was an abundant supply for food and ceremonial needs. As coastal BC developed, commercial fishing, sawmills and logging, agriculture, mining and human settlement have damaged and continue to harm the habitat that supports salmon.

Currently, improved fisheries management, habitat protection and stock enhancement programs minimize harmful impacts and reverse past damage, but problems still remain. Changing ocean conditions that may be a product of global warming have led to poor survival in the ocean for some populations of salmon. Expanding human populations demand fishing opportunities on one hand, and land and water for agriculture, forestry and towns on the other. Balancing these needs, while maintaining and enhancing stocks and habitat, poses a considerable challenge for the management and conservation of Pacific salmon stocks. [17]

Pacific salmon live in cool waters and southern BC represents the southern limit of their range. Climate change that results in the warming of ocean water has an impact on salmon survival. Salmon may move further north to seek cooler waters and other species, such as tuna and

[17] http://www.dfo-mpo.gc.ca/zone/underwater_sous-marin/salmon/salmon-saumon_e.htm

mackerel, could move in to replace the salmon. Warmer freshwater would impact cold-blooded salmon by causing returning salmon to burn more energy on the way to spawning grounds. Reduced numbers of salmon reaching spawning grounds may result in fewer salmon leaving the streams in spring.

Scientists agree that climate and ocean conditions are changing - whether naturally or due to global warming – and that these changes will have many impacts, including ocean temperatures, currents, and fertility. All of these factors will affect fish populations. There is evidence that natural fluctuations occur and are significant, and that overfishing, if it occurs at the same time as the natural decline, may collapse the fishery.

Research done by Beamish and Bouillon (1993) has shown a correlation between changes in fish abundance in the Northeast Pacific to the Aleutian Low, a low-pressure system near the Aleutian Islands. During winter, the intense low causes strong storms that stir up the ocean. Changes in temperature and fertility ripple outward, altering fish abundance far across the ocean.

The possibility that climatic conditions in the ocean ("ocean regimes") might affect fish abundance has been around for several decades. During the 1980s, Beamish and a few other scientists began correlating fish numbers to ocean temperature, showing how ocean climate changes affected populations. This research has established that changing climate regimes have direct impact on salmon populations and health. Even so, how these climate changes influence Pacific salmon populations and health is not fully understood. It is known that early marine growth to a critical size is necessary for survival through the first winter (Beamish and Mahnken, 2001; Farley et al., 2007).

# SEA LICE SPECIES AFFECTING SALMON IN BRITISH COLUMBIA

The two species of sea lice most commonly reported on salmonids in British Columbia (BC) are: *Lepeophtheirus salmonis* (*L. salmonis*) and *Caligus clemensi* (*C. clemensi*). *Caligus clemensi* is similar to *C. elongates* found in the Atlantic ocean in that it has a broad host ranges that include both non-salmonid teleost and elasmobranch hosts (Margolis et al. 1975, Kabata 1979). Many of these non-salmonid hosts are common in the vicinity of seawater salmon farms and serve as a source of parasites for infection of salmonids.

*Lepeophtheirus salmonis* has a circumpolar distribution and is believed to have a more limited host range, primarily salmonids (Kabata, 1979), and consequently, is sometimes referred to as the salmon louse. Jones et al., (2006c) reported *L. salmonis* on threespine sticklebacks (*Gasterosteus aculeatus*), a species that is associated with out-migrating juvenile pink and chum salmon in the Broughton Archipelago.

Outbreaks of disease caused by sea lice on farmed salmon are frequently reported in many regions internationally. The exceptions to these sea lice outbreaks are Japan and Canada's west coast (British Columbia) (Johnson et al., 2004). In BC heavy infestations and damage are rare and aquaculture veterinarians do not consider the salmon louse to be a serious health risk. This apparent difference has been difficult to explain until recently when it was determined that the parasitic copepod referred to as *L. salmonis* in the Pacific Ocean is genetically quite different to that copepod referred to by the same name in the Atlantic Ocean.

Todd et al. (2004) compared North Pacific and North Atlantic *L. salmonis* and found significant but low differentiation when six microsatellite loci variations were assessed. A more extensive study was recently conducted by Yazawa et al. (2008) who examined nuclear DNA sequences from approximately 15,000 expressed sequence tags (ESTs), the complete mitochondrial genome (16,148 base pairs), and 16S rRNA and Cytochrome oxidase subunit I (*COI*) genes from 68 salmon lice collected from Japan, Alaska and western Canada. On average, nuclear genes are 3.2% different, the complete mitochondrial genome is 7.1% different, and 16S rRNA and *COI* genes are 4.2% and 6.2% different respectively. These significant and sizeable genetic differences suggest that the Pacific lineage of *L. salmonis* is distinct from that occurring in the Atlantic Ocean. Yazawa et al. (2008) conclude that *L. salmonis* found in the Pacific Ocean is a different species than the sea louse of the same name that occurs in the Atlantic Ocean and that the reduced genetic diversity within the Pacific form of *L. salmonis* suggests that there was introduction into the Pacific from the Atlantic Ocean. The level of divergence is consistent with the hypothesis that the Pacific form of *L. salmonis* co-evolved with Pacific salmon (*Onchorhynchus* spp.) and the Atlantic form co-evolved with Atlantic salmonids (*Salmo* spp.) independently for the past 2.5-11 million years. The genetic differences may help explain apparent differences in pathogenicity and environmental sensitivity documented for the Atlantic and Pacific forms of *L. salmonis*.

### *Sea Lice on Adult Wild Pacific Salmon*

The salmon louse *Lepeophtheirus salmonis* is known to infect all Pacific salmon species. This parasite is commonly seen by commercial and recreational fisherman. A number of studies have reported on sea lice infections of Pacific salmon. Common terms used to evaluate sea lice are:

Abundance – the average number of sea lice for all fish examined
Intensity - average number of sea lice per fish infected with sea lice
Prevalence – the average number of fish infected with sea lice.

One important body of work on sea lice infections of Pacific salmon was conducted over an eight year period in the central subarctic Pacific by Nagasawa and others. In Nagasawa

(1985), chum salmon were collected in November 1984 utilizing gill net and long line along the western part of the North Pacific Ocean. Only adult *Lepeophtheirus salmonis* were counted. All the chum salmon caught were mature indicating they were returning to local rivers. Almost 60% of the fish were infected with sea lice with most observed around the head, back, and perianal regions. The prevalence of sea lice appeared to be equal among all sizes of fish and the mean sea lice intensity increased with increased size of fish. In the spring of 1982 and 1983 (Nagasawa, 1987), salmon and trout were caught by gill net in the central North Pacific Ocean south of the Aleutian Islands and the number of attached adult *L. salmonis* was recorded. Lice were found on all species but abundance varied among species. With several year classes of salmon in the water, the correlation was made that abundance of lice increased with increasing fish age. Pink salmon (comprising 28.7% of all species examined), which are in sea for only one year (life history), were the most heavily infested with 67% of all adult *L salmonis* counted present on this species. Chum salmon had the second highest infection rates with 24% of total adult lice present on 5 different age groups. Sockeye salmon appeared to have the lowest *L. salmonis* prevalence. On the heavily-infected Chinook salmon, the sea lice were grouped in clusters.

In spring 1990 (Nagasawa and Takami, 1993), pink and Masu salmon (a salmon species found in Asia but not North America) were caught by gill net in the northern part of the Sea of Japan. In this study only adult female *L. salmonis* were counted. The fish collected were of similar age and the pink salmon had significantly more lice than the Masu. The lice counts on the Pink salmon were similar to counts in the 1987 report. The Masu salmon seemed to be somewhat resistant to sea lice. In the early summer of 1991 (Nagasawa, 1993), Pacific salmon were caught by long-line in the central North Pacific Ocean and Bering Sea. The fish were examined for adult female *L. salmonis*. The long line method of sampling produced significantly higher lice counts than the previous sampling events. As in other reports, abundance varied between species. Again, Pink salmon, which were in sea for one year, were the most heavily infested with 78.4% of all adult female *L. salmonis* counted being on this species even though pink salmon constituted only 41.7% of all species examined. Chum salmon were the next most heavily infected with 15.9% of total adult lice on 5 different age groups. Sockeye salmon appeared to have the lowest prevalence of *L. salmonis*. In the species that had multiple year classes in the sample, the prevalence and abundance increased with increasing age and size. In a larger study that took place from mid-June 1991 to 1997 (over a period of 7 years), samples were collected from 21 regions in the North Pacific Ocean (Nagasawa, 2001). Adult female *L. salmonis* were counted. Again, the conclusion was that pink and chum salmon are the most important hosts for *L. salmonis* in the North Pacific Ocean. Pink salmon are considered unstable hosts for *L. salmonis* because even though they have high infestation levels, the pink salmon populations exhibit considerable annual fluctuations. Chum salmon are stable hosts because although they exhibit only medium infestation levels, this species' annual abundance at sea is consistently high. Additionally, the above studies suggest that the spread of *L. salmonis* on Pacific salmon likely occurs in the open-ocean since the prevalence of infection tends to increase with increased age.

In another study (Ho and Nagasawa, 2001), farmed Rainbow trout and coho salmon were sampled monthly from November 1992 to March 1993. All stages of *L. salmonis* were counted. The study concluded that chum salmon were a source of infection in farmed Rainbow trout and that coho were highly resistant to infestation of early life stages (only pre-adult and adult stages were seen) of *L. salmonis*. The authors speculated that the initial infection on farmed rainbow trout originated from the wild chum since the life stages of *L. salmonis* on returning chum were pre-adult and adult –the same life stages observed on the rainbow trout in December.

In 2004, a study was conducted in the coastal waters of British Columbia to look at sea lice on returning adult Pacific salmon (Beamish, 2005). Two marine areas were selected on the central coast, one of which had salmon farms and one which had no salmon farms. Sampling was done with hook and line gear. Attempts were made to capture representative samples of five Pacific salmon species (Chinook, coho, chum, pink and sockeye salmon). Sea lice numbers were identified according to the general development stages of chalimus, preadult, adult male, adult female and gravid female. In this study almost 100% of all Pacific salmon examined had sea lice with both L. *salmonis* and *Caligus clemensi* present. Most gravid females were *L. salmonis*. Gravid *C. clemensi* were rarely found. The intensity of sea lice was highest in pink, then chum salmon, with sockeye having the third highest prevalence with average intensities ranging from 41.5 to 52.0 lice per fish. The intensity of sea lice infection on Chinook (ranging from 16.1 to 18.5) and coho was considerably lower. The prevalence and intensities of sea lice were similar in each area. The authors concluded that sea lice are common parasites of adult Pacific salmon in coastal areas and that the presence or absence of salmon farms has no influence. The presence of copepodids and chalimus on adult salmon returning to their natal river suggests that transmission of salmon lice also occurs in coastal waters. The intensity of the infections indicates that natural production of sea lice could be large during the coastal migration of adult Pacific salmon. Adult Pacific salmon are a significant source of sea lice in the summer and fall when they return to their natal rivers for spawning.

In 2002-2003 Trudel et al (2007) undertook a study to assess the influence of seasonal and spatial variations in prevalence and abundance of salmon lice on Pacific salmon over a broad geographical range from the Oregon coast to the Arctic Ocean. Only motile stages of *L. salmonis* were counted. The effects of water temperature on sea lice infestations were studied also. The study found that all size classes of Pacific salmon were infected with sea lice throughout the year and the study area. Lice infestation varied with size class, species, season and year as found in previous studies. Large salmon were more heavily infected than small salmon and infestation increased over time, with lower values during the spring and higher values in the following winter. No effect of water temperature was apparent.

In summation, reports that investigated sea lice on adult Pacific salmon suggest that prevalence of sea lice *L. salmonis* is high and that lice reproduction and re-infection occurs in both the high seas and in coastal waters. Infection appears to increase with length of exposure. There was no indication of detrimental effects for the intensity levels observed which in some cases were high. Pink and chum salmon are the natural hosts for *L. salmonis*. Beamish et al. (2005) were the only group to report on *C. clemensi* and it is possible that this parasite is more commonly associated with coastal water.

## SEA LICE ON SALMON FARMS IN BRITISH COLUMBIA

### *Monitoring Programs*

Prior to 2003, enumeration of sea lice only occurred if there was a health and welfare concern at the farm site and, generally, few records were kept. In 2003 the provincial government of British Columbia instituted stringent sea lice monitoring systems and control measures in response to concerns expressed in 2002 about potential negative impacts that sea lice from Atlantic salmon farms were having on juvenile wild pink salmon (*Onchorynchus gorbachu*). In March 2003, regular sea lice monitoring started on Atlantic salmon farms in the Broughton Archipelago. Originally, this monitoring was part of the Broughton Archipelago Sea Lice Action Plan. In October 2003, this plan was expanded to include all BC salmon farms as part of a broader program - the Sea Lice Monitoring and Auditing Program[18].

Atlantic salmon farms are required to monitor levels and to submit reports monthly for chalimus and motile stages of *C. clemensi* and *L. salmonis*. The current protocol for monitoring sea lice on Atlantic salmon farms requires that 3 pens (20 fish per pen) are assessed. Fish are

[18] http://www.al.gov.bc.ca/ahc/fish_health/Sealice/Sealice_monit_04-05.pdf

sedated and examined for sea lice. The anesthetic totes are also examined for lice that may have detached from the host fish. Motile stages of *L. salmonis* and *C. clemensi* are enumerated, identified and counted. Attached stages (copepodid and chalimus stages) are also counted but not speciated. The farms report to a central database owned by the BC Salmon Farmers Association (BCSFA) and monthly reports summarizing sea lice abundance levels by fish health zone are provided to the BC Ministry of Agriculture and Lands (BCMAL) and are available online[19].

Starting in January 2004, the BCMAL initiated random sea lice audits on Atlantic salmon farms to confirm the validity of the data reported by the industry. At present, the program has technicians conducting sea lice audits on 50% of the farms stocked with Atlantic salmon between April and June (quarter 2) and 25% of farms during January-March (quarter 1), July-September (quarter 3) and October-December (quarter 4). As a result of very low levels of sea lice reported on Atlantic salmon farms located in zone 3.1, the requirement for monthly monitoring was discontinued in 2006; however, BCMAL continues to audit farms in the region. Farmers of Pacific salmon, coho and Chinook salmon (*O. kisutch* and *O. tshawytscha* respectively), were also required to monitor and report quarterly sea lice abundance levels, but this component of the program was dropped at the end of 2004 due to low numbers of lice and the stress associated with the handling required to make the assessment (Saksida et al., 2006).

The sea lice monitoring program stipulates that during the period of wild juvenile pink salmon out–migration (March to June), farms are expected to maintain motile *L. salmonis* levels below three motile stages per fish. This is done either by treatment with SLICE® (emamectin benzoate) or immediate harvest. Since it is acknowledged that 1) there are large numbers of wild salmonids with sea lice that migrate back to the coastal regions of British Columbia every summer/fall that greatly influence the sea lice levels observed on the farmed salmon and 2)

[19] http://www.al.gov.bc.ca/ahc/fish_health/sealice_monitoring_results.htm

serious gross lesions resulting from sea lice are not observed, treatment requirements during the remainder of the year are up to the discretion of the attending veterinarian and the farmer.

### *Sea Lice Management and Treatment*

In British Columbia, sea lice treatments are only available under veterinary prescription and are administered via fish feed. This has allowed BCMAL to collect very accurate treatment data. The data (Figure 11) shows that prior to 2000 ivermectin was available, but was rarely used. Emamectin benzoate (SLICE®) became available in 2000 and is currently the only product available for treatment. The treatment regime is the same as that used in Europe (seven day treatment at 0.05 mg/kg fish/day). In Canada, the withdrawal time from SLICE treatment to harvest is 68 days –considerably longer than in any other salmon farming countries, including the United States. The option of bath treatments is not available in BC.

There are two reports which discuss sea lice treatments as they occur on British Columbia salmon farms. Saksida et al. (2006) examined sea lice data collected from all farms between October 2003 and December 2005. This study included the 73 Atlantic salmon farms and 26 Pacific salmon farms that were active (stocked) and participated in the program. The average number of SLICE® (emamectin benzoate) treatments per generation ranged from zero to three depending on the zone. Approximately 60% of these treatments occurred in the winter and spring (January through June). There were no treatments on farmed Pacific salmon. Saksida et al. (2007a) examined sea lice data from all farms active in the Broughton Archipelago from March 2003 through December 2005. The average number of treatments per generation was 1.6 and it was reported that sea lice levels remained lower than pretreatment levels for 5 months following a SLICE® treatment.

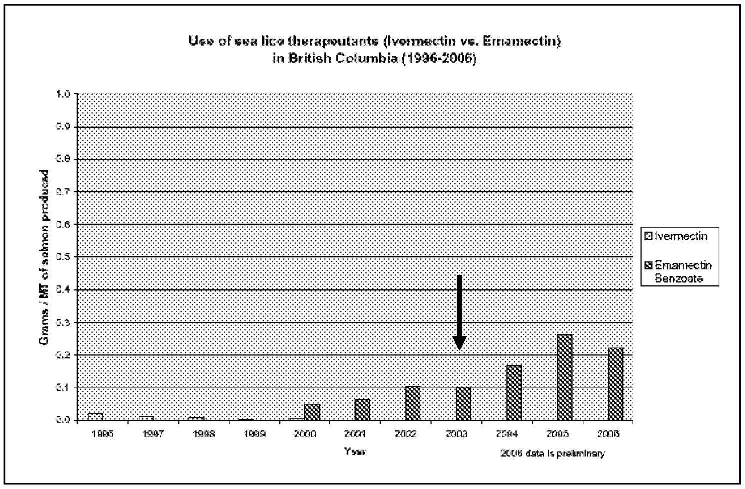



**Figure 11 - Shows the quantity of products used by the Aquaculture industry for sea lice treatment between 1996 and 2006 (supplied by BCMAL). The arrow indicated the year when the monitoring and treatment trigger levels were established.**

## *Sea Lice on Atlantic Salmon Farms*

Sea lice on Atlantic salmon farms have been routinely monitored and available on the provincial government website (see monitoring programs section) since 2004. Figures 12a and b show the data collected for 2007 on Yr2 populations (salmon in their second year in seawater) in the Campbell River and Tofino regions. Over the last few years, sea lice levels have decreased in many regions including the Broughton even though there is no indication that there has been an increase in treatments. Table 2 is extracted data from the BCMAL website showing the mean sea lice levels during March to June – the suggested out-migration period for juvenile pink salmon- for all the zones since 2004. The table shows that 95% of the zones maintained abundance below three motile *L. salmonis* during this period. In addition it shows that over 80% of the zones also met the Norwegian trigger of 0.5 adult female *L. salmonis*. In addition to industry levels reported on the BCMAL website, Marine Harvest

Canada has been reporting sea lice levels on individual farms on their company web site[20]. As well as tabulated data available on the internet, there are several published reports available that summarize portions of the data.

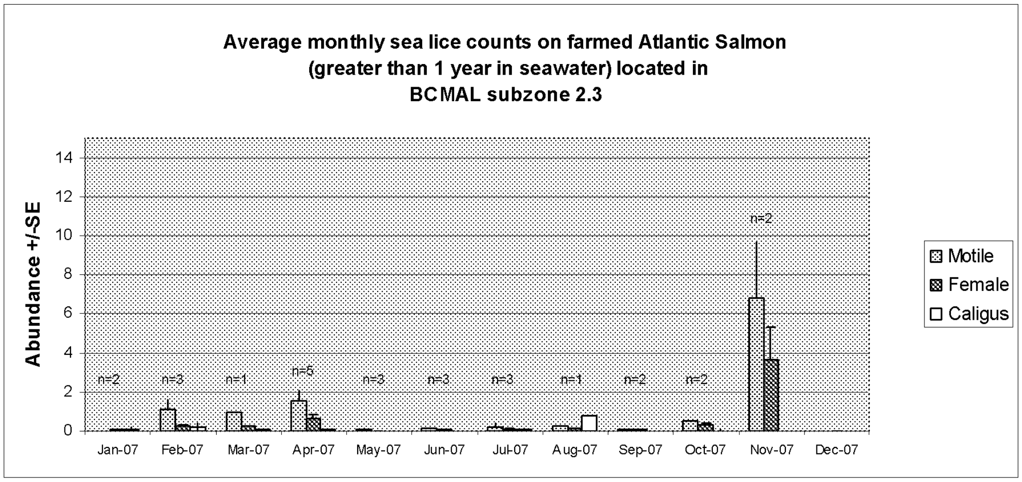
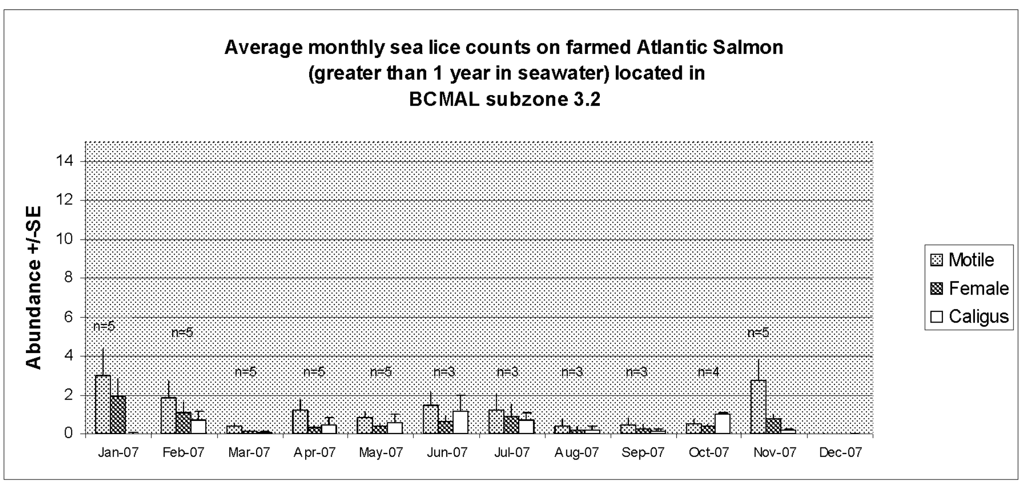



**Figure 12a - Shows the average number of motile *L. salmonis* (motile), adult female *L. salmonis* (female) and motile *C. clemensi*(Caligus) for 2007 on Atlantic salmon farms located in Tofino (zone 2.3)**




**Figures 12 b - Shows the average number of motile *L. salmonis* (motile), adult female *L. salmonis* (female) and motile *C. clemensi*(Caligus) for 2007 on Atlantic salmon farms located in Campbell River (zone 3.2)**

[20] http://www.marineharvestcanada.com/farming_fish_health_broughton.html

**Summary of Sea Lice Data Collected on Atlantic Salmon Farms**

**KEY**
**Mobile** ~ *Lepeophtheirus* sp (pre adult and adult stages) **Yearclass 1** ~ For salmon 1 year or less in seawater.
**Female** ~ Adult female *Lepeophtheirus* sp (adult female) **Yearclass 2** ~ For Salmon 2 years or more in seawater.
**Caligus** ~ sp. (pre adult and adult)

**Atlantic Salmon Sea Lice Abundances**

| Zone/subzone | Yearclass 1 | | Yearclass 2 | | | Yearclass 1 | | Yearclass 2 | | | Yearclass 1 | | Yearclass 2 | | | Yearclass 1 | | Yearclass 2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.3 | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female |
| **Mar-04** | 0.2 | 0.1 | 2.6 | 1.5 | **Mar-05** | 1.7 | 0.6 | 2.3 | 1.3 | **Mar-06** | 0.3 | 0.1 | 1.1 | 0.4 | **Mar-07** | 1.1 | 0.4 | 1.0 | 0.3 |
| **Apr-04** | 0.1 | 0.1 | 0.1 | 0.1 | **Apr-05** | 0.8 | 0.2 | 1.1 | 0.5 | **Apr-06** | 1.3 | 0.1 | 3.7 | 1.3 | **Apr-07** | 1.2 | 0.6 | 1.5 | 0.6 |
| **May-04** | * | * | 0.1 | 0.1 | **May-05** | 1.1 | 0.4 | 0.0 | 0.0 | **May-06** | 2.3 | 0.5 | 4.0 | 1.7 | **May-07** | 1.6 | 0.4 | 0.1 | 0.0 |
| **Jun-04** | 1.5 | 1.0 | 0.8 | 0.5 | **Jun-05** | 0.5 | 0.1 | 0.1 | 0.1 | **Jun-06** | 1.2 | 0.3 | 2.1 | 1.0 | **Jun-07** | 1.0 | 0.4 | 0.1 | 0.1 |
| 2.4 | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female |
| **Mar-04** | 0.2 | 0.0 | 8.8 | 3.5 | **Mar-05** | 0.1 | 0.0 | 0.7 | 0.3 | **Mar-06** | 0.1 | 0.0 | 0.7 | 0.5 | **Mar-07** | 0.7 | 0.1 | 0.3 | 0.1 |
| **Apr-04** | 0.4 | 0.0 | 2.6 | 1.3 | **Apr-05** | 0.1 | 0.0 | 0.6 | 0.3 | **Apr-06** | 0.2 | 0.0 | 1.0 | 0.5 | **Apr-07** | 0.2 | 0.0 | 0.3 | 0.1 |
| **May-04** | 0.5 | 0.2 | 0.4 | 0.2 | **May-05** | 0.1 | 0.0 | 0.5 | 0.3 | **May-06** | 0.1 | 0.0 | 1.3 | 0.5 | **May-07** | 0.2 | 0.0 | 0.5 | 0.2 |
| **Jun-04** | 0.3 | 0.1 | 0.3 | 0.1 | **Jun-05** | 0.1 | 0.0 | 0.7 | 0.5 | **Jun-06** | 0.2 | 0.1 | 1.2 | 0.7 | **Jun-07** | 0.4 | 0.0 | 0.9 | 0.4 |
| 3.1 | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female |
| **Mar-04** | * | * | 0.3 | 0.2 | **Mar-05** | 0.1 | 0.0 | 0.1 | 0.0 | **Mar-06** | 0.1 | 0.1 | 0.2 | 0.1 | **Mar-07** | | | | |
| **Apr-04** | 0.2 | 0.0 | 1.2 | 0.7 | **Apr-05** | 0.1 | 0.0 | 0.1 | 0.1 | **Apr-06** | 0.1 | 0.0 | 0.5 | 0.3 | **Apr-07** | | | | |
| **May-04** | 0.1 | 0.0 | 0.6 | 0.4 | **May-05** | 0.1 | 0.1 | 0.2 | 0.1 | **May-06** | 0.1 | 0.0 | 0.2 | 0.1 | **May-07** | | | | |
| **Jun-04** | 0.3 | 0.1 | 1.4 | 1.0 | **Jun-05** | 0.2 | 0.1 | 0.1 | 0.1 | **Jun-06** | 0.1 | 0.0 | 0.2 | 0.1 | **Jun-07** | | | | |
| 3.2 | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female |
| **Mar-04** | 0.9 | 0.3 | 0.1 | 0.0 | **Mar-05** | 0.8 | 0.2 | 2.7 | 0.9 | **Mar-06** | 4.9 | 2.2 | 1.9 | 0.7 | **Mar-07** | 0.5 | 0.0 | 0.4 | 0.1 |
| **Apr-04** | 1.2 | 0.2 | 1.0 | 0.0 | **Apr-05** | 0.9 | 0.2 | 4.9 | 1.8 | **Apr-06** | 0.7 | 0.0 | 1.9 | 0.6 | **Apr-07** | 0.7 | 0.2 | 1.2 | 0.3 |
| **May-04** | 0.5 | 0.2 | 2.0 | 0.4 | **May-05** | 1.6 | 0.4 | 1.1 | 0.6 | **May-06** | 0.6 | 0.0 | 1.1 | 0.5 | **May-07** | 0.9 | 0.3 | 0.8 | 0.4 |
| **Jun-04** | 0.7 | 0.2 | 2.1 | 0.4 | **Jun-05** | 1.7 | 0.5 | 0.3 | 0.1 | **Jun-06** | 1.2 | 0.3 | 0.4 | 0.2 | **Jun-07** | 0.4 | 0.2 | 1.5 | 0.6 |
| 3.3 | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female |
| **Mar-04** | 1.0 | 0.3 | 2.0 | 1.0 | **Mar-05** | 1.1 | 0.3 | 1.4 | 1.0 | **Mar-06** | 2.7 | 0.9 | 0.8 | 0.4 | **Mar-07** | 0.3 | 0.2 | 1.1 | 0.7 |
| **Apr-04** | 1.6 | 0.1 | 4.4 | 1.1 | **Apr-05** | 1.6 | 0.5 | 0.4 | 0.2 | **Apr-06** | 1.0 | 0.2 | 1.1 | 0.4 | **Apr-07** | 0.3 | 0.1 | 1.1 | 0.4 |
| **May-04** | 2.5 | 0.4 | 7.0 | 4.0 | **May-05** | 1.4 | 0.6 | 1.1 | 0.4 | **May-06** | 0.6 | 0.1 | 0.9 | 0.3 | **May-07** | 0.4 | 0.1 | 0.9 | 0.3 |
| **Jun-04** | 2.4 | 0.7 | 4.5 | 2.0 | **Jun-05** | 1.3 | 0.5 | 1.5 | 0.7 | **Jun-06** | 0.2 | 0.0 | 1.2 | 0.7 | **Jun-07** | 0.2 | 0.1 | 0.2 | 0.0 |
| 3.4 | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female |
| **Mar-04** | 3.7 | 1.3 | * | * | **Mar-05** | 1.8 | 0.6 | * | * | **Mar-06** | 0.6 | 0.2 | 0.7 | 0.4 | **Mar-07** | 0.3 | 0.0 | 1.3 | 0.2 |
| **Apr-04** | 8.0 | 1.4 | * | * | **Apr-05** | 1.0 | 0.2 | 1.0 | 0.3 | **Apr-06** | 0.6 | 0.0 | 0.4 | 0.0 | **Apr-07** | 0.5 | 0.1 | 1.0 | 0.2 |
| **May-04** | 15.7 | 7.6 | * | * | **May-05** | 0.8 | 0.2 | 0.3 | 0.0 | **May-06** | 0.7 | 0.0 | 4.2 | 1.9 | **May-07** | 0.6 | 0.0 | 1.2 | 0.3 |
| **Jun-04** | 1.9 | 0.1 | 2.6 | 1.2 | **Jun-05** | 0.5 | 0.1 | 0.7 | 0.0 | **Jun-06** | 0.6 | 0.0 | 1.5 | 0.8 | **Jun-07** | 0.8 | 0.3 | 1.1 | 0.1 |
| 3.5 | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female | | Mobile | Female | Mobile | Female |
| **Mar-04** | * | * | * | * | **Mar-05** | 0.4 | 0.1 | * | * | **Mar-06** | 0.2 | 0.1 | 0.3 | 0.1 | **Mar-07** | | | 0.1 | 0.0 |
| **Apr-04** | * | * | * | * | **Apr-05** | 0.1 | 0.0 | * | * | **Apr-06** | 0.1 | 0.0 | 0.1 | 0.1 | **Apr-07** | | | 0.2 | 0.0 |
| **May-04** | 0.1 | 0.0 | * | * | **May-05** | 0.2 | 0.1 | 0.1 | 0.0 | **May-06** | 0.1 | 0.1 | 0.0 | 0.0 | **May-07** | | | 0.2 | 0.0 |
| **Jun-04** | 0.0 | 0.0 | * | * | **Jun-05** | 0.2 | 0.0 | 0.3 | 0.1 | **Jun-06** | 0.0 | 0.0 | 0.3 | 0.1 | **Jun-07** | 0.0 | 0.0 | 0.7 | 0.2 |

**Table 2 - Data extracted from BCMAL website showing mean abundance levels by zone for farms with Atlantic salmon less than one year in sea water (Year class 1) and salmon greater than one year in seawater (Year class 2) during the period of wild juvenile out migration (March through June).**

During the summer of 2006, Saksida et al. presented a summary of *L. salmonis* on Atlantic salmon farms from the BC sea lice monitoring program at the International Symposium on Veterinary Epidemiology and Economics. Between October 2003 and December 2005, 73 Atlantic salmon farms and 26 Pacific salmon farms were active (stocked) and participated in the program. Lice were categorized as: non-motile stages of either species, only motile *L. salmonis*, or only motile *C. clemensi*. Means were calculated for seven regions: five on the east coast of Vancouver Island (areas 3.1 to 3.5, moving from south to north) and two on the west coast of Vancouver Island (areas 2.3 and 2.4, moving from south to north). The mean annual abundances for each of the regions ranged from 0.30 to 3.29 lice per fish. The authors reported there were significant differences between zones as well as between years. Zones 3.3 and 3.4 (the zones which contain Broughton Archipelago farms) had the highest mean abundance levels for motile *L. salmonis* in 2004. Zone 3.3 had the highest mean abundance levels for motile *L. salmonis* in 2005. Overall, farms with second year production fish had 2.5 times higher motile *L. salmonis* than first year production farms with mean abundances of 2.95 and 1.18 mobile *L. salmonis*, respectively, for each year of production. For the most part, audited findings were similar to that reported by the farms. The authors suggested that the observed regional differences may be linked to salinity patterns such that those regions with the highest salinity reported the highest sea lice abundance levels. Another influence on farm abundance and infestation patterns is the interaction with native fish, especially the five species of wild adult Pacific salmon which carry *L. salmonis* in high levels when they return to spawn in the summer and fall. It is possible that the variation in lice abundance among the different zones may be related partially to the species of wild salmon found in that zone and to the respective run sizes.

Two other reports prepared by many of these same authors provided a more in-depth evaluation of sea lice data collected from farms located in the Broughton Archipelago (Saksida et al. 2007a, 2007b). Data were included from the twenty farms active in Broughton Archipelago from March 2003 through December 2005. In addition to sea lice counts, information such as fish age, time of year, farm location, water temperature and salinity, and treatment were collected. Categories used for sea lice were chalimus (both non-motile *L. salmonis* and non-motile *C. clemensi* together), adult female *L. salmonis*, all motile *L. salmonis*, and all motile *C. clemensi*. Medians were presented in addition to mean lice abundances because sea lice counts were not normally distributed. Of the twenty farms that were operating during the study, thirteen farms had full production cycles, two had smolt only, three were primarily grow-out sites, and two were broodstock sites. It was noted that even within the Broughton Archipelago there were regional differences observed with one group of farms having consistently lower sea lice levels that the others. There was no significant annual variation in mobile *L. salmonis* abundance for the region as a whole but in some of the areas significant annual variation was observed. A fairly consistent seasonal sea lice enumeration pattern was observed with farm lice numbers higher in the late fall and winter and lower in the spring and summer. The exception was spring 2004 when farms in several areas observed a rise in motile *L. salmonis*. As reported in many papers that describe the European situation, the authors noted that motile *L salmonis* levels increased the longer the Atlantic salmon were in saltwater; however, the rate of increase (an increase of 2% per month) appears to be lower than what has been reported in Europe. Adult female (with and without egg-strands) *L. salmonis* levels constitute a higher proportion of total motile stage levels in Yr2 populations than in Yr1 populations. Saksida et al. (2007a) reported that motile *C. clemensi* abundance levels were always lower than *L. salmonis* and that, in 2003, levels were significantly higher in Yr2 populations compared to Yr1 populations. During the out-migration period (March-June), motile *L. salmonis* abundance levels in the Yr1 populations were significantly higher in 2004 than 2003 (4.1 and 0.7 respectively) while motile *C. clemensi* abundance levels were significantly higher in 2003 then either 2004 or 2005 among Yr2 populations (2.4, 0.4 and 0.2 respectively). There was no significant difference in the level of treatments among the areas – the average number of treatments per production cycle was 1.6 with sea lice levels remaining low for up to 5 months following treatment. Gross signs of damage to the fish and re-infestation following treatment were not observed. The authors suggested that the possible reasons for lower sea lice infestation levels were the less pathogenic and/or more easily treated nature of this strain compared to European strains. Additional factors may include the presence of many different wild Pacific salmonid species and the existence of non-salmonid *L. salmonis* hosts. Saksida et al. (2007b) developed a model to evaluate factors that may be associated with *L. salmonis* infestation and found that water temperature and salinity were not significant factors. During January 2003 through December 2005, surface water salinities ranged from 7.3 ppt to 34 ppt and temperatures ranged from 5 to 13.2 C. Mean salinities were lowest in August and highest in March, while the mean water temperatures were lowest in January and highest in August.

Beamish et al. (2006) analyzed farm data similar to data included in the Saksida et al. (2007a) report and calculated similar estimates of sea lice abundance for Atlantic salmon in their second year in salt water. Beamish et al. did not separate the Atlantic salmon into the different age categories. The prevalence of sea lice infected Atlantic salmon (year classes combined) ranged from 85% in February to 46% in August. The abundance of motile lice (*L. salmonis* and *C. clemensi*) ranged between 6.5 motile lice per fish in February to 1.2 motile lice per fish in July. Between March and June, the abundance of motile sea lice on farmed fish ranged from a high of 4.6 in March to a low of 2 lice per fish in June. The intensity of all lice stages on fish was high in February (21 lice/ fish) and low in July (3.3 lice / fish). The overall average abundance for the entire Broughton Archipelago area between February and September for all Atlantic salmon sampled (Yr1 and Yr2) was 3.1 lice per fish examined; however, only 64% of the fish were infected with sea lice.

Using sea lice counts from the Marine Harvest Canada and some conservative lice egg-production estimates, Orr (2007) predicted louse egg production from twelve active sites in the Broughton Archipelago. The paper estimated that the maximum lice egg production occurred during November and December 2003. By January/February egg production was down by 50%. And by the time the out-migration of wild salmonid species occurred, lice production was down to 12% of the maximum estimated levels. While the author discusses the lack of complete data and areas of interpolation for estimates, there was no sensitivity analysis provided or information on viability of egg to infective life stage. The significance of louse egg production to juvenile pink and chum salmon would depend on many factors including water temperatures and salinity (which influence hatching and viability of the louse) and, in particular, current speed. These three factors impact the probability of contact between parasite and host –but none of these factors were discussed in the paper.

Overall, the sea lice data reported on Atlantic salmon farms to date appear to indicate that patterns of infestation and pathogenicity are quite different to what has been commonly reported in Europe and the east coast of North America. In BC, the sea lice levels appear to be lower and require fewer treatments to maintain these low levels. Currently, sea lice in BC do not appear to pose a significant health risk to farmed salmon. Since the monitoring program has been established, sea lice levels have declined on the farmed salmon. Sea lice monitoring and assessing practices that are either company-initiated or part of BCMAL's Sea Lice Monitoring and Auditing Program are ongoing.

## EFFECTS OF SEA LICE ON JUVENILE PACIFIC SALMON AND RETURNING ADULTS

Until recently, very little research was conducted on the effects of sea lice on juvenile Pacific salmon: most studies examined lice on Atlantic salmon and trout. The crux of the sea lice debate in British Columbia (BC) revolves around the impact that sea lice (particularly *L. salmonis*) have on juvenile pink salmon and the resulting impact on adult pink salmon returns. The controversy about the effect of sea lice on juvenile Pacific salmon and resulting returns has its source in research which was published in respected, peer-reviewed journals where pink salmon mortality rates associated with sea lice (from farmed salmon) are suggested to range from 9-95% (Krkosek et al., 2006). More recently, this estimate was revised to 16-97% (with an average of 80%) (Krkosek et al., 2007b). The same authors incorporated these mortality rate values into mathematical models to conclude that sea lice from farmed salmon were negatively impacting the wild pink salmon. However, the original analysis of mortality and resulting inferences and conclusions were derived from experiments that were not controlled, and for alternative causes of mortality that could not be ruled out (Morton and Routledge, 2005a). The latter report contained results from three trials conducted on wild pink and chum salmon with naturally infected pink salmon, caught in the wild and held in captivity, in comparison with uninfected salmon. The trials were conducted over a three month period (March to May) on populations of out-migrating pink salmon. Trials were carried out for up to 35 days for pink salmon and 47 days for chum. Mortality in pink salmon over the three trials ranged from 8 to 100% and in Chum salmon, over course of the two trials, between 3 and 80%. The highest mortality was observed during the second trial and the lowest mortality was recorded in the first trial. During the trials, pink salmon mortalities occurred earlier than chum salmon mortalities. However, the authors did note a substantial decrease in prevalence and intensity in sea lice for both salmon species over the duration of each trial with over 75% of the initial lice load lost on the pink salmon by the end of the trial period and over 50% lice loss on chum salmon. The authors noted that a high proportion of pink and chum salmon mortalities were infected with motile stages (preadult and adult stages) whereas the majority of the surviving fish were not infected. The authors concluded that wild juvenile pink and chum salmon mortality can occur from 1-3 lice, irrespective of fish size or species. However, to infer causation based on the study design cannot be justified, primarily because the authors failed to confirm the cause of death. There was no evaluation of the health status of the animals at any time during the study. No attempts were made to assess the presence of an underlying condition that may make some fish unhealthy and either 1) more susceptible to infestation by the sea louse or 2) less able to shed the lice. The authors state that weights and lengths were taken; however, no data was provided. A separate report published by the same authors but in a different journal (Morton and Routledge, 2006) indicates that fish used in Morton and Routledge (2005a) likely ranged from 0.41g to 13.0g (average 2.25g). Overall, there is no information on what the growth rates were during the trial (did the fish grow and was there was a difference in growth between the exposure groups?). The authors indicated that the fish ate voraciously but stopped feeding just before they died (approximately 24-36hours before death). However, active feeding behaviour does not always imply that the fish are indeed eating, and since individual fish were not tracked, the authors cannot infer that the 'loners' observed were the mortalities picked 24-36hours later. Overall, the major flaws outlined above suggest that results and conclusions derived from this work are poor benchmarks to use when estimating mortality associated with sea lice. Even so, these results were used to make assumptions and to draw conclusions regarding data in subsequent research papers (Krkosek et al., 2006 and 2007b).

Since the publication of the Morton and Routledge reports in 2005a and 2006, there have been a number of lab based studies conducted on the lethal and sublethel effects of sea lice on juvenile pink and chum salmon. The findings of these newer studies appear to contradict the findings of Morton and Routledge. For instance Jones et al. (2008b) reported results from three conducted on Pink salmon ranging in weight from 0.3g, 0.7g and 2.4g respectively. This weight range contains similar and smaller size fish than those examined in Morton and Routledge (2005a). Salmon were exposed to up to 100 *L. salmon*is copepodids and the study ran for 37 days. Mortality occurred in the two trial groups with weights less than 1g (37% and 5% respectively in the highest exposure groups) but no mortality was observed in the trial conducted on the largest fish (over 2g). The authors observed that the majority of the mortalities occurred within the first twenty-six days post-infection (dpi). Greater than 80% of the dead fish were infested with chalimus stages while, of the majority that survived the exposure to the end of the trial, over 30% were infected with preadult and adult stages. The remaining survivors appeared to have shed their lice. Abundance of *L. salmonis* was lower in the trial conducted on the largest fish (greater than 2g) as compared to fish in the lower weight groups (0.3 and 0.7g). Histological changes in the skin included a thickening of the epidermis, infiltration of the dermis with fibroblasts by the end of trial 1 and the first evidence of scales by the end of trial 2; scales were evident throughout trial 3. The authors suggest the innate resistance to *L. salmonis* displayed by pink salmon develops in fish heavier than 0.3g and appears to be functional by 0.7g. This resistance appears to coincide with changes to the epidermis and dermis, including the formation of scales. The results from this study indicate that the window of susceptibility to *L. salmonis* infection among migrating, post-emergent pink salmon is during the brief period between emerging into the marine environment at approximately 0.3g and when the salmon reach 0.7g. In nature, pink salmon display daily growth rates between 3.5% and 7.6%. This was a follow-up study to Jones et al. (2006a) who reported results on two exposure trials conducted on pink and chum salmon as well as on stickleback. The animals in this trial were considerably larger – final weights of 10, 12 and 2.4grams were reported for the pink, chum and stickleback respectively. In the first trial, exposure rates were 155 copepodids per fish and, in a second trial, 271 copepodids per fish. In both trials no mortality was observed in the pink salmon and only one chum and one stickleback died (both mortalities occurred in trial 1). In Jones et al. (2008a) it was reported that reducing feed rations to approximately 33% of full ration controls in pink salmon had no effect on prevalence or abundance of *L. salmonis*. There was still an observed rejection of *L. salmonis* in all groups suggesting that the defence function of the pink salmon to *L. salmonis* was not compromised by a brief period of reduced rations (27-65days) even though fish on reduced rations were significantly smaller and had lower condition factor than the controls. Despite reduced size due to suboptimal rations, juvenile salmon retained the capacity to reject *L. salmonis* infestations. This work is corroborated by a recent study (Jones et al. 2008b) that shows pink salmon are susceptible to sea lice infection only during their first month in seawater after which they develop an innate immunity. This study estimates the lethal dosage for these small fish.

These studies support the hypothesis that pink salmon have an innate immunity to sea lice. Conversely, exposure trials with larger Atlantic salmon at 55g (compared to 0.2 to 10g pink salmon) exposed to a similar number of copepodids (200) had an average infestation rate of 178 lice per fish and all fish died twelve dpi coinciding with the moult to the preadult stage (Ross, Rirth et al., 2000).

Interestingly, the initial prevalence and abundance of infections were higher on stickleback than either chum or pink salmon in Jones et al. (2006a). The initial prevalence and intensity of infection on chum salmon were higher than those on pink salmon and both declined during louse development. The findings suggest that the stickleback appear to possess the least resistance followed by chum then pink salmon, and all three species are considerably more resistant to infestation than Atlantic salmon. The study found no difference in the rate of development of the *L salmonis* among the three species although development beyond preadult was not observed on the stickleback. This life stage development rate appears to be consistent with development rates reported on BC farmed Atlantic salmon by Johnson and Albright (1991). This report provides evidence that the stickleback (a non-salmonid) may act as a temporary host.

Additional studies have looked at the sub-lethal effects of sea lice on juvenile Pacific salmon. Jones et al. (2007a) evaluated the sub-lethel physiological effects of sea lice infestations on pink and chum salmon. Two trials were reported involving exposure to 243 and 735 copepodids (low exposure and high exposure) respectively. Consistent with previous trials, prevalence and abundance decreased over the length of the low exposure trial in both the chum and pink salmon. However, at both exposure levels the prevalence and abundance of *L. salmonis* was significantly higher on chum salmon. Additionally, the weights of exposed chum salmon following high exposure were significantly lower than the control groups. Hematocrit levels of exposed chum salmon were less than the control group. Neither weight nor hematocrit levels were affected by either exposure level in pink salmon. Histological lesions were associated with the attachment location of the lice; however, no mortality was associated with either exposure level or trial species. Pink salmon showed a higher expression of IL8, a potent neutrophil chemotactic factor. The results of this study suggest a relatively enhanced innate resistance in juvenile pink salmon compared to juvenile chum salmon.

Webster, Dill and Butterworth (2007) reported on three trials that examined infection risks, behaviour and energetic costs associated with sea lice infections of pink salmon. The salmon weighed between 2 and 5 g, 100 animals were exposed to 4000 copepodids and the studies were conducted for up to fourteen days. Similar to the above reports, these studies found decreasing prevalence and intensity of lice throughout the duration of the experiment. Lice density appears to be negatively correlated with length (i.e. longer fish have fewer lice) but there was no relationship with fish condition factors. No mortalities were associated with sea lice exposure; however, skin lesions were observed, but not described, at 14dpi. Fish with lice were reported to exhibit significantly higher rates of leaping behaviours shortly after exposure (2dpi) than the control groups, though this behaviour decreased significantly over the duration of the study. As well, the study reported that infected fish preferred fresh water whereas uninfected individuals preferred saltwater. The paper suggested that behaviour modification, such as increased jumping, may increase predation risk; however, it appeared that this behaviour decreased over time.

Field observations on fish infected with juvenile sea lice, as well as observations from laboratory exposure to copepodid and chalimus stages of both *L. salmonis* and *C. clemensi* in pink and chum salmon have reported little gross pathology (Morton et al., 2004; Jones and Nemec, 2004; Beamish et al., 2006). The most severe lesion reported on juvenile pink and chum salmon is the presence of small circular pigmented areas where non-motile sea lice were presumed to have been (Morton and Routledge, 2005a; Webster et al., 2007).

Finally, Fast et al. (2002) conducted a study on the east coast of Canada on another Pacific salmon species – coho salmon. Similar to the studies conducted on pink and chum salmon, they found that *L. salmonis* disappeared from experimentally infected coho salmon between ten and twenty-one days post-exposure while levels on rainbow trout and Atlantic salmon remained high. This finding provides evidence that another Pacific salmon species, coho salmon, may also have an innate immunity to *L. salmonis*, particularly in comparison to either rainbow trout or Atlantic salmon.

There are a number of ongoing studies, many which have been funded by the Pacific Salmon Forum. A team consisting of veterinary epidemiologists, fish pathologists and fish parasitologists (Saksida, Marty, Jones and St Hilaire) are assessing the health of the wild juvenile pink salmon during their out-migration through the Broughton Archipelago to determine whether sea lice infections have any effect on health parameters and to examine for other lesions/pathogens that may have health implications. The animals collected in the field were examined visually and assessed histologically to determine the effects of sea lice. Preliminary results found very low intensity and prevalence values that varied over time. Very few negative health outcomes were associated with sea lice infestation. Brauner and Farrell, researchers from the University of British Columbia are conducting laboratory and field trials to characterize the sub-lethal physiological disturbances associated with different levels of sea lice infestation of juvenile pink salmon. Factors which are being examined include the effects on growth, swimming performance and osmoregulatory status. This was the first year of the study and techniques are still being developed; however, these researchers did find that most of the lice on the pink salmon caught in the wild were quickly shed in the laboratory. This observation was noted in other lab exposure trials as well. Finally, researchers from Simon Fraser are examining the effects of sea lice infections on predator avoidance. A preliminary summary of the findings from all three studies are posted on the Pacific Salmon Forum web site[21].

Over the last several years there has been a tendency, by certain individuals and environmental groups, to ascribe any low returns of pink salmon to sea lice infections on juvenile pinks. Furthermore, these same reports assume a causative relationship between

[21] http://www.pacificsalmonforum.ca/

salmon farms (as a 'reservoir' of sea lice) and sea lice infections of pink salmon. These claims ignore the literature and data reported by salmon biologists, which show that variability in pink salmon returns on the Pacific North American coast has been a phenomenon ever since pink salmon runs started to be assessed and before salmon farms existed in the area. The theory that sea lice primarily from Atlantic salmon farms infect and kill pink salmon juveniles is further undermined by the majority of the studies which have found little or no pink salmon mortality resulting from *L. salmonis* exposure –even at levels that have shown to kill Atlantic salmon smolts. Pink salmon appear to be able to shed the lice effectively. Mortality appears to be transitory in pink salmon occurring only in very small fish with evidence that immunity starts to develop by the time the fish are only 0.3g and is fully functional by the time the fish reach 0.7g. Mortality appears to be associated with the attached stages rather than motile stages as suggested in Morton and Routledge (2005a). Interestingly, malnutrition does not appear to impact the fish's immunity to the louse. Other Pacific salmon species, such as chum and coho, exhibit immunity as well, but to varying degrees.

The findings from most studies are contrary to the conclusions in Morton and Routledge (2005a) who suggest that one to two motile lice per juvenile pink and chum salmon will kill the animal, irrespective of its size. In fact, only non-motile stages were associated with the mortalities observed in the laboratory exposure studies cited. It appears that pink salmon quickly develop immunity to lice following their emergence from the rivers and subsequent out-migration to the sea. The results of most studies suggest that over the course of the juvenile salmon's out-migration, there is an increased resistance to sea lice. Immunity is close to being fully developed by the time the pink salmon reach 0.7g and, by this weight, scales are present also. Based on the DFO monitoring program, the pink salmon reach this size in less than one month in seawater[22]. Chum salmon also exhibit immunity to lice. Threespine stickleback were observed to be the host species for *L. salmonis;* however, while there was no

[22] http://www.pac.dfo-mpo.gc.ca/sci/mehsd/sea_lice/bulletins_e.htm

evidence to indicate that the lice develop beyond pre-adult stages on the stickleback, these animals may act as a host for these pre-adult stages only. The lack of proper data assessments calls into question whether the high mortalities observed in Morton and Routledge (2005a) were the result of the fish's inability to mount an appropriate immune response due to some other underlying pathology, rather than the direct result of sea lice infection. Also questionable are the conclusions reported by Krkosek et al. (2006) and Krkosek et al. (2007b) that utilize mortality estimates from mathematical models (from Morton and Routledge, 2005a) to determine that sea lice from farmed salmon were a significant cause of mortality among juvenile pink salmon and pink salmon runs.

### *Sea Lice Levels on Wild Juvenile Pink Salmon*

The majority of the reports of sea lice infestations on juvenile salmon have been conducted in the Broughton Archipelago. As reported by numerous authors and studies, table 3 provides a summary of the sea lice levels on wild juvenile salmon in the Broughton in addition to sea lice levels on the farms.

The first report of sea lice on juvenile salmon found a high prevalence of sea lice in Broughton Archipelago juvenile pink salmon sampled by Morton and Williams (2003) in 2001. Prevalence was estimated as 75% with an average of 11.5 lice per fish. Between 15% and 25% of the lice were motile stages (i.e. up to 2.8 motile lice per fish). Fish were sampled using a dip net which may have biased their sampling towards the slow-swimming, sick fish that, naturally, had more sea lice. There is strong evidence to suggest that the fish included in this study were smaller than the fish collected in the same area by DFO in 2001, 2003, 2004, 2005, 2006 and 2007 (DFO, 2001[23]; DFO, 2006[24]; DFO, 2007; Jones et al., 2006c; Jones and Hargreaves, 2007b). Based on the DFO data, by the end of June (when the Morton and Williams survey occurred) pink salmon in that area have been larger than 3.5g (range 3.5g to 10.3g) and by the end of July the fish have been, on average, between 5 and 10g. Chum salmon tend to be larger than pink salmon with weights ranging between 5 and 18g. In comparison, the juvenile salmon collected by Morton and Williams during the entire study period in 2001 (mid June to mid August) were on average between 2.2 and 2.9g.

Fisheries and Oceans Canada (DFO) also evaluated juvenile salmon for sea lice in 2001 and reported that 60% of the pink salmon sampled in Queen Charlotte Strait in late June to early July were infected with sea lice at an intensity of 2.7 lice per fish with 33% of the lice present as motile stages (DFO 2001). Sixty-six percent of the chum sampled from Queen Charlotte Strait and the Strait of Georgia (combined) had lice and the average intensity of the lice on infected individuals was 2.9 lice per fish or 0.95 motile lice per fish. A direct comparison with Morton and Williams cannot be made as the samples were collected outside the Broughton region (further seaward) and the pink and chum salmon were larger (5.6g and 16.8g respectively). Furthermore, the study was not specifically designed to assess sea lice on juvenile fish and as a result the techniques used to capture the fish (trawls and purse seines) likely resulted in underestimated prevalence and intensity of sea lice on the fish. Nevertheless, the true 2001 estimate of sea lice levels on pink salmon is perhaps somewhere between the DFO estimates (60% prevalence; intensity 2.7) and those reported by Morton and Williams 2003 (75%; intensity 11.5).

[23] http://www-comm.pac.dfo-mpo.gc.ca/publications/sealicereport_e.pdf
[24] http://www.pac.dfo-mpo.gc.ca/sci/mehsd/sea_lice/bulletins_e.htm

**Table 3 - Provides a summary of the sea lice levels on wild juvenile salmon reported by various authors.**

| | | | | *L. salmonis* | | | *C.clemensi* | | | *L.salmonis and C.clemensi* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Data source | Species | Fish # | Prevalence | Intensity | Abundance | Prevalence | Intensity | Abundance | Prevalence | Intensity | Abundance |
| 2001 | Morton and Williams 2003 | Pink salmon | | | | | | | | 75 | 11.5 | |
| 2001 | http://www-comm.pac.dfo-mpo.gc.ca/publications/sealicereport_e.pdf | Pink salmon | 195 | | | | | | | 60 | 2.7 | 1.6 |
| 2001 | http://www-comm.pac.dfo-mpo.gc.ca/publications/sealicereport_e.pdf | Chum salmon | 116 | | | | | | | 66.4 | 2.9 | 1.9 |
| 2002 | Morton et al 2005 (1) | pink and/or chum | 491 | 91.8 | 7.4 | 6.8 | | | | | | |
| 2003 | Morton et al 2005 (1) | pink and/or chum | 366 | 36.1 | 1.8 | 0.6 | | | | | | |
| 2003 | Jones, Wosniok and Hargreaves 2006, Jones and Nemac 2004 | Pink Salmon | 7124 / 7438 | | | | | | | 24 | 1.7 | 0.4 |
| 2003 | Jones, Wosniok and Hargreaves 2006, Jones and Nemac 2004 | Chum salmon | 10683 / 11271 | | | | | | | 27.3 | 2.2 | 0.6 |
| 2003 | Jones, Wosniok and Hargreaves 2006, Jones and Nemac 2004 | Three spined Stickleback | 2720 / 2815 | | | | | | | 60.4 | 6 | 3.6 |
| 2003 | Saksida, Constantine et al 2007 (1) | Farmed Atlanitc salmon | 12-16 (~60 fish per farm/month) | | | (Y1) 0.7 (Y2) 3.6 | | | (Y1) 0.8 (Y2) 2.4 | | | |
| 2004 | Morton et al 2005 (1) | pink and/or chum | 535 | 94.5 | 10.2 | 9.8 | | | | | | |
| 2004 | Jones and Hargreaves 2007, Jones, Wosniok and Hargreaves 2006 | Pink Salmon | 1905 | 62.3 | 4.5 | 2.8 | | | | 66.6 | 4.8 | 3.2 |
| 2004 | Jones and Hargreaves 2007, Jones, Wosniok and Hargreaves 2006 | Chum Salmon | 3182 | 58.6 | 12.0 | 7.0 | | | | 73 | 11.9 | 8.7 |
| 2004 | Jones, Prosperi-Porta et al 2006, Jones, Wosniok and Hargreaves 2006 | Three spined Stickleback | 1103/ 1419 | 83.6 | 18.3 | 1.3 to 73.2 | 42.8 | 4.2 | 0.02 to 5.9 | 83.4 | 20.8 | 17.3 |
| 2004(1) | Saksida, Constantine et al 2007 | Farmed Atlanitc salmon | 14-17 farms (~60 fish per farm/month) | | | (Y1) 4.1 (Y2) 5.2 (female 2.3) | | | (Y1) 0.4 (Y2) 0.4 | | | |
| 2005 | Jones and Hargreaves 2007, Jones, Wosniok and Hargreaves 2006 | Pink Salmon | 3882 | 26.4 | 1.7 | 0.6 | | | | 31.2 | 1.9 | 0.6 |
| 2005 | Jones and Hargreaves 2007, Jones, Wosniok and Hargreaves 2006 | Chum Salmon | 2316 | 23.1 | 2.5 | 0.5 | | | | 33.2 | 2.9 | 1 |
| 2005 | Jones, Wosniok and Hargreaves 2006 | Three spined Stickleback | 1298 | | | | | | | 58.3 | 5.4 | 0.6 |
| 2005(1) | Saksida, Constantine et al 2007 | Farmed Atlanitc salmon | 13-17 farms (~60 fish per farm/month) | | | (Y1) 1.4 (Y2) 1.3 (female 0.5) | | | (Y1) 04 (Y2) 0.2 | | | |
| 2006 | http://www.pac.dfo-mpo.gc.ca/sci/mehsd/sea_lice/2006/2006_intro_e.htm | Pink Salmon | 3453 | 15.6 | 1.4 | 0.2 | 8.8 | 1.3 | 0.1 | | | |
| 2006 | http://www.pac.dfo-mpo.gc.ca/sci/mehsd/sea_lice/2006/2006_intro_e.htm | Chum salmon | 3906 | 15.1 | 1.4 | 0.2 | 9.0 | 1.7 | 0.2 | | | |
| 2006(2) | http://www.al.gov.bc.ca/ahc/fish_health/Sealice_monitoring_results.htm | Atantic Salmon in zone 3.3 | 10-15 farms (~60 fish/farm/month | | | 1.0 (female 0.45) | | | 0.1 | | | |
| 2007 | http://www.pac.dfo-mpo.gc.ca/sci/mehsd/sea_lice/2007/2007_intro_e.htm | Pink Salmon | 4056 | 13.6 | 1.4 | 0.2 | 5.3 | 1.2 | 0.1 | | | |
| 2007 | http://www.pac.dfo-mpo.gc.ca/sci/mehsd/sea_lice/2007/2007_intro_e.htm | Chum salmon | 4643 | 14.3 | 1.5 | 0.2 | 6.8 | 1.5 | 0.1 | | | |
| 2007(2) | http://www.al.gov.bc.ca/ahc/fish_health/Sealice_monitoring_results.htm | Atantic Salmon in zone 3.3 | 13-15 farms (~60 fish/farm/month | | | 0.5 (0.2 female) | | | 0.2 | | | |

**(1)** **Motile L.salmonis abundance from March-June by yearclass (1 and 2) - if available adult female abundance is from April-June**
**(2)** **Motile L.salmonis abundance calculated from data available on government web site.**

In 2002, Morton et al. (2004) conducted another evaluation of sea lice on juvenile pink and chum salmon in the Broughton Archipelago area. The authors commenced sampling earlier in the year and sampled weekly from mid April for ten weeks at six sites and twice from one additional site. Again the fish were collected using a dip net; average weight was 4.45g. The report describes a high proportion (90%) of the pink and chum salmon infected with sea lice with an average intensity of seven lice per fish although this was not broken down into motile and non-motile lice. Abundance peaked mid June. In this paper comparisons were made with juvenile pink and chum salmon collected from four locations on the central coast. The authors reported that *L. salmonis* was significantly higher around farms in the Broughton regions as compared to the other regions and *C. clemensi* was significantly higher around farms in both the Broughton and Bella Bella. The problem with the comparison is that no standard sampling protocol was employed. As such, samples were collected at varying times in the spring (any time between April to July); different collection methods were utilized (from dip-netting to purse seining); and locations had significant salinity (ranging between 1.4 and 33ppt) and fish species differences. For example, in the Broughton, 1072 pink/chum salmon (averaged weight 1.07g) were collected from mid April to mid June using a dip net (salinity >12ppt); in Bella Bella 154 pink/chum (average weight 0.63g) were collected at the end of June and early into July using a dip net as well (salinity 11.9-21ppt); in Rivers inlet 250 pink salmon (average weight 3.9 g) were collected in May to July using a purse seine (salinity 1.3-14); and in Prince Rupert 566 pink/chum salmon (1.02g) were collected using a beach seine in May/June (salinity 33ppt). Unfortunately, no other data was collected during this time interval for comparison.

Fisheries and Oceans Canada started conducting extensive surveys in 2003 to evaluate the prevalence of sea lice on juvenile pink and chum salmon in the Broughton Archipelago. DFO collected juvenile pink salmon, juvenile chum salmon, and threespine stickleback (*Gasterosteus aculeatus*) via beach and purse seine (Jones and Nemec 2004). The fish were collected over a course of fifteen weeks between March 3 and June 13, 2003. Over 115 different sites in the

Broughton Archipelago were sampled and separated into eleven geographic zones which were then combined, for modeling purposes, to four larger regions based on distance to open-ocean. Surface seawater temperature and salinity data were collected from each zone. Temperature was collected in all zones between weeks five and fifteen (except for one zone) with some sporadic sampling prior to week five. Salinity was also measured in each zone. Sea lice were counted and identified as motile *L. salmonis*, motile *C. clemensi*, or immature sea lice of which 58% were identified to life stage and genus. There were 11,271 chum salmon, 7438 pink salmon, and 2815 threespine sticklebacks collected. Overall, sea lice were found on 27.1%, 24.0%, and 61.3% of three fish types respectively. Intensities of sea lice were 2.18, 1.65, and 5.95 respectively. Non-motile lice were identified on 23.5% of chum and 17.2% of pink salmon, and 60.7 % of threespine stickleback. The 4282 non-motile lice were classified as 60.1% *C. clemensi* and 39.9% *L. salmonis* on the pink salmon while on the chum, 64.8% were *C. clemensi* and 35.2% were *L. salmonis*. The prevalence numbers for motile stages of *L. salmonis* were 4.4% and 6.0% for chum and pink salmon, respectively, and for *C. clemensi* were 3.5% and 4.0% respectively. Prevalence of infection by non-motile lice on pink and chum juveniles appeared to peak at the start of May. At the same time, the prevalence of infection for both motile *L. salmonis* and *C. clemensi* on pink and chum juveniles began to increase. With the exception of motile *L. salmonis* on chum, the prevalence of motile stages for both species continued to increase until the end of the study.

Pink salmon migrating from the Broughton Archipelago were sampled during the first week of August 2003 in Queen Charlotte Strait and the Broughton Archipelago (Beamish et al., 2005). Fish were examined for sea lice and for skin lesions associated with sea lice, but none were found to have lesions 'exposing muscle'. There was no mention of whether fish had less severe lesions that could be attributed to sea lice. The prevalence of both sea lice species (*L. salmonis* and *C. clemensi*) on fish was 10% and the intensity of lice on infected fish was 1.25 lice per fish. Motile sea lice stages represented approximately 64% of all lice stages on the fish and most of the lice were *L. salmonis* (90%). Unfortunately, the authors did not report the prevalence and intensity of sea lice in the two comparison areas which were surveyed separately. In 2003, Morton et al. (2005b) also reported lower proportions of sea lice infected fish (n=671) sampled at three sites in the Broughton Archipelago. The authors reported that 36% of the 366 fish examined (pink and chum are reported together) were infected with sea lice (authors did not differentiate between species of lice) at an average intensity of 1.8 lice per fish. The DFO values were lower, but not substantially, to those reported by Morton et al. (2005b).

Fisheries and Oceans continued the extensive sea lice survey during the spring of 2004 and 2005 migration seasons (Jones et al., 2006b; Jones et al., 2006c; Jones and Hargreaves, 2007b). In the 2004 sampling year, the prevalence of all stages of both *L. salmonis* and *C clemensi* on pink and chum salmon were significantly higher than in 2003. In 2004, *L. salmonis* prevalence levels of 63, 59 and 83% were recorded on pink salmon, chum salmon and stickleback respectively; intensity levels were reported as 5, 12 and 21 respectively. Morton et al. (2005b) reported a significantly higher prevalence of 94.5% with an infection intensity of 10.2 lice per fish (chum and pink combined) collected from three sampling sites. Interestingly, the fish evaluated by Morton et al (2005b) were substantially smaller than those collected by DFO (Jones and Hargreaves, 2007b): 1.34g (in Morton's study) compared to greater than 3g (in the DFO study) –even though both samples were taken in May. These size differences may suggest selective sampling for unthrifty fish by Morton et al. Morton et al. (2005b) collected samples using a dip net and in 2004 switched to beach seine; the DFO samples were collected with beach and purse seines. In the 2005 sampling season, Jones et al. (2006c) and Jones and Hargreaves (2007b) noted that the prevalence and intensity levels had returned to approximately the 2003 levels. Morton did report that in 2004 water temperatures were over 2C higher than in 2002 and 2003. Brooks (2005) and Brook and Stucchi (2006) looked at the role environmental factors including water temperature, salinity and current may play in survival and the dispersion of the infective stages of *Lepeoptheirus salmonis* in the Broughton Archipelago.

For years 2003-2005, the abundance of lice on chum were higher than on pink salmon (P<0.05). Sticklebacks had a higher abundance than pink or chum salmon in all years (P<0.05) (Jones et al., 2006c; Jones and Hargreaves, 2007b). In the 2004 and 2005 samples, there were both spatial and temporal variations in the data. The abundance of lice was higher on fish collected from areas closest to the ocean and with the highest salinities. Larger salmon size correlated with a reduction in lice abundance and maturity. Pink salmon also supported a higher proportion of motile lice than chum salmon. Poisson regression was used on the 2005 data to determine if any of the measured factors could increase the probability of high lice intensity. The intensity models for all stages of *L. salmonis* and *C. clemensi* indicated that host species, geographic zone, collection period and salinity were all important risk factors. The model for motile *L. salmonis* predicted zone and collection period as risk factors, while the model for motile *C. clemensi* included these two factors plus salinity. From the modeling, factors found to be important for the prevalence of non-motile stages were increasing salinity and fish length –this was true for both chum and pink salmon. For motile *L. salmonis* prevalence, factors included salinity and increasing fish size, which is likely a function of time spent in sea water. For chum salmon, the same pattern emerged with temperature as an important risk factor. For motile *C. clemensi* prevalence, increasing temperature, salinity and length were important risk factors. Area was always an important factor and usually the areas closest to the ocean, which likely reflect longer estuary residence times, were at highest risk for both non-motile and motile sea lice.

The sea lice survey continued in 2006 and 2007. Data are presented on the DFO web site[25]. The prevalence and intensity reported in these two years are even lower than any of the levels reported in the previous years. Total lice prevalence levels are similar to those documented in the north coast –in regions devoid of salmon farms- by Gottesfeld et al. (2005) where wild

[25] http://www-sci.pac.dfo-cmpo.gc.ca/mehsd/sea_lice/2006/Marine_Weekly_Results/28mar05apr06_e.htm

juvenile pinks were surveyed for sea lice by trawl and dip net off the northern coast of BC between May and July 2004. Prevalence of all lice was 13.6%, with an intensity of 1.22 and abundance of 0.17. The prevalence levels of *L. salmonis* and *C. clemensi* were 2.7% and 10.9% respectively. Interestingly, the prevalence levels by louse species in the Broughton Archipelago is reversed (higher levels of *L. salmonis* vs. *C. clemensi).*

There seems to be some discrepancy between authors evaluating sea lice in the Broughton Archipelago. This was particularly evident during the 2004 sample period where reported abundance and prevalence differed by 30% or more. It is possible that this difference may be related to sampling methodology as well as sample area and size. The research conducted by DFO was far more extensive and more likely an accurate reflection of the sea lice abundance and prevalence in the regions. The findings from the reports suggest that there is an annual variation in sea lice abundance and intensity in pink and chum salmon and that during the last few years the levels are the lowest recorded in the region. The abundance of lice was higher on fish from the areas closest to the ocean with the highest salinities. Pink salmon supported a higher proportion of motile lice than chum salmon. The sea louse *L. salmonis* was evident on non-salmonid species, particularly the threespine stickleback, with higher prevalence and intensity observed on this species than either pink or chum salmon. It does not appear, however, that the lice reach maturity. Presence of particular sea lice life stages is related to time of year with motile sea lice evident later in the season –evidence that sea lice develop on the juvenile salmon.

### *Source of Sea Lice on Juvenile Pacific Salmon*

A significant amount of effort has been put into suggesting that farmed salmon are the primary source of sea lice on juvenile pink and chum salmon in the Broughton Archipelago. For example, Morton et al. (2005b) reported on three years (2002-2004) of sea lice monitoring on wild juvenile salmon in the region. The authors concluded that the decrease in infection levels seen in 2003 was caused by the fallowing of three specific farms in a single channel during the migration period (Figure 13). The report associated the better returns seen in 2004 to the absence of these three farms. Krkosek et al. (2005, 2007b) assessed sea lice on juvenile salmon in the same region and proposed that sea lice pressures imposed by farms were four fold higher than ambient levels using mathematical models. There are several major concerns with all of these papers.

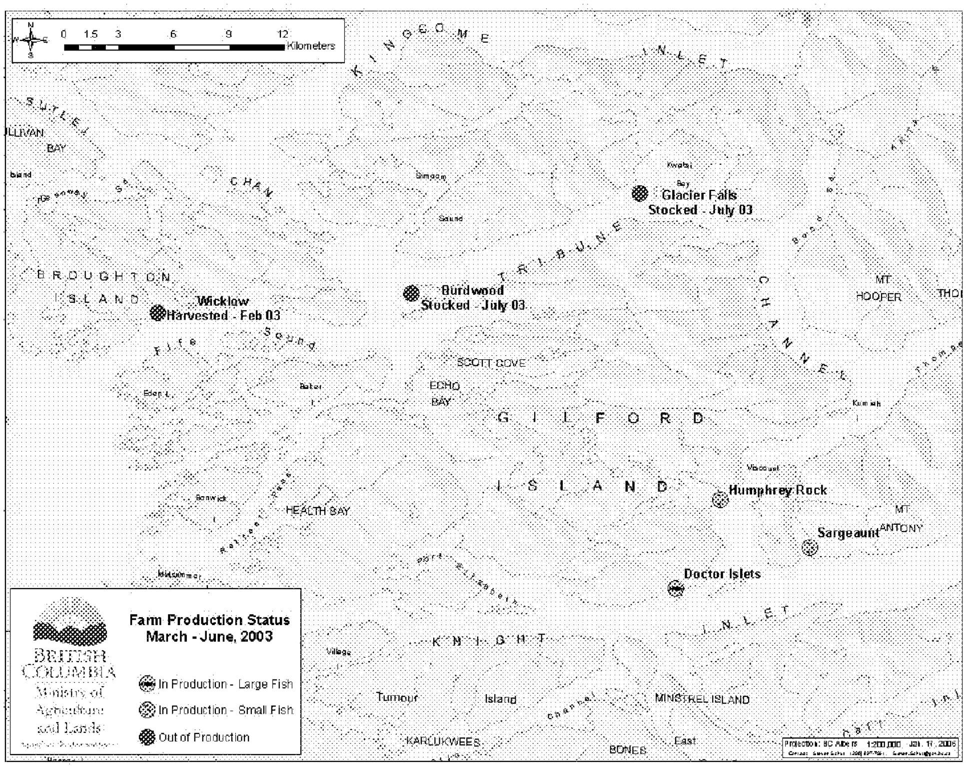



**Figure 13 - shows the 3 farms of interest fallowed in the Broughton**

Firstly, these papers make the assumption that overall salmon production in the region was lower in 2003 –this was not the case. In fact, government data show that salmon production did not change in the region between 1998 and 2003[26] and the number of farms did not differ significantly during the out-migration period in 2003, 2004 and 2005 (Figure 14 and Table 4). This period covers the exceptionally high returns which were observed in 2000 and 2001, the low returns of 2002 and 2003 and the periods of the out-migration (spring 2003) fish that returned in 2004. These periods occurred before any regular sea lice monitoring and treatment requirements were established. Beamish et al. (2006) showed that even though industry production in 2003 was similar to 2001 and 2002, marine survival of the pink salmon that out-migrated in 2003 and returned in 2004 was exceptional at 34.2% (normal levels are less than 10%). This high survival rate suggests that factors other than salmon farms and sea lice may play a more significant role in the return sizes. Additionally, the authors make the assumption that almost all of the juvenile salmon in the region migrate past these three farms even though there is no data to corroborate this (Figure 15).

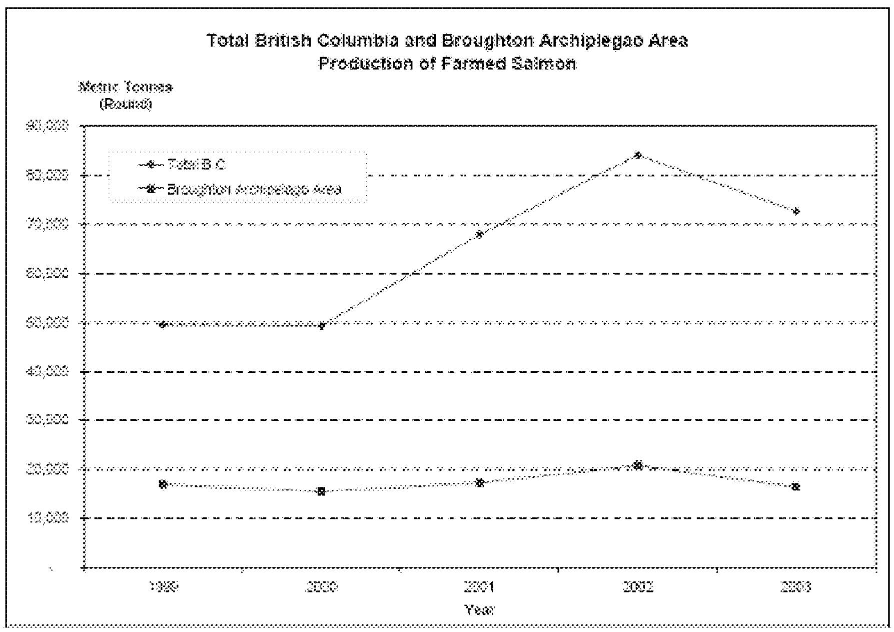



**Figure 14 - shows the annual farmed salmon production in the Broughton Archipelago Area in comparison to overall BC production.**

[26] http://www.al.gov.bc.ca/ahc/fish_health/Sealice/Prod_Fallowing_BA.pdf

**Table 4 – Farm numbers in operation in each year and numbers of farms without fish during the estimated period of smolt out-migration of 2003, 2004 and 2005**

| Year | Average number of farms active with fish during year and range | Sites without fish | | | |
|---|---|---|---|---|---|
| | | March | April | May | June |
| 2003 | 13.7 (12 – 16) | 12 | 12 | 14 | 14 |
| 2004 | 15.5 (14 – 17) | 10 | 10 | 12 | 12 |
| 2005 | 14.9 (13 - 17) | 10 | 10 | 11 | 13 |

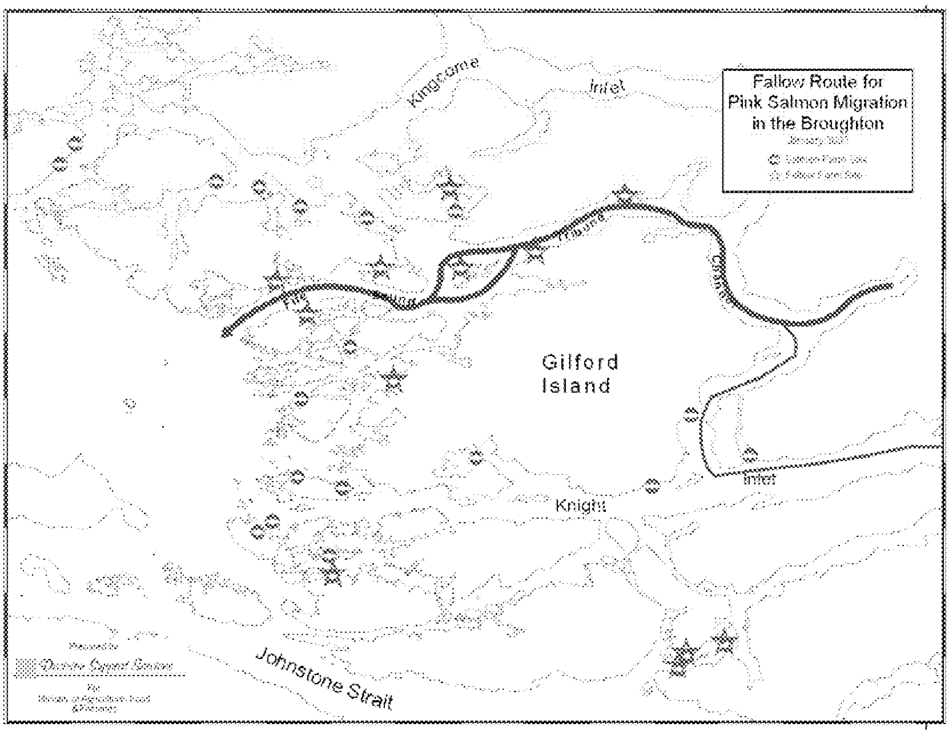



**Figure 15 - Juvenile salmon migration route proposed in Morton et al. (2005b) and Krkosek et al. (2007b)**

Secondly, the reports assume that the lice observed on wild juveniles came from farms adjacent to the collection site even though these studies provide no sea lice data from the salmon farms. Finally, these reports appear to ignore the effects of environmental factors such as water temperature, salinity and water dynamics which would affect survival and dispersion of the nauplii and copepodid stages (Brooks and Stucchi 2006). Interestingly, during a recent wild pink salmon survey, two sampling sites located in Tribune and Fife (Glacier Falls and Wicklow respectively) had higher prevalence of lice (all stages included) than the location in Queen Charlotte Strait (Midsummer Island) ($Z= 3.03$, $p= 0.002$ and $Z= 4.21$, $p=<0.001$, respectively). The farm located near Glacier Falls had been fallow for at least one year, while farms located near Midsummer Island and Wicklow were stocked (Saksida et al. on-going project, http://www.pacificsalmonforum.ca/). Additionally, these farms do not appear to experience significant sea lice cycling (or re-infestation) further suggesting that local environmental factors and dispersion are significant.

In Krkosek et al. (2006, 2007b), the authors use: sea lice data and perceived migration routes outlined in their previous work (discussed above); mortality data outlined by Morton and Routledge (2005a) that have not been demonstrated in any other studies; and mathematical models, to demonstrate the apparent effects that the sea lice from farms had on the survival of pink salmon. Their conclusions were that sea lice from farms resulted in a huge mortality range: from less than 10% to greater that 95%. In addition to the concerns of the original studies on which this paper was based (discussed above and in the effects of lice on salmon section), there is concern that the authors appeared to be very selective in the return data used in the analysis. For example, the authors omitted the returns to the Glendale river system. The authors suggested that systems, such as the Glendale, were omitted because these systems were enhanced and, as such, confounded their estimates of 'natural' changes (Krkosek et al 2007b). However, the Kakweiken river data was included even though it was enhanced in 1989 –just one year after the Glendale (Beamish et al., 2006). The Glendale has contributed almost 90% of the Broughton pink salmon returns in odd years and 40% of the returns in even years since 1999. It is therefore very likely the salmon assessed by the authors to develop their model were actually from the river system (the Glendale), that they chose to omit in their analysis. Furthermore, farm data, both published and publically available on the internet, which provided sea lice levels for the farms in the area and showed that the levels on the farms are low, were ignored. Instead, the authors utilized the presence of a stocked farm as a proxy. All these concerns raise questions about the validity of the results and conclusions.

Table 3 provides a summary, from various sources, of the sea lice levels observed on the farms and on the juvenile salmon in the Broughton Archipelago. The data show that in 2004 sea lice levels were higher on both the wild and Yr1 farmed salmon. Since 2004, the DFO data indicates a declining trend in both the prevalence and intensity of sea lice on the wild juvenile salmon. Farm data shows that since 2004 sea lice levels are lower. During this same period, table 3 shows that the decline in sea lice levels on wild salmon was somewhat to significantly larger (depending on species) than the decline on farmed salmon. One ongoing project is evaluating the sea lice data collected from the farms in the Broughton Archipelago and comparing it with juvenile salmon data collected by DFO. The project is a being conducted by S. Saksida, S. Jones, B. Hargreaves, D. Stucchi, A. Donald and W. Wosniok. The project is co-funded by the Pacific Salmon Forum, DFO and BCMAL. The analysis should be completed shortly and a paper will follow.

Other potential sources for sea lice have been posed. Beamish et al. (2007) stated that *L. salmonis* is commonly found on Pacific salmon returning to spawn on the coast. These authors proposed that the transport of sea lice, *L. salmonis*, back to the coast is likely a strategy incorporated into the life cycle to improve transmission of infectious stages and to ensure survival of the species. The authors suggested that this strategy may include other juvenile species of salmon which remain in the coastal areas and which may serve as overwintering hosts (in addition to host opportunities provided by resident coho and Chinook salmon which do not migrate to the open sea). In a report by Gottesfeld et al. (2005), wild juvenile pinks were surveyed for sea lice by trawl and collected by dip net off the Northern coast of BC –in an area devoid of salmon farms- between May and July 2004. Prevalence of all lice was 13.6%, with an intensity of 1.22 and abundance of 0.17. The prevalence of *L. salmonis* and *C. clemensi* were 2.7% and 10.9% respectively. In this area, there were few *L. salmonis* and many more *C. clemensi*. Early in the sampling process, adult salmon were infrequently seen, but were more abundant later in the season. This report suggests that wild salmonids could be the potential source of sea lice, and particularly *L. salmonis*, found on juvenile pink and chum off the coast of Northern BC. The potential over-wintering hosts of *L. salmonis* in northern BC are Dolly Varden (*Salvenlinus malma*), steelhead (*Oncorhynchus mykiss*) and possibly juvenile Chinook salmon. Returning Chinook salmon were observed to have heavy lice loads including a large number of gravid females.

One surprising observation was the large number of attached to preadult stages of *L. salmonis* found on threespine stickleback (*Gasterosteus aculeatus*) which had a high prevalence of all sea lice species. Identification of the lice revealed that the sticklebacks were infected with both *L. salmonis* and *C. clemensi*. Sticklebacks had a higher abundance of both sea lice species than either pink or chum salmon in all years (Jones et al., 2006c; Jones and Hargreaves 2007b). Jones and Nemec (2004) found stickleback at most times that they found pink and chum salmon, exposure to these fish species would occur for the duration of migration. Although it does not appear that *L. salmonis* reach maturity on the stickleback, direct transfer of pre-adult lice from stickleback to juvenile salmon may be possible. Stickleback are non-salmonid, year-round residents of the estuaries and could be a potential source of *C. clemensi* and *L. salmonis*. There is, however, very little known about the extent of their distribution and population size along the BC coast. Two surveys have found herring infected with *C. clemensi* (Jones and Nemec 2004; Gottesfeld et al. 2005).

A number of reports have studied sources of sea lice and possible host relationships. Three potential sources of sea lice for wild juvenile pink and chum salmon have been proposed: farmed salmon, wild salmonids, and wild non-salmonids. The relative importance of each potential source would likely vary between locations and would be influenced by: the relative abundance of the infective stages of lice; environmental factors such as salinity, temperature and current which would influence the success of settlement; and the susceptibility of the host at the time of exposure as it appears that juvenile chum and pink salmon quickly develop an innate immunity to sea lice (as discussed in the effects on pink salmon section). Therefore, although the source of infection is a vital factor, the overall effect of the lice on the population is more important. The most compelling argument for an over-wintering capability by the sea lice population is the lice's need to continue its relationship with different generations of salmon hosts. An alternate host could serve as a plausible bridge for transmission between salmon generations.

# CONCLUSION

This overview attempts to provide a balanced portrayal of all available data from which to make an informed impression of the sea lice debate. There are many gaps in the information regarding sea lice (for example, life cycles and intermediate hosts) and the interactions between sea lice infections of farmed and Pacific salmon. Any information that helps fill in these gaps is welcome, but only if it provides a thorough and unbiased study. Inconsistencies can be seen in and improvements can be suggested for almost any research project. As such, most research is seen as adding to a body of knowledge and furthering an understanding of the subject. It is another step forward towards discovery. Research should not be used to promote one particular message from a vested interest. Unfortunately, salmon farming, and the sea lice issue in particular, have become the subject of a well organized marketing campaign. Science is about findings answers, not creating scenarios to pick and choose data thereby ensuring a predetermined outcome. When the premeditated outcome of science is the delivery of a marketing message, the methods and results of that research have to be questioned.

This report attempted to discuss inconsistencies in some studies and to show how their existence calls into question the validity of the conclusions made. While both sides of the sea lice debate have a vested interest, only one side (NGOs) has marketed its message. By repetition these negative messages have become fact in the public's perception. And it is hard to turn public perception around: especially when a thorough understanding of the issue is still a long way off. From its perspective, the industry has utilized research from other sources (such as government) as well as its own data to create a more complete picture of the issue. The stance of the industry is substantiated by independent and governmental research. A statement by DFO regarding the sea lice debate in the Broughton Archipelago is included as Appendix 1 in this report.

Regarding the sea lice debate, the following statements can be made:

- There is no evidence that pink runs are declining in British Columbia –these runs have always undergone natural fluctuations
- Pacific salmonids appear to have an innate immunity to sea lice infection
- Environmental influences on and sources of infection of sea lice on pink salmon are not fully understood
- Sea lice infections of Atlantic salmon in BC are monitored, regulated and controlled and are not a fish health or disease management issue
- There is evidence that the Pacific *L. salmonis* is not the same species as the Atlantic sea louse of the same name

Balance in understanding has to be infused into the debate. Reasonable risks can be and are being mitigated. Regulations are in place to reduce the risks presented by a contained population. These regulations include regular monitoring, assessing and auditing to ensure that a complete sea lice management program is in place. In fact, BC's salmon farming industry operates under some of the toughest fish health and operating practice regulations in the world. These regulations ensure that the opportunity for sea lice transfer from farmed to wild salmon is negligible. Data from farms, government auditing programs and independent research indicate that wild populations are not substantially at risk from sea lice infections of farmed salmon. In fact, the current DFO monitoring program has provided data showing that sea lice on juvenile pink and chum salmon are on the decline. This valuable information allows sea lice management to move away from the precautionary principle to a science-based program that can be developed in BC for BC.

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# APPENDIXES

# APPENDIX I

## *DFO STATEMENT ON THE SEA LICE SITUATION IN THE BROUGHTON*

### Focus on Science, Wild Pacific Salmon, and Salmon Aquaculture[27]

In June 2005, Canada's Policy for Conservation of Wild Pacific Salmon[23] was announced. This policy is a strong commitment to the conservation of wild salmon and their habitats, recognizing this goal as DFO's first priority in resource management decisions related to Pacific salmon. To achieve this, DFO will consider the ecosystem of salmon as a whole: the living resources, the aquatic habitats and interactions among species, the effects of ocean and climate variation, and the impact of development and human activities. Within this context, the development of salmon aquaculture is one of numerous human activities which influence Pacific salmon.

In the issue concerning salmon farms, sea lice, and wild salmon in the Broughton Archipelago, DFO has undertaken extensive research, both in the field and the laboratory. The department also welcomes independent scientific research into the potential impacts of sea lice and the interactions of wild and farmed salmon. Some recent papers have, however, generated media reports stating that sea lice produced from salmon farms are a major cause of losses in wild salmon populations.

DFO has obtained comprehensive data from the Broughton Archipelago over four years of sampling juvenile salmon and sea lice infections and fish health, plus monitoring annual

[27] http://www.pac.dfo-mpo.gc.ca/SCI/aquaculture/sealice/statement_e.htm

returns of adult salmon. See the backgrounder entitled, "2003 - 2005 Results" that compares sea lice levels on pink and chum salmon in the Broughton Archipelago and Knight Inlet during this time period. In 2006, DFO's sampling shows that sea lice infections on wild salmon in the Broughton Archipelago are the lowest since observations began in 2002.

Laboratory studies have assessed the impact of sea lice infection and survival of small pink and chum salmon. Comparison of juvenile pink and chum salmon infected and non-infected with sea lice in 2003 and 2004 indicated no significant differences in health or size of the sampled fish.

DFO research does not support the close association between salmon farms, sea lice, and loss of wild salmon reported by others.

**Findings-to-Date**[28]

Sea lice are naturally-occurring parasites found in every ocean and on many species of fish around the world. They are very common on all Pacific salmon adults during their return migration in coastal waters of B.C. Wild salmon can transfer sea lice to salmon farms and, if left untreated, farmed salmon can transfer sea lice back to the marine environment.

Sea lice were significantly more abundant on juvenile pink and chum salmon in 2004, compared to either 2003 or 2005. 2006 research indicates sea lice levels are the lowest ever among farmed and wild salmon

Findings are outlined in the Pacific Region Pink Salmon Action Plan Bulletins

**Specifics:**

[28] http://www.pac.dfo-mpo.gc.ca/SCI/aquaculture/sealice/findings_e.htm

1. Two different species of sea lice, *Caligus clemensi* and *Lepeophtheirus salmonis*, have been found to commonly infect juvenile pink and chum in the Broughton.
2. *Caligus clemensi* was found to be the most abundant sea lice on juvenile pink and chum salmon in 2003, whereas *Lepeophtheirus salmonis* was most abundant in both 2004 and 2005.
3. 2006 research indicates sea lice levels are the lowest ever among farmed and wild salmon.
4. Several different developmental stages of both species of sea lice were found on juvenile pink and chum salmon. In all years the majority of the sea lice observed on juvenile pink and chum salmon were the early (non-motile) developmental stages.
5. Sea lice were significantly more abundant on juvenile pink and chum salmon in 2004, compared to either 2003 or 2005.
6. Sea lice were also observed to infect other fish species in the Broughton. In all three years (2003-2005), sea lice abundance was significantly greater on threespine stickleback (*Gasterosteus aculeatus*) than on juvenile pink or chum salmon. This research is the first reported case of *L. salmonis* infecting stickleback.
7. The abundance of later development stages of *L. salmonis* generally coincided with growth of pink salmon. Mature (motile) lice occurred more frequently on larger juvenile pink salmon. This pattern was less obvious during growth of chum salmon.
8. The total abundance of the sea lice *L. salmonis* on juvenile pink and chum salmon generally declined sharply as the salmon grew in size.
9. Significant variation in surface seawater salinity was observed in different areas of the Broughton.
10. The abundance of sea lice was minimal on juvenile pink and chum salmon and sticklebacks in areas with the lowest salinity.

11. Salmon species, size and location, as well as seawater salinity were all found to be significant predictors of the number of sea lice.

# APPENDIX II

***THE GREAT SALMON RUN: COMPETITION BETWEEN WILD AND FARMED SALMON***