Pacific Fisheries Resource Conservation Council

2002 Advisory: The Protection of Broughton Archipelago Pink Salmon Stocks

Prepared by

Pacific Fisheries Resource
Conservation Council

November 2002

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Pacific Fisheries Resource Conservation Council
Conseil pour la conservation des ressources halieutiques du pacifique

November 2002

Hon. Robert G. Thibault, P.C., M.P.
Fisheries and Oceans Canada
Centennial Tower
200 Kent Street
Ottawa, Ontario
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Hon. John van Dongen, MLA
Ministry of Agriculture, Food and Fisheries
Room 137
Parliament Buildings
Victoria, BC
Canada V8V 1X4

Re: Conservation of pink salmon populations in the Broughton Archipelago, B.C.

Dear Ministers,

The Pacific Fisheries Resource Conservation Council (PFRCC) presents to you its 2002 Advisory on the *Protection of Broughton Archipelago Pink Salmon Stocks*.

The PFRCC's primary concern in this issue is the need to protect and provide safe passage for the 2002 pink salmon brood year (2003 juvenile migrants) on their seaward migration through the Broughton Archipelago. The previous brood year, the 2000 spawners, sustained unprecedented declines in numbers of returning spawners in 2002 with returns between a hundredth and a thousandth of the parental year. **In numerical terms, the number of pink salmon spawners in the Broughton Archipelago decreased from 3.615 million fish to 147 thousand fish.** Pink salmon populations do experience fluctuations, marked at times, and some have argued that the declines were consistent with past observations. In fact DFO and Council analyses confirm that the magnitude of decline and occurrence in several streams was beyond what has been previously observed and very unlikely to have been caused by chance alone. Further, the spawner declines were virtually confined to the Broughton Archipelago, leading us to conclude that the decrease was specific to conditions in the Broughton Archipelago. There is evidence that the Broughton pink juveniles were infested with sea lice, a condition essentially unreported for juvenile pink salmon in the natural environment elsewhere.

While scientific certainty is not absolute, European research does indicate that sea lice abundance can be associated with salmon farming. Given this evidence, combined with the presence of sea lice on Broughton Archipelago pink salmon smolts, and the fact the decline in numbers was limited to Broughton Archipelago fish, the Council believes that sea lice were associated with the decline observed in the Broughton Archipelago. Where there is a risk of serious or irreversible harm the precautionary approach calls for action based on the best evidence available. In this Broughton Archipelago case, the absence of any evidence of some other cause, than sea lice, justifies action.

The PFRCC considers the decreased numbers of pink salmon spawners to be a crisis. Accordingly, we advise that all measures necessary to assist smolts passage through the Broughton Archipelago without enduring sea lice infestations should be taken.

In this regard our attached report recommends a lower risk approach for your consideration. A higher risk approach is also presented, but it is not Council's preferred option. For either option there should be concerted monitoring and scientific study.

Given the timing of juvenile salmon movement into the sea it is urgent that action be taken as soon as possible with the Council recommending that action be agreed upon with implementation starting by mid-January 2003.

Sincerely,
Hon. John Fraser
Chair

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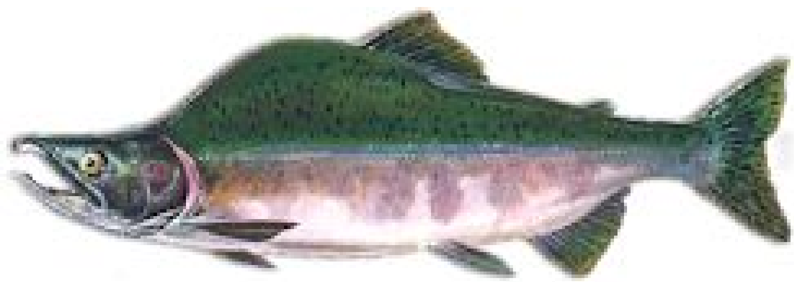
TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

INTRODUCTION

Pink Salmon



The Pacific Fisheries Resource Conservation Council (PFRCC) hosted an October 28, 2002 public consultation regarding the status of pink salmon spawning populations in the Broughton Archipelago (see Map 1). While the Broughton Archipelago also has numerous other salmonids, with different life cycles than pinks, the consultation was limited to pink salmon. The reason for the consultation was to obtain information on the Broughton Archipelago pink salmon declines and potential reasons for those declines. The notes taken of the meeting, presentations or material related to those presentations are attached as Appendix 1.

BACKGROUND

This consultation followed public controversy regarding sharp drops in the number of pink salmon spawners in 2002 compared to the brood year numbers in 2000. Many, but not all, have related the cause to sea lice originating from local salmon farms. For instance, a letter has recently been addressed to the Minister of Fisheries and Oceans' (DFO) office by Ms. A. Morton (Oct. 19, 2002).

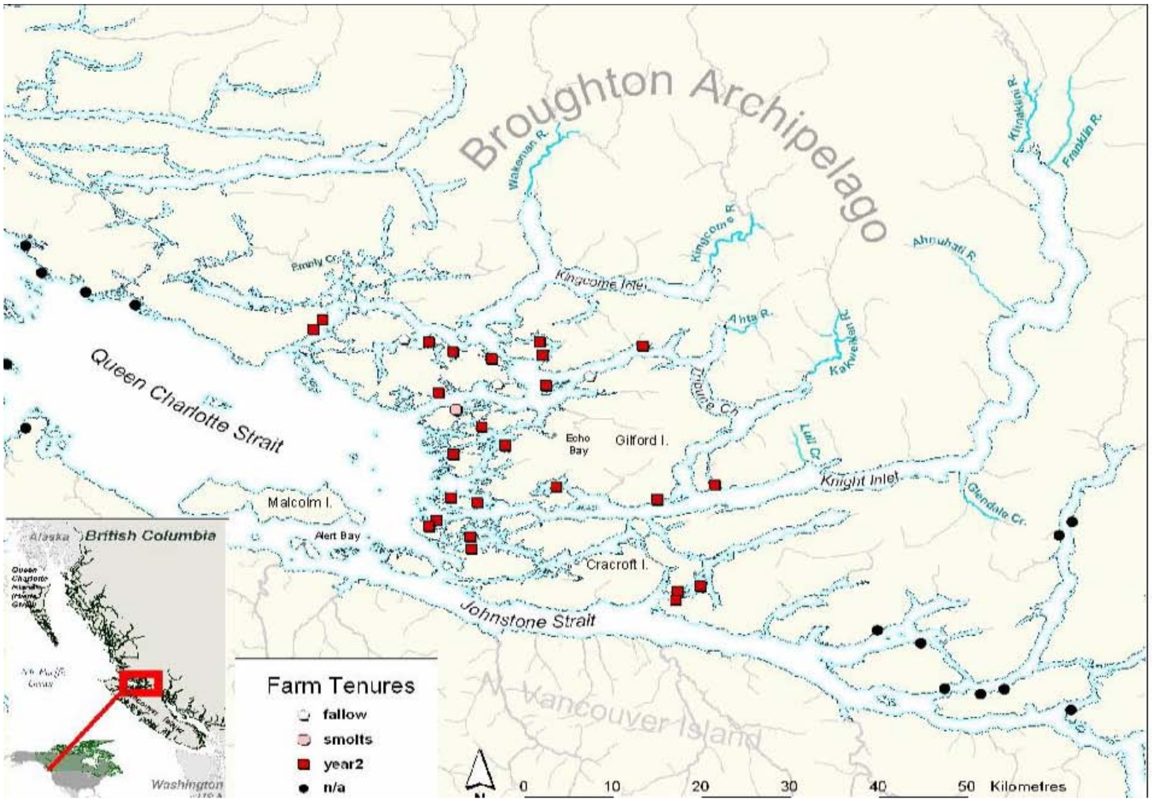
> *"I am writing in regards to the profound crash of all pink salmon runs in Kingcome and Knight Inlets and Tribune Channel. This is the first time this has happened since DFO record keeping commenced in 1953. The disappearance of these 5 million fish comes amid good to excellent pink salmon returns everywhere else on this coast from Alaska south. I have scientific evidence this crash is due to the sea louse,* Lepeophtheirus salmonis*, infection on the juvenile pink salmon that went to sea in 2001".*

The possibility of sea lice epidemics associated with intensive salmon farming in the Broughton Archipelago as the principle cause of the decline has generated a heated debate.

Pink Salmon Returns in 2002

At the October 28th meeting DFO presented information regarding the 2002 and historical counts of pink salmon in the Broughton Archipelago and surrounding areas (Appendix 1, Annex 1). As for past years, data on spawning population sizes were collected through a combination of aerial and foot inspections. These were repeated at numerous times during the spawning season. This year the fishery was greatly reduced compared to historical patterns. Even so, the numbers of pink salmon spawning in local streams decreased from 3.615 million fish in 2000 to 147 thousand fish returning in 2002. This said, as with most fisheries data, care should be taken in terms of the absolute numbers involved, but the decline is a source of major concern for the future of these populations (Figure 1).

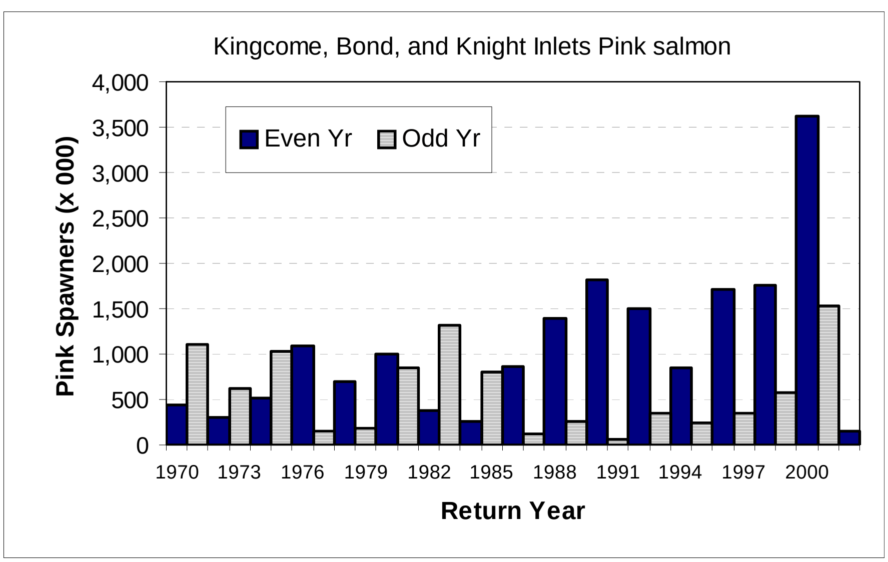
MAP 1



The PFRCC recommends urgent action be taken to minimize any chance of a similar level of decline of pink salmon in future years.

Figure 1. Annual spawning escapements of pink salmon to Kingcome, Bond, and Knight Inlets

By even and odd-year lines, 1970–2002.



Pink salmon numbers do fluctuate from year to year and in analyzing declines it is necessary to account for normal variability in pink salmon returns. DFO analyzed the data using spawner escapement, total recruitment, (catch + escapement) and recruits per spawner as a measure of survival variability. To account for the naturally high variability of pink salmon the analyses used the 50-year (25 generations) record for pink salmon streams in the study area and thus took into account the observed fluctuations in salmon numbers due to natural and methodological sources. Information presented indicated that most stocks in the Kingcome, Bond and Knight inlets had declined to between a hundredth and thousandth of the parental year. Information was also presented on pink numbers in adjacent areas of the coast, with most adjacent areas showing increases. The DFO presentation concluded that returns and survival in the Broughton Archipelago were extremely low; and that the extent of reductions in numbers and survival in several streams were well outside the range that can readily be attributed to natural variability, based on the past data.

The PFRCC's Scientific Advisor independently analyzed the pink salmon escapement data and arrived at similar conclusions (Appendix 2). The level of decreases in 2002 (occurring in 24 percent of the 29 streams surveyed) was exceptional and observed only twice in 581 (0.3 percent) previous observations. The magnitude of the decreases and simultaneous occurrence in several proximate streams is cause for major concern.

It should be stressed that the above DFO and PFRCC analyses were restricted to an examination of the even-year pink salmon cycle. The reason for this is that unlike other salmon species pinks have a rigid two-year life cycle with no overlap in spawning populations. Accordingly a comparison of the variation observed with the 2002 returns compared to the 2000 brood year is most validly related to an even-year pink salmon analysis. However, the PFRCC, in addressing concerns raised externally, also analyzed the fluctuations observed in historical odd-year pink salmon. However, odd-year data analysis led to the same conclusion: that the reductions were well outside the range that can be attributed to natural variability (Appendix 2).

There has been some subsequent discussion that the level of declines in pink salmon were not out of the ordinary—that salmon populations may crash after exceptionally large escapements. Spawning stock sizes were at record levels for two streams in 2002 (Kakweiken River and Glendale Creek) but extreme reductions observed during 2002 occurred in other streams as well (seven streams had extreme reductions) leading Council to conclude that reductions were not associated with large escapements alone.

REASONS FOR THE DECLINE

General

At the PFRCC Consultation, DFO presented an overview of environmental reasons for decline (Appendix 1, Annex 2). None of the natural variables, such as streamflow, temperature or oxygen levels provided obvious explanations. DFO suggested that something in the nearshore marine environment of the Broughton Archipelago likely caused the decline. This was based on the localized nature of the decline in the Broughton compared to elsewhere and the knowledge that pink salmon use near-shore environments during their early marine life.

Sea Lice

At the Consultation information was presented on the European experience and research on sea lice, and its effect in areas such as Ireland, Scotland, and Norway. Areas exposed to salmon farms show higher average lice levels on wild fish, compared to fish further from farms. Sea lice were found to be a threat in areas of intense salmon farms. In Norway up to 50 percent mortality of brown trout occurred near the farms. Juvenile salmon in spring are at a higher risk (See Appendix 1, Annex 3).

Ms. Alexandra Morton presented her 2001 and 2002 studies in the Broughton Archipelago area. She used dip nets to collect pink salmon juveniles in the near-shore environment. She documented (Appendix 1, Annex 4) many instances of lice on juvenile salmon. In 2001 she observed over 700 juveniles and noted that the incidence of lice was greater in fish farming areas. She also noted that chum salmon juveniles were impacted similarly to pink salmon juveniles. In 2001 78 percent of the juvenile salmon examined were infected at or above the lethal level (based upon the European experience) of 1.6 lice/g host weight. Initial results of her 2002 study support higher levels of sea lice incidence nearer to salmon farms.

DFO also conducted a survey of pink salmon in the Broughton Islands during 2001, using different sampling methodology (report not presented at the Consultation). Few pink salmon were captured in the immediate area of the Broughton Archipelago. Of the pink and chum salmon captured 78 percent had 2 or fewer lice per fish, and the report concludes that the fish sampled were in healthy condition.

There has been discussion, heated at times, regarding the appropriateness of both Ms. Morton's sampling and of DFO's sampling. This debate over sampling techniques has tended to cloud the fact that there was an exceptional observation of sea lice prevalence in the areas of dense salmon farming. Noteworthy, pink salmon researchers in Alaska (who have carried out extensive pink salmon studies) note that they have never seen sea lice on a juvenile pink salmon.

It is clear to the Council that both Ms. Morton's and DFO's sampling programs attempted to respond to an unusual biological observation. More rigorous sampling programs and studies are needed in the future. However, regardless of sample methodology, numerous qualitative samples identified sea lice presence on a large percentage of pink salmon and substantial concern exists that the decline in pink salmon returns is related to those observations.

The PFRCC recommends that more study be conducted in BC waters, concerning sea lice and salmon farms so as to improve knowledge and decision-making.

The BC Salmon Farmers Association declined the opportunity to make a presentation regarding their operations and how they might have or not have been tied to the Broughton Archipelago pink salmon and sea lice observations. During the Consultation discussions, aquaculturists noted sea lice occurred on farmed salmon but that chemotherapeutants were utilized to keep the number of lice at a low level. In the past *Ivermectin*, a licensed prescription product, has been used to treat sea lice. It has a long withdrawal period (3 months) and so is not favoured when fish are nearing marketing. More recently *Emamectin benzoate* (SLICE™) has been utilized. This therapeutic is incorporated into the salmon feed and has a short withdrawal period (7 days quoted at the PFRCC Consultation).

Comment at the Consultation suggests that the level of lice present that triggers treatment in the net pens is very low. However as of yet this number of lice is unknown—at the Consultation meeting there was no answer given to a question on what levels of lice triggered the application of chemotherapeutants. It is also clear that the treatments are intended to protect the farmed fish rather than wild fish. Further, there is a very real potential of a sea lice infestation from salmon farms even with a low level of lice on the farmed fish, given that there are in the order of 25 salmon farms in the Broughton Archipelago (albeit with some farms fallow), and that there are an average of at least 500,000 fish per occupied tenure and that each female louse produces a substantial number of eggs.

Relationship between sea lice and pink salmon declines

Even if there were absolute scientific proof that pink salmon were getting infected with sea lice originating from salmon farms, it would not be entirely certain that the sea lice were the reason for the declines in pink salmon. Typically pink salmon suffer very high natural mortalities. However, the fact that populations of pink salmon in nearby waters to the Broughton Archipelago did not plummet and generally increased in abundance suggests that the cause of the decline originated in the waters of the Broughton. At this time no other factors that could have caused these exceptional Broughton declines have been identified.

Precautionary Measures

While scientific proof is not yet absolute there is extremely suggestive circumstantial evidence that sea lice are associated with salmon farming. The Council believes that sea lice were associated with the decline observed in the Broughton pink salmon. Guidance on how to deal with the level of uncertainty faced in this case comes from the concept of the “Precautionary Approach/Principle.” This precautionary approach is a distinctive approach to managing threats of serious or irreversible harm where there is scientific uncertainty. The precautionary approach recognizes that the absence of full scientific certainty shall not be used as a reason to postpone decisions where there is a risk of serious or irreversible harm. Even though scientific information may be inconclusive, decisions have to be made to meet society’s expectations that risks be addressed. Once decisions are made they should be evaluated in light of evolving science and society’s chosen level of protection. When managing the oceans and its resources, Canada’s Oceans Act prescribes that the precautionary approach be applied.

The PFRCC recognizes the great difficulty, perhaps impossibility, of arriving at absolute scientific certainty regarding the cause of the pink salmon collapse.

The PFRCC recommends that the time for action is now. While recognizing that some may argue that more study be done prior to implementing any measures to protect juvenile pink salmon passage, the PFRCC concludes that such a strategy may lead to irreparable harm to the Broughton Archipelago pink salmon stocks.

The PFRCC recommends that Canada and BC undertake urgent actions to maximize the chance of safe passage of fish through the Broughton Archipelago during April 2003.

CONSERVATION MEASURES

Given the concerns over the linkage between sea lice and survival of pink salmon the Council has identified short-term options designed to minimize risk to juvenile salmon on their seaward migration through the Broughton Archipelago and long-term scientific work to provide more solid scientific evidence.

Lower Risk Option

The PFRCC concludes that to minimize risk to the safe passage of fish via the threat of sea lice that there be fallowing of all salmon farms in the Broughton Archipelago. Given the life cycle of sea lice it is concluded that fallowing must be complete 6 weeks prior to pink salmon entering the marine environment. As the salmon may enter the marine environment as early as mid-April fallowing should be complete by the end of February 2003.

Within the mandate of the PFRCC, we preferentially recommend the lower risk option as it has the greatest chance of ensuring the safety of juvenile wild salmon on their seaward migration.

Higher Risk Option

In the absence of acceptance of our preferred recommendation, PFRCC concludes that the crucial elements of a higher risk option for control should include sea lice control and study, geared to protecting wild fish.

The PFRCC recommends that, consistent with the intent of Canada's Oceans Act, that all stakeholders including government agencies urgently and co-operatively develop and implement a sea lice control plan specific to the Broughton Archipelago in 2003.

The Council notes that all stakeholders have expressed concern over the level of pink salmon declines and have expressed the desire to work co-operatively together to solve the problem. In particular, the BC Salmon Farmers Association has written to the Council regarding the Broughton pink salmon crash. While the Association is concerned about the lack of conclusive evidence they are prepared to work in coordination with others to design a sea lice management plan.

The PFRCC recommends that implementation should commence prior to mid-January (otherwise the program is not likely to be effective). In addition, this option should include immediate monitoring of sea lice and juvenile pink salmon and research into the ecology and life history of sea lice.

The Council recommends that, should there be failure to reach consensus on a response plan, that government take affirmative action to ensure safe passage of juvenile fish in spring 2003. This said, the Council strongly endorses multi-party initiatives, as they result in strong outcomes when they are able to reach successful conclusion.

A Broughton Archipelago response plan would logically have both short-term and long-term measures to minimize risks and to improve the knowledge base over time and hence to improve decision-making.

Short-term Measures

In order to protect the juvenile pink salmon it is important that a short-term response plan be developed by mid-January 2003. This is so that measures can start immediately thereafter to minimize the presence of sea lice by the time of the April migration of the pink salmon.

The PFRCC recommends that to manage risk the response plan must include a mix of strategies to minimize, if not eliminate, the threat of sea lice to wild pink salmon.

Elements of such a plan might include 1) strategic fallowing of salmon netpens judged to be the highest risk to pink salmon migrants; 2) by accelerated marketing of mature fish; 3) the strategic, coordinated application by all Broughton farms of chemotherapeutants to kill (not simply shed) the sea lice; in this regard, and in order to be consistent with the precautionary approach and to reduce costs and stress on the farmed fish it should be assumed that lice are present, that farms in the Broughton be fully treated, and that documentation of sea lice levels take place when fish need to be handled—the purpose of these controls is to protect wild fish and hence the Council acknowledges they may be beyond what is required for the farmed salmon's health; 4) good fish health management; 5) close co-operation between farms.

Environmental Monitoring and Research

The PFRCC strongly recommends that a rigorous *environmental monitoring* program be developed by scientists and stakeholders. The plan should include juvenile pink salmon monitoring (results could be very relevant to the future siting of salmon farms), environmental monitoring and monitoring of sea lice. Such a plan should be relevant to both a short-term and long-term resolution of the issue.

The PFRCC recommends that a rigorous *scientific study* be undertaken to enhance understanding of the relation between sea lice and other factors as related to pink salmon abundance. The program should be developed by scientists and the stakeholders and jointly funded by governments and industry. There should be external oversight of the program via a committee composed of stakeholders combined with external scientific advisors. The plan should focus on the control of sea lice on salmon farms and the ecological processes involved in the production of sea lice.

Finally, the PFRCC recommends that the results of monitoring and research be carefully scrutinized to determine if salmon farms and wild fish can successfully co-exist in the Broughton Archipelago. If so, conservation measures should be adapted, as necessary, to maximize protection of wild fish.

Integrated Coastal Zone Management

In addition to employing general conservation measures and Integrated Management approaches at salmon farms in the Broughton Archipelago the PFRCC recommends that the Central Coast Land and Coastal Resource Management Plan make use of information gained on juvenile pink salmon distributions. Should the North Island Straits Coastal and Marine Plan of the province be adopted the PFRCC recognizes the benefits of allowing the potential modification to that plan so that knowledge gained can be used to add or modify coastal zone conservation areas in the Broughton Archipelago.

APPENDIX 1. CONSULTATION MEETING ON PINK SALMON ESCAPEMENTS IN THE BROUGHTON ARCHIPELAGO

Notes, presentations and related material from the PFRCC Broughton Archipelago Consultation meeting of October 28th.

> Consultation Meeting on Pink Salmon Escapements in the Broughton Archipelago
> October 28, 2002
> Coast Discovery Hotel
> Campbell River, BC

Minutes

Attendance

Gordon Ennis, Manager, PFRCC; Hon. John Fraser, Chair, PFRCC; Brian Riddell, Scientist, PFRCC; Murray Chatwin, PFRCC; Blair Holtby, Head Salmon Assessment Section, DFO; Clare Backman, Stolt Seafarms; Gary Robinson, Stolt Seafarms; Dale Blackburn, Stolt Seafarms; Jeanine Siemens, Stolt Seafarms; Ted Perry, DFO; Ron Kadowaki, DFO; Gordon McEachen, DFO–Central Coast; Pieter Van Will, DFO–Central Coast; Christiane Cote, DFO–Communications; Karen Barry, DFO; Greg Savard, DFO–Central Coast; Lloyd Webb, Fishing Vessel Owner's Assn; Les Rombough, Area D Salmon Gillnetters Assn; Odd Grydeland, Heritage Salmon; Ken Wilson, Sierra Club BC; Otto Langer, David Suzuki Foundation; Alexandra Morton, Raincoast Research; Bud Graham, MAFF; Vivian Krause, Nutreco; Linda Sams, Marine Harvest Canada; Tim Davies, Grieg Seafood BC; Alvin Sewid, Mamaleleqala/Kwe'Kwa'Sot'Enox; Harold Sewid, Thomas Sewid, Mamaleleqala/Qwe'Qwa'Sot'Enox; Craig Orr, SFU–Centre for Coastal Studies; Al Martin, MAFF; Jennifer Hann, Heritage Salmon; Mary Ellen Walling, BC Salmon Farmers Association; Jerry Alfred, Kwakiutl Territorial Fisheries Commission; Robert Mountain, Kwakiutl Territorial Fisheries Commission; Roy Cranmer, Musgamagw Tsawataineuk Tribal Council; Ward Griffiden, West Coast Fishculture

Call to Order

Hon. John Fraser chaired and called the meeting to order at 10:00 a.m. The PFRCC provides independent advice to the federal and provincial fisheries Minister related to the status of salmon and steelhead stocks and their habitat. In this regard, this meeting is a public consultation, the objective of which is to obtain information on the Broughton Archipelago pink declines and potential reasons for those declines.

Update on Salmon Stock Status

See attached #1 for more information.

Dr. Blair Holtby presented information regarding the 2002 and historical count of pink salmon in the Broughton and surrounding areas. Dr. Holtby noted some facts to guide the understanding of the information:

- owing to methodology employed the counts of spawning salmon should be considered indices.
- exploitation rates have been significantly reduced in recent years.
- the reduction in fishing means that the catch component of the numbers (relatively accurate estimates) has been reduced and that aerial and foot inspections, which are indices with greater uncertainty, now account for the significant majority of the total estimated numbers.

Pink salmon numbers do fluctuate naturally from year to year probably because small fry have no compensatory mechanisms to deal with environmental variability. Dr. Holtby analysed the data using escapement, recruitment (catch+escapement) and recruits per spawner as a measure of survival. The analyses used the 50-year (25 generations) record for pink producing systems in the study area and thus took fully into account the observed fluctuations in data due to natural and methodological sources. Information presented indicated that stocks in the Bond and Knight inlets had declines of 100–1000 fold. Declines in the Kingcome Inlet and adjacent portions of Johnstone Strait on Vancouver Island were also large but not as precipitous. Information was also presented on pink numbers in adjacent areas, none of which showed the declines in the Bond and Knight areas, most adjacent areas showing increases. Probability analysis indicated that returns and survival were about average in most areas but in Bond/Knight, Kingcome and adjacent portions of Johnstone Strait were extremely low. The reductions in numbers and survival were well outside the range that can readily be attributed to natural variability, based on the past data. The spatial area of the decrease suggests the reason for the declines is not a freshwater cause. Global events in the open ocean such as El Niño are evident in the data but have affected the entire study area and not just portions of it. Therefore, Dr. Holtby concluded that causal factors should be sought in near shore environments through which pink salmon migrate out of the inlets and through Johnstone Strait.

Dr. Riddell noted that the exceptional nature of the returns during 2002 is more notable when considered over several streams at once and not just by stream as presented by Dr. Holtby. The degree of reduction in several streams in one local area is very exceptional compared to the historical record used in this presentation.

Potential Causes for Fluctuation

See attached #2 for more information.

Pieter Van Will discussed environmental variables such as discharge, temperature and oxygen as potential causes for the decline. Although environmental variables can cause declines in some years none of the environmental variables examined stands out as impacting numbers of the 2000 brood year. Also, Mr. VanWill noted that in other years with high escapements there were declines in pinks but not as big as this year. He noted the positive or average pink returns in nearby areas

International Experience with Sea Lice

See attached #3 for more information.

Dr. Craig Orr presented the European experience on sea lice and its effect in areas such as New Brunswick, Ireland, and Norway. Sea lice showed a survival rate of 60% after one week in fresh water with a possible survival rate of up to three weeks. Areas exposed to farm fish show higher mean lice levels in the fish, while areas away from lice infestation show lower levels. In Norway up to 50 percent mortality of brown trout occurred near the farms. Sea lice are a threat in areas of intense salmon farms. Juvenile (small) salmon in spring are at a higher risk. There is a physiological impact to the fish during the free-swimming copepodid stage. The economical impact on Scotland showed a 48–72 million-dollar total cost attributed to sea lice (treatment of lice, lost growth, market downgrading etc.). Sea lice treatment in Scotland consists of; chemicals (11 feeds and bath treatments), cleaner fish, vaccines, semio chemicals. Slice (administered in feed) is a valuable treatment of sea lice, although, some salmon showed resistance to organophosphates and pyrethroids. Norway has routine counting, medical treatments, and risk management with the emphasis on smolt migration periods. Fallowing is known to decrease lice infestation.

Monitoring was discussed with some farms utilizing monthly monitoring and others monitoring depending upon the time period.

The SFU Lice Summit recommends:

- Establishment of a sea lice working group
- Obtaining baseline data—start comparative studies
- Examine behaviour, physiological response of infected fish
- Study efficiency impacts of current treatment
- Set and apply lice load
- Study lice survival in freshwater
- Public reporting

Sea Lice Work in Area 12

See attached #4 for more information.

Alexandra Morton presented her studies (2001 and 2002) on sea lice, noting the copepodid event in Area 12. Her study presented many photographs of infected fish (and a few uninfected fish) showing various lice infection and stages. In 2001, she observed over 700 salmon and noted that the incidence of lice was greater in fish farming areas. She has also noted that chums are impacted similarly to pinks. Lice (different species) were also observed on other species such as arrowtooth sole, pollock, and greenling. Survival rate of the fish studied would vary depending upon the size of the fish and amount of lice that was present on fish. The least infected area was the Embly Lagoon area—in this case Alexandra indicated the pink fry were swept out to sea quickly and pushed away from the vicinity of the farm. In 2001 78 percent of the juvenile salmon examined were infected at or above the lethal level of 1.6 lice/g host weight. In 2002, *L. salmonis* lice were approximately 10 times more abundant on juvenile salmon from “directly exposed” sites and 3 times more abundant at the post-smolt site compared to “less exposed” sites. Young stage pink and chum showed similar patterns. She was interested in knowing what the stocking rate was now compared to when the Salmon Aquaculture Review was conducted.

Recommendations received from Dr. Paddy Gargan, lice expert, Central Fisheries Research Board of Ireland, are to fallow farms at least six weeks before migration (until November) to protect second generation of fish based on evidence from Norway and Ireland that no level on farm salmon has been proven effective in stimulating recovery of wild adjacent salmonid populations. Harvest fish before spring migration of wild salmon. Take farm fish away from routes of wild fish migrations.

In response to a question regarding her sampling methodology Dr. Brian Riddell indicated he followed up with Alaska and they indicated that pink fry were in the uppermost part of the water column and that surface sampling for pink and chum is routine in Alaska and that they seldom sample below 3m during the early sea-life stages. Once pink salmon reach about 5.5cm, their behaviour changes to a more pelagic feeding behaviour as opposed to the shoreline and surface orientation during smaller sizes. Sampling for pink salmon during early sea-life is usually conducted with a small paired-surface trawl or seines. Larger trawls, such as used by DFO in their Broughton work, are not used in Alaskan inshore waters. Also, Alaskan biologists have told Dr. Riddell that they do not find lice on pink salmon juveniles in Alaska.

In response to a question regarding whether pink salmon might pick up sea lice in freshwater, Alexandra Morton indicated that a literature search had been unable to find a single credible reference that juveniles might pick up lice from “natural reservoirs” as they leave rivers.

Concerns and Recommendations

There has been a dramatic drop in pinks, we should know what has caused this, how can we find out problem before progeny of this year go to sea—John Fraser

Flood lights in farms attracting wild fish to those locations and contributing to lice transfer—R. Cranmer

Any short term response will not have anymore information than we have now upon to base a response. Focus on short-term action for pinks leaving streams; while we will not be fully confident of the cause during the short-term it would behove us to control those things that we can—T. Perry

Assure standards are brought to bear on environmental factors, in longer- term need to focus on applied studies and prevention.—T. Perry

Decisions regarding fallowing of farms need to be acted on now because restocking of farms in question is imminent. Farms should be fallowed 6 weeks before fry come out (Apr.19). Believes farms should be fallowed permanently.—A. Morton

Farms responsibility regarding the lice infestations—J. Alfred

The 2002 event was significant. Short and long term research concerning the potential issues on sea lice needed to ensure survival of pink salmon—G. Savard

DFO should look at migratory pathways rather than simple farm siting guidelines. The precautionary principle needs to be applied. A risk adverse approach is required — O. Langer

There is an acknowledged need for improved monitoring on the farms and local environments, and the need for controls for comparisons. There are opportunities for more research funded through the new trust funds provided by the Provincial government, could research sea lice mechanisms, biology, and lighting issues. Suggested that the BC Science Council focus on the issue early next year, possibly via a workshop to identify monitoring, reporting, and a phased plan of research.—A. Martin

Stolt monitors and treats sea lice when present. (The threshold number of lice prior to treatment and fish stocking densities used was not stated.)—O. Grydland

Hold workshop to help line up technical expertise and support—T. Perry

The need for decisions is now. Notes that Stolt and Heritage is about to put fish into farms now (and if fallowing occurs this could have a big cost implication)—A. Morton

All are concerned about the pink salmon issue. Open to discuss management plans. Believes it premature to blame the salmon farms.—O. Grydeland

Company concerned with the event and open to exploring factors. We know that there has been a significant event.—D. Blackburn

We have a problem and we need to work together to correct the stock of pink salmon—T. Sewid

Two options open, 1: to fallow farms and 2) to manage risk and monitor—R. Kadowaki

Review SFU recommendations, need for better science, communication with Ottawa, and communication on stocking. Work would be expensive. The environmental theme of Aquanet is under-funded.—C. Orr

Urgency needs to be emphasized to Minister, needs to be commitment and openness, business as usual would be irresponsible.—O. Langer

Improve poor communication between parties. Can't wait for more studies—there is a real problem here.—R. Cranmer

Council needs to provide advice in the face of what we know and what we know we do not know. The difficulty in needing to act quickly is we won't have all the information we need. Best action would be collaborative action—Hon. J. Fraser

PFRCC must advice on the basis of risk to the natural pink salmon populations in this region. Short-term response must address conservation of this resource and longer-term can address studies and preventative actions. Should seek co-operative actions with local industry in the immediate period.—B. Riddell

Adjournment

Hon. J. Fraser adjourned the meeting at 3:00 p.m., expressing a matter of urgency to work on resolving the issues at hand. Thanking participants for the civil accord and general good will expressed during the meeting.

At the end, Greg Savard spoke on behalf of DFO and indicated DFO wanted to find out the cause of the problem and do something about it.

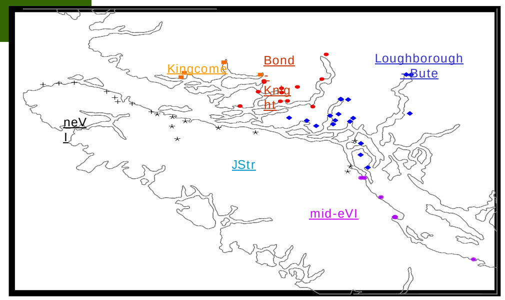
Presentations

Authors (Holtby, Van Will, Orr and Morton) have submitted either the PowerPoint presentations used in the consultation meeting, or printed materials that are very similar. These will be posted on the Council website (www.fish.bc.ca).

ANNEX #1. SLIDES

Annex #1 Slide 1. Study Area

Study Area



Upper Vancouver Island
CLUXEWE RIVER
KEOGH RIVER
NAHWITTI RIVER
QUATSE RIVER
SHUSHARTIE RIVER
SONGHEES CREEK
STRANBY RIVER
TSULQUATE RIVER

Johnstone Strait
ADAM RIVER
AMOR DE COSMOS CREEK
HYDE CREEK
KOKISH RIVER
MENZIES CREEK
MILLS CREEK
MOHUN CREEK
NIMPKISH RIVER
SALMON RIVER
TSITIKA RIVER

Mid Vancouver Island
CAMPBELL RIVER
ENGLISHMAN RIVER
OYSTER RIVER
PUNTLEDGE RIVER
QUINSAM RIVER
TSOLUM RIVER

Kingcome Inlet
CARRIDEN CREEK
EMBLEY CREEK
KINGCOME RIVER
WAKEMAN RIVER

Bond to Knight
AHNUHATI RIVER
AHTA RIVER
AHTA VALLEY CREEK
GILFORD CREEK
GLENDALE CREEK
HOEYA SOUND CREEK
KAKWEIKEN RIVER
KAMANO BAY CREEK
KLINAKLINI RIVER
KWALATE CREEK
LULL CREEK
VINER SOUND CREEK

Loughborough to Bute
APPLE RIVER
CAMELEON
HARBOUR CREEK
CUMSACK CREEK
FANNY BAY CREEK
FRAZER CREEK
FULMORE RIVER
GRANITE BAY CREEK
GRASSY CREEK
GRAY CREEK
HEYDON CREEK
HOMATHKO RIVER
HYACINTHE CREEK
KANISH CREEK
ORFORD RIVER
PHILLIPS RIVER
READ CREEK
STAFFORD RIVER
WORTLEY CREEK

Annex #1 Slide 2. Escapement and Catch

Escapement and Catch

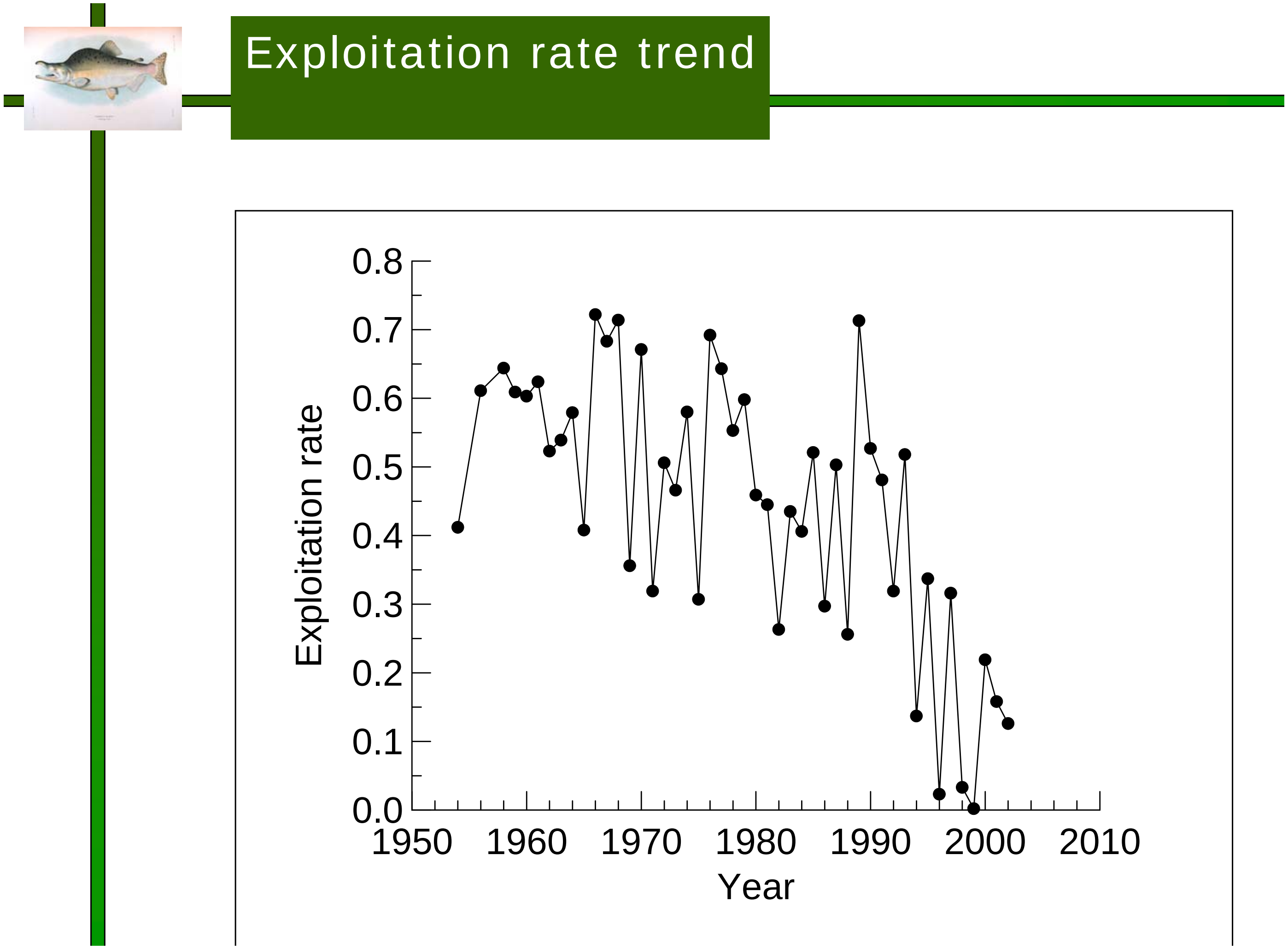
- Aerial + foot inspections, most of streams counted each year.
- Generally peak counts with several inspections.
- Due to apparent long survey life reasonable indices of abundance, although they are subject to the usual caveats that accompany most escapement data collected by DFO.
- Catch is problematic without stock ID of catch.
- Non-Fraser (even) years catch in approach and terminal fisheries partitioned by escapement.
- Fraser (odd) years catch was first partitioned using PSC estimates of Fraser component and then partitioned by escapement.
- Should be considered very approximate.

Annex #1 Slide 3. Recruits/Spawner

Recruits/Spawner

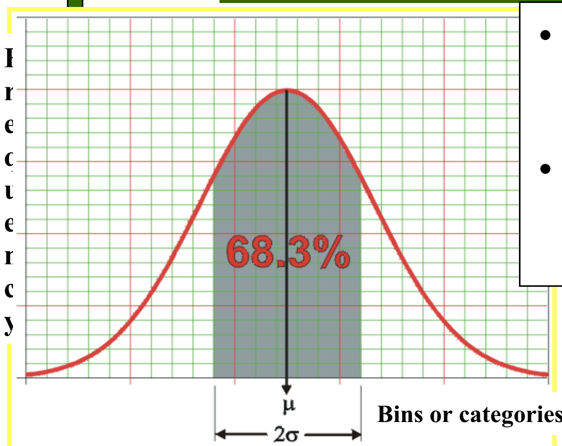
- The number of adult fish (catch + escapement) that return per spawner in the brood year.
- A useful measure of survival. On average must be greater than 1 for sustainable fisheries to be possible.
- Problems when there are dramatic changes in harvest rates and/or when one component of the recruitment is an index. In this case escapement is likely an index.
- There were significant decreases in harvest rates in the mid-1980’s and again through the 1990’s, transferring catch (hard estimate) to escapement (an index) => recruits may appear to fall if escapement index underestimates true escapement.
- Comparisons within the 1990’s should be considered cautiously.

Annex #1 Slide 4. Exploitation rate trend



Annex #1 Slide 5. How likely is an observation?

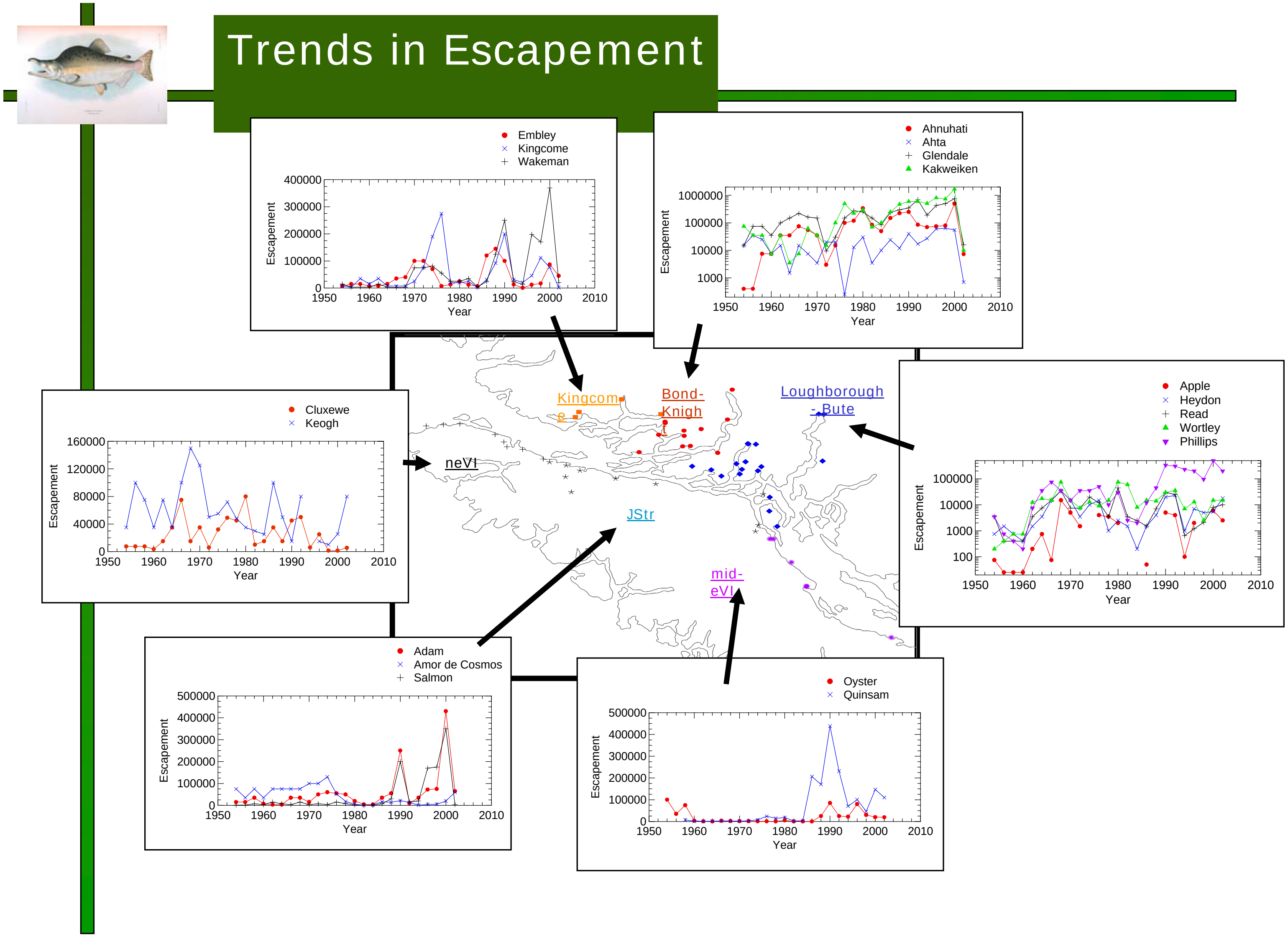
How likely is an observation?



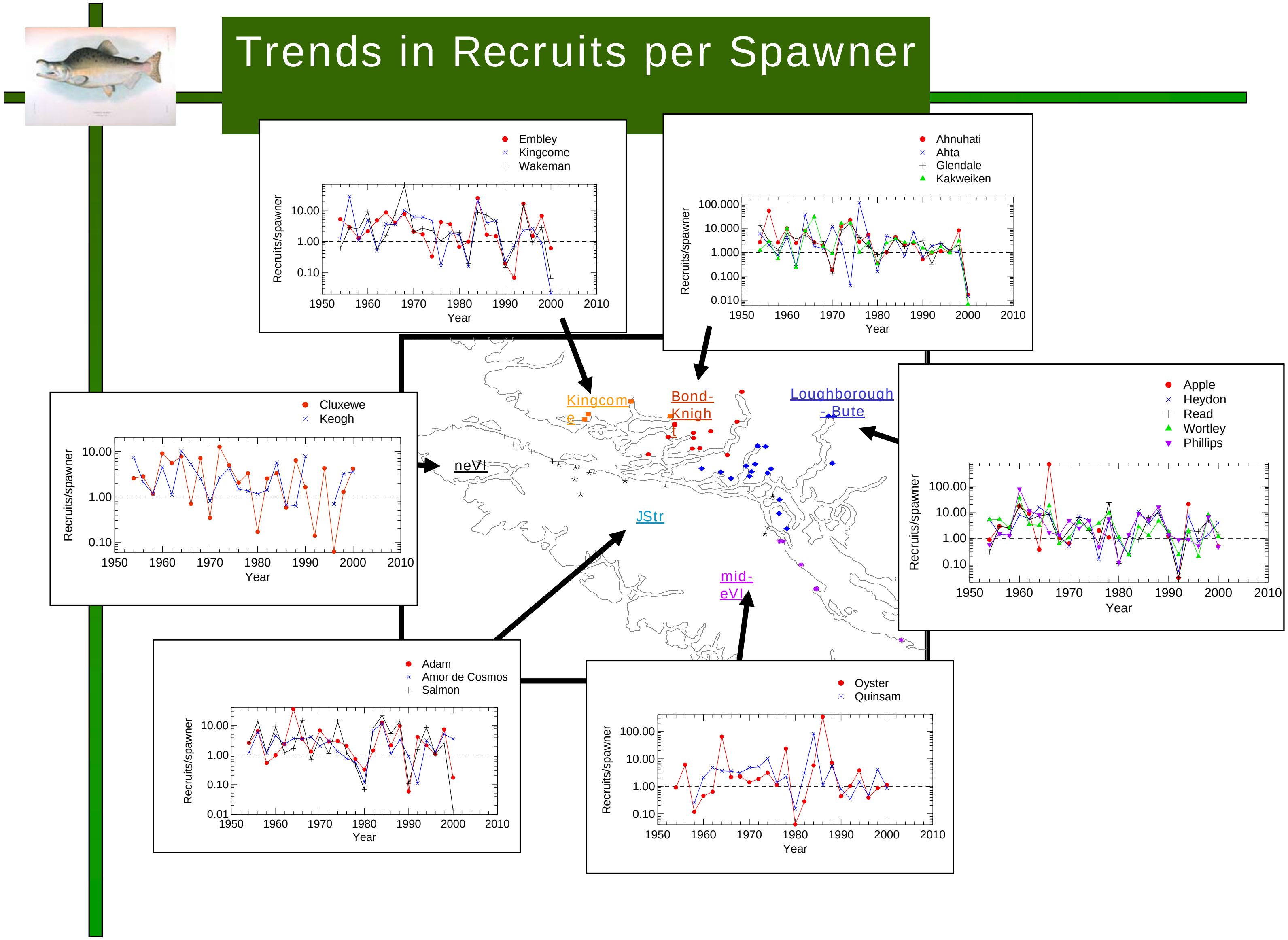
- Escapement, Recruitment, Recruits/Spawner typically have 'log-normal' distributions.
- Given a time series the mean and standard deviation of the distribution can be estimated.

- It is then possible to estimate what proportion of a large number of observations would be less than or greater than any particular observation.
- That proportion or probability is a measure of how unusual a particular observation might be.
- Available time series (1954-2002) are adequate to estimate distributions for most streams in the study area.

Annex #1 Slide 6. Trends in Escapement

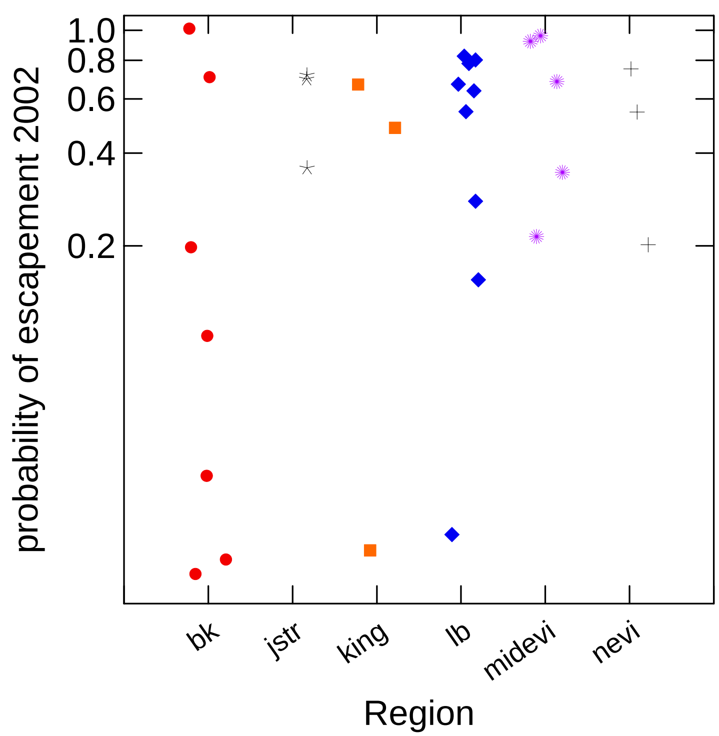


Annex #1 Slide 7. Trends in recruits per spawner



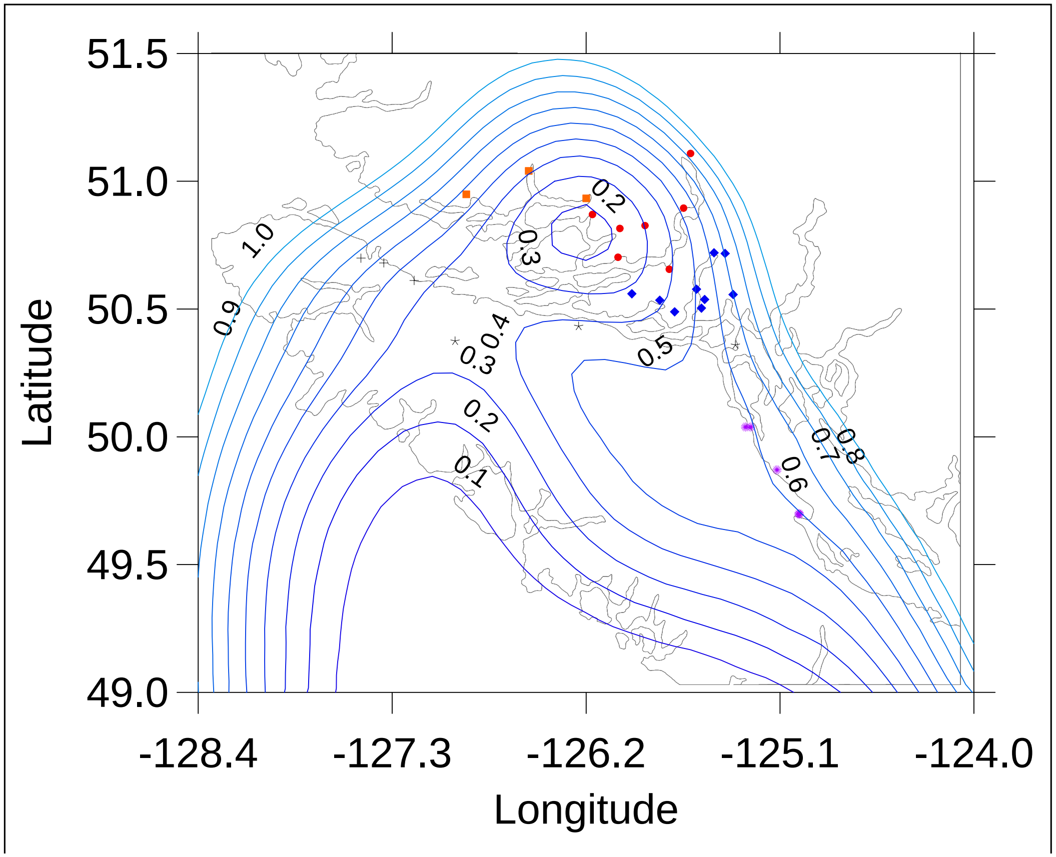
Annex #1 Slide 8. How likely was the observed escapement?

How likely was the observed escapement?



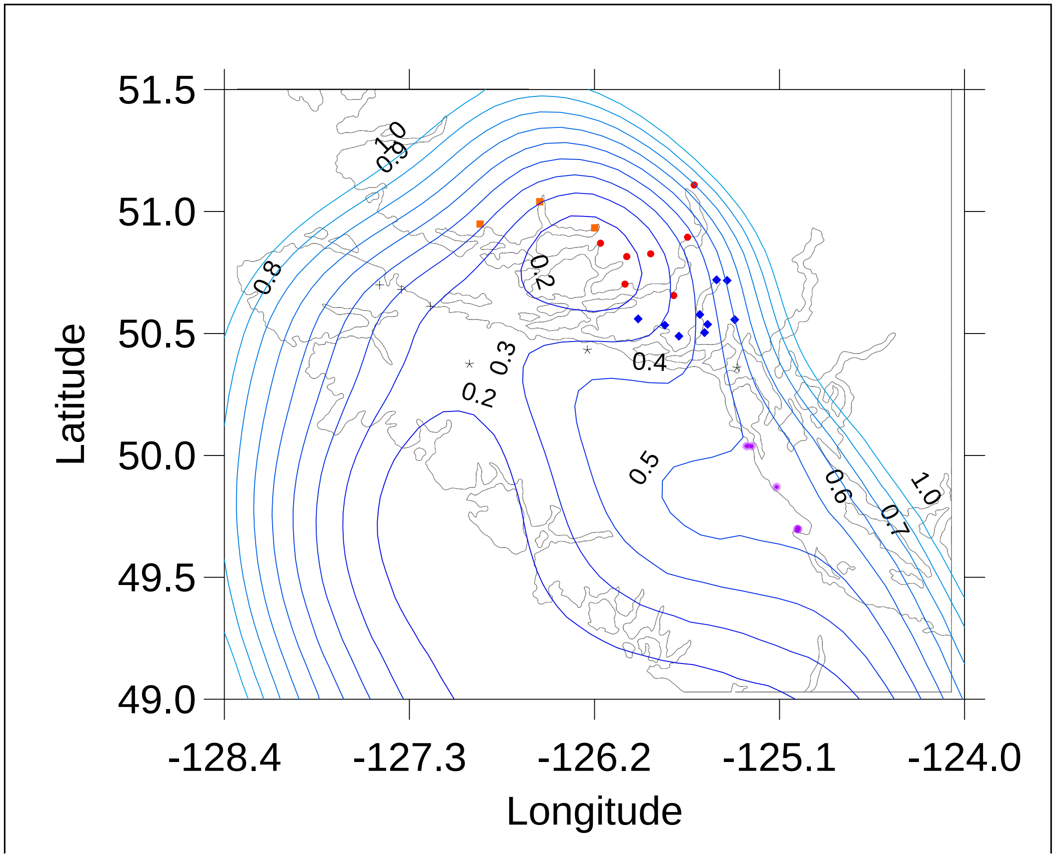
Annex #1 Slide 9. How likely was the observed escapement?

How likely was the observed escapement?

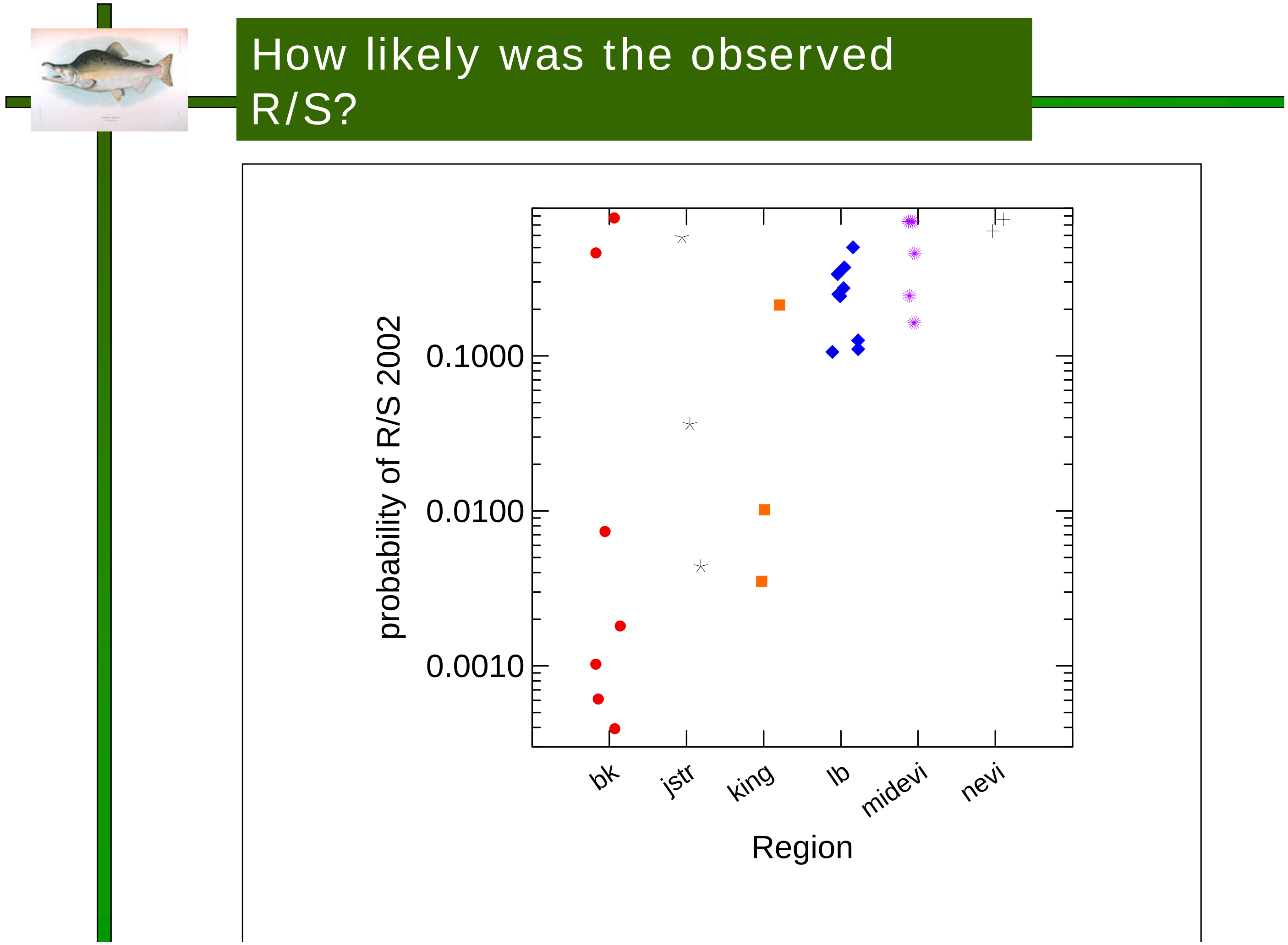


Annex #1 Slide 10. How likely was the observed recruitment?

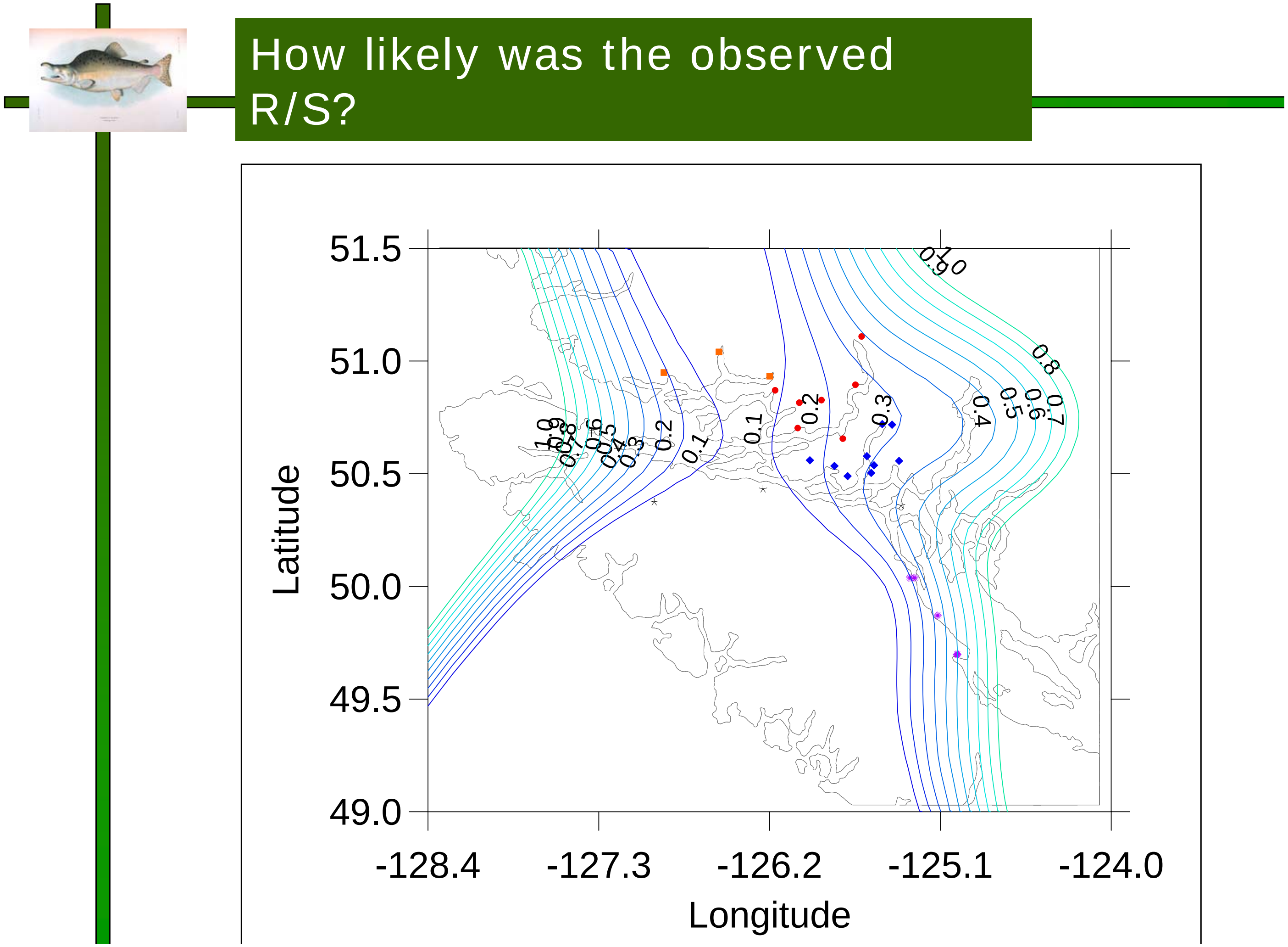
How likely was the observed recruitment?



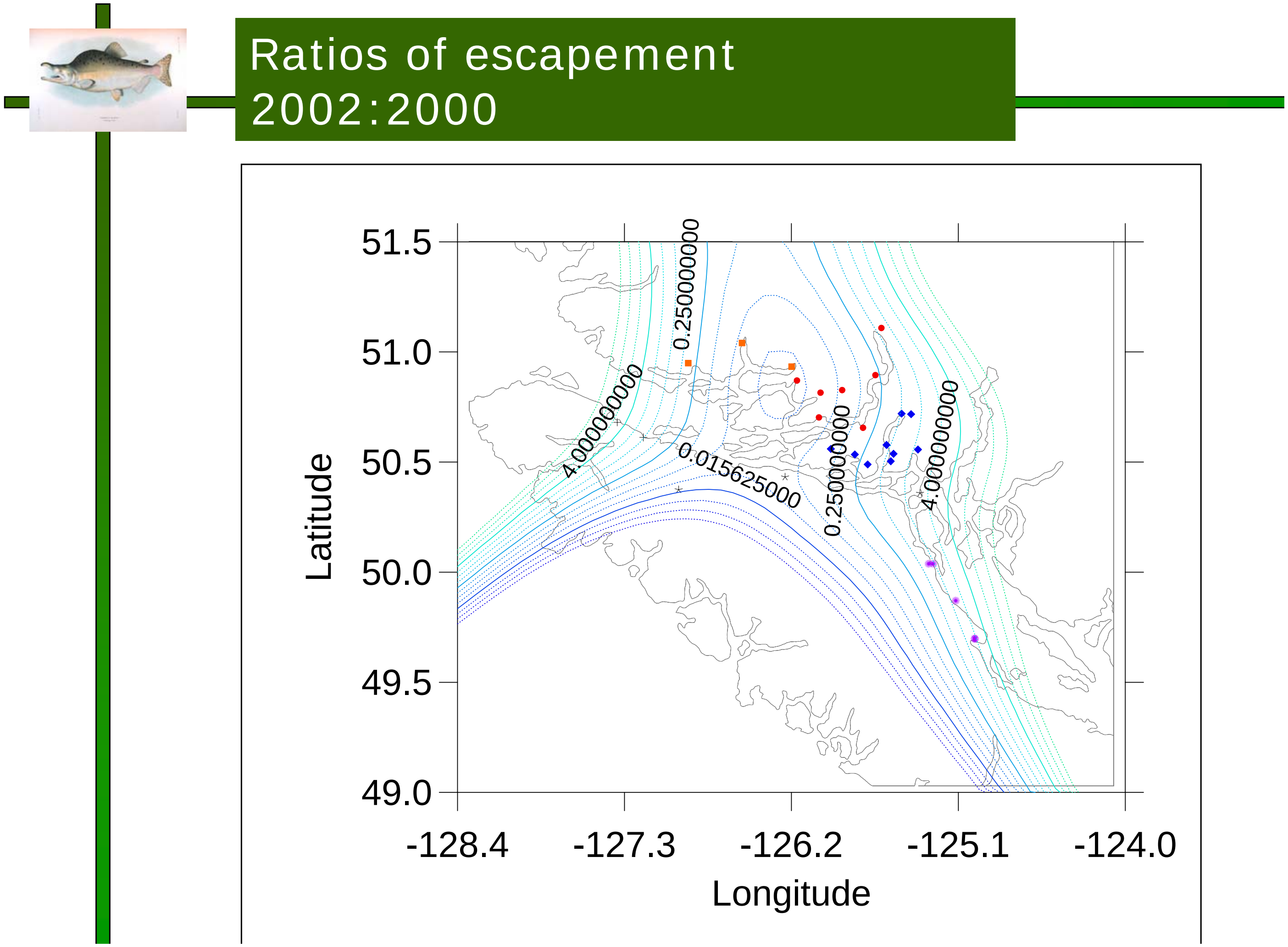
Annex #1 Slide 11. How likely was the observed R/S?



Annex #1 Slide 12. How likely was the observed R/S?

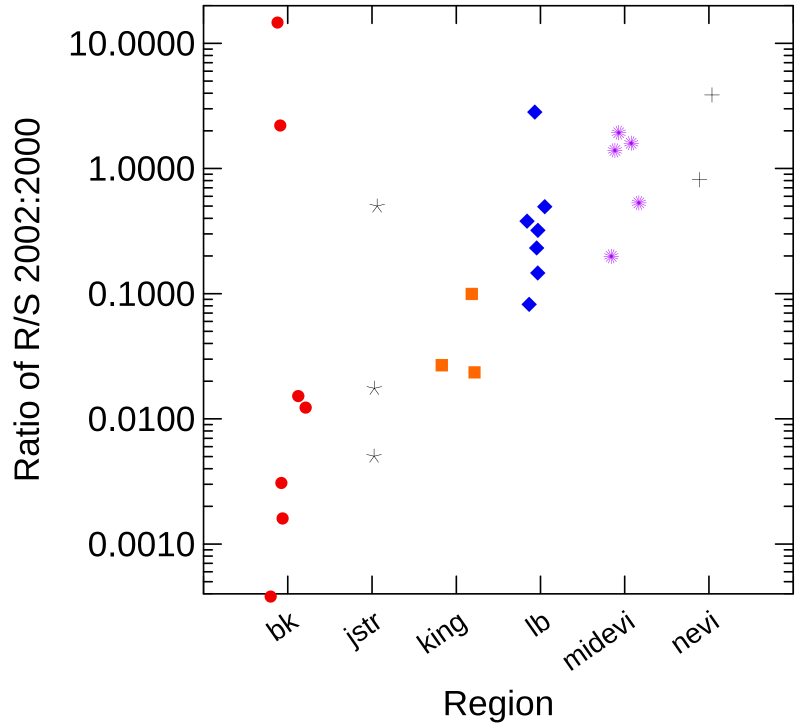


Annex #1 Slide 13. Ratios of escapement 2002:2000



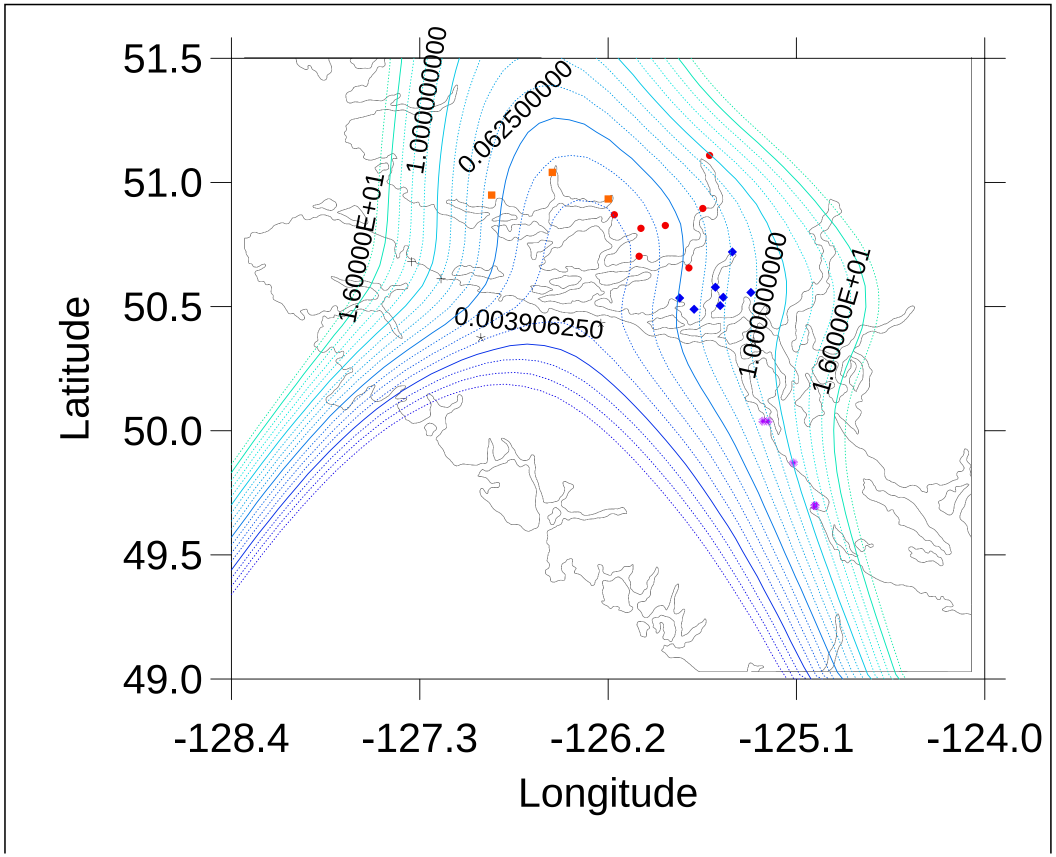
Annex #1 Slide 14. Ratios of R/S 2002:2000

Ratios of R/S 2002:2000



Annex #1 Slide 15. Ratios of R/S 2002:2000

Ratios of R/S 2002:2000



Annex #1 Slide 16. Conclusions

Conclusions

- Escapement, recruitment and especially R/S were depressed and in some cases severely in most of the streams of Kingcome, Bond and Knight Inlets as well as the adjacent portions of Vancouver Island bordering the Johnstone Strait.
- Streams to the north and south were not similarly affected.
- Comparisons take into account variability of pink populations.
- Causal factor(s) may be FW although the scale of the phenomenon is too large for most hydrologic and climatic risk factors.
- More likely causal factor(s) should be sought in the near-shore environment during the migration of pink salmon fry out of the mainland inlets and perhaps through Johnstone Strait.

ANNEX #2. SLIDES

Annex #2 Slide 1. Study area pink

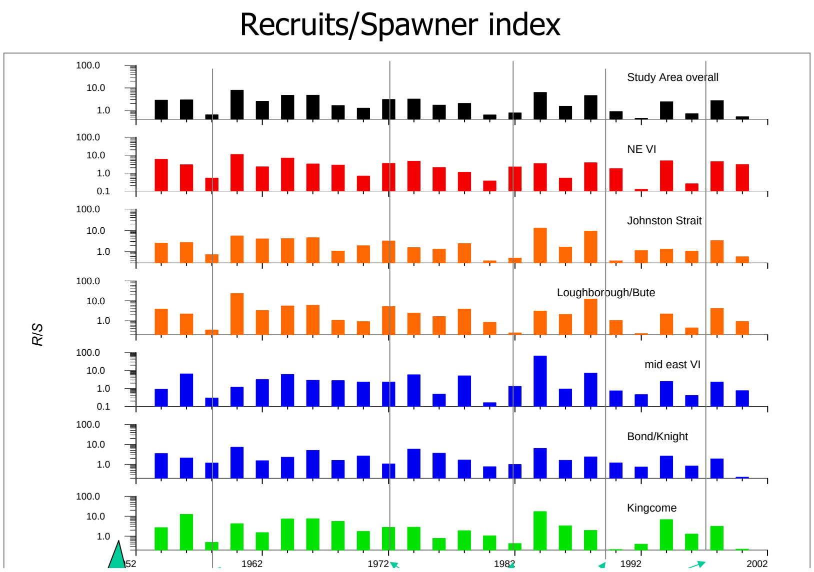
Study Area Pink:
A Historic Review

Annex #2 Slide 2. Potential causes for variability in study area pink production

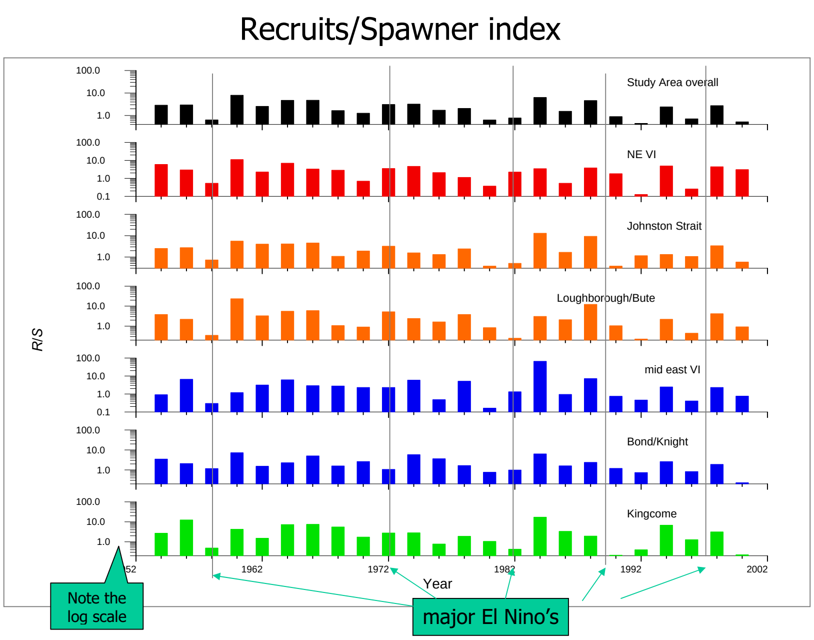
Potential Causes for Variability in
Study Area Pink Production

- Broad based and/or Site Specific
  - Environmental
  - Biological

Annex #2 Slide 3. Recruits/Spawner index 1



Annex #2 Slide 4. Recruits/Spawner index 2



Annex #2 Slide 5. Even year study area pink production

Even Year Study Area Pink Production

Year	JS Catch	Mainland Catch	Updated Escapement	Total Stock	Exploitation	Brood Escapement	R/S
1952	2,706,500		1,036,900	3,743,400	72.3%		
1954	399,200		568,600	967,800	41.2%	1,036,900	0.93
1956	920,200		585,600	1,505,800	61.1%	568,600	2.65
1958	1,365,800		754,600	2,120,400	64.4%	585,600	3.62
1960	344,100		227,000	571,100	60.3%	754,600	0.76
1962	750,700		684,400	1,435,100	52.3%	227,000	6.32
1964	853,900		619,800	1,473,700	57.9%	684,400	2.15
1966	3,438,500		1,322,600	4,761,100	72.2%	619,800	7.68
1968	3,695,700		1,476,900	5,172,600	71.4%	1,322,600	3.91
1970	2,341,100		1,149,700	3,490,800	67.1%	1,476,900	2.36
1972	729,600		713,200	1,442,800	50.6%	1,149,700	1.25
1974	1,548,600		1,122,400	2,671,000	58.0%	713,200	3.75
1976	3,777,600		1,677,700	5,455,300	69.2%	1,122,400	4.86
1978	1,347,400		1,089,500	2,436,900	55.3%	1,677,700	1.45
1980	1,192,800		1,405,700	2,598,500	45.9%	1,089,500	2.39
1982	194,500		545,800	740,300	26.3%	1,405,700	0.53
1984	232,000		338,800	570,800	40.6%	545,800	1.05
1986	574,500		1,358,700	1,933,200	29.7%	338,800	5.71
1988	354,734	291,266	1,874,000	2,520,000	25.6%	1,358,700	1.85
1990	123,967	3,742,736	3,465,200	7,331,903	52.7%	1,874,000	3.91
1992	901,294	211,700	2,375,800	3,488,794	31.9%	3,465,200	1.01
1994	199,798		1,263,700	1,463,498	13.7%	2,375,800	0.62
1996	59,062		2,476,000	2,535,062	2.3%	1,263,700	2.01
1998	76,879		2,243,400	2,320,279	3.3%	2,476,000	0.94
2000	368,365	1,083,674	5,165,600	6,617,639	21.9%	2,243,400	2.95
2002	113,537			113,537			
AVERAGE	1,100,398	1,332,344	1,421,664	2,672,358	45.9%	1,265,667	2.69

Preliminary by-catch numbers from Fraser Sockeye Directed Fisheries

Annex #2 Slide 6. Potential causes for variability in study area pink production

Potential Causes for Variability in Study Area Pink Production

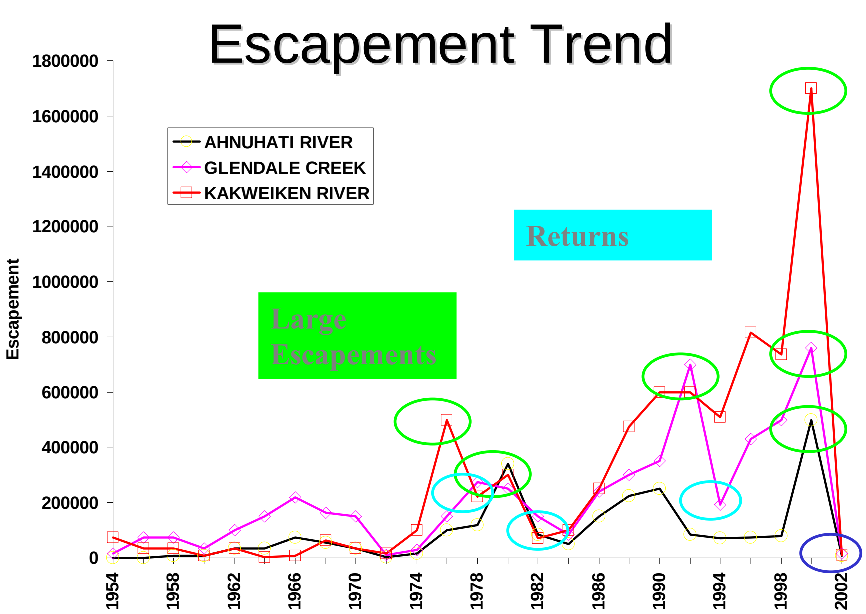
- Biological Variables
  - Fresh Water Survival
    - Spawning stock densities (Carrying Capacity)
    - Stress, disease, parasitism
  - Marine Survival:
    - Size of out-migrant fry
    - Marine Productivity
    - Migration Pathways

Annex #2 Slide 7. Fraser River pink salmon production for odd brood years from 1961-present

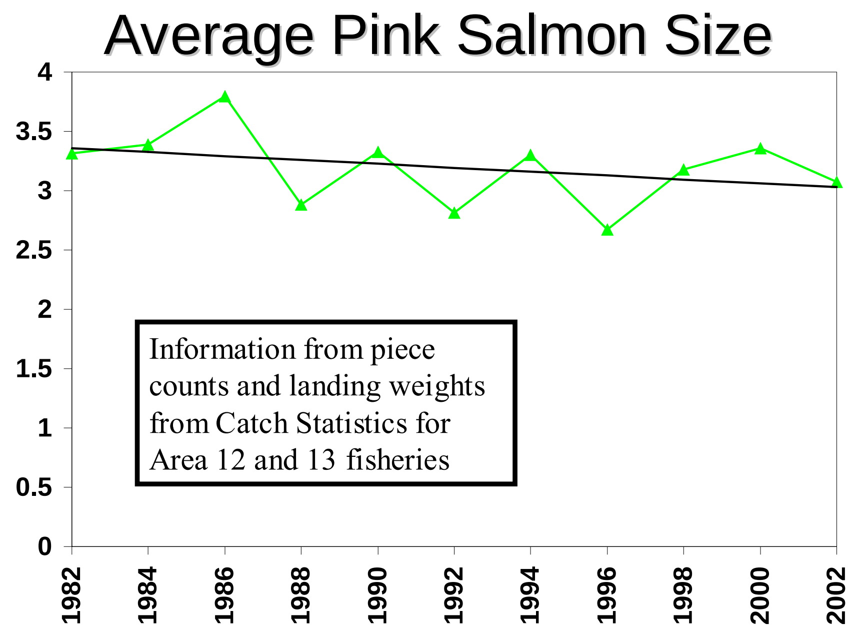
Fraser River pink salmon production for odd brood years from 1961-present.

Brood Year	Spawners Total (millions)	Spawners Female (millions)	Potential Egg Deposition (millions)	Fry Production (millions)	Adult Returns (Catch + Escapement) (millions)	% Survival Freshwater	% Survival Marine	Average To Date
1961	1.094	0.654	1,569	143.6	5.477	9.2%	3.8%	3.8%
1963	1.953	1.216	2,435	284.2	2.320	11.7%	0.8%	2.3%
1965	1.191	0.692	1,488	274.0	12.968	18.4%	4.7%	3.1%
1967	1.831	0.973	2,132	237.6	3.928	11.1%	1.7%	2.8%
1969	1.529	0.957	2,018	195.6	9.767	9.7%	5.0%	3.2%
1971	1.804	1.096	1,923	245.4	6.789	12.8%	2.8%	3.1%
1973	1.754	1.009	1,865	292.4	4.894	15.7%	1.7%	2.9%
1975	1.367	0.781	1,493	279.2	8.209	18.7%	2.9%	2.9%
1977	2.388	1.362	2,960	473.3	14.404	16.0%	3.0%	2.9%
1979	3.561	2.076	3,787	341.5	18.685	9.0%	5.5%	3.2%
1981	4.488	2.560	4,814	590.2	15.346	12.3%	2.6%	3.1%
1983	4.632	2.931	4,702	554.8	19.104	11.8%	3.4%	3.2%
1985	6.461	3.561	5,900	256.1	7.172	4.3%	2.8%	3.1%
1987	3.224	1.856	3,471	406.9	16.484	11.7%	4.1%	3.2%
1989	7.189	4.383	7,198	360.0	22.173	5.0%	6.2%	3.4%
1991	12.943	8.002	12,330	697.0	16.983	5.7%	2.4%	3.3%
1993	10.768	6.454	9,192	439.0	12.904	4.8%	2.9%	3.3%
1995	7.175	4.248	10,233	272.3	8.176	2.7%	3.0%	3.3%
1997	2.842	1.740	2,863	252.8	3.586	8.8%	1.4%	3.2%
1999	3.422	1.885	2,702	222.8	21.106	8.2%	9.5%	3.5%
2001	19.843	9.543	16,274	680.9		4.2%	0.0%	3.3%
Average	4.831	2.761	4,826	357.1	11.524	10.1%	3.3%	

Annex #2 Slide 8. Escapement trends



Annex #2 Slide 9. Average pink salmon size

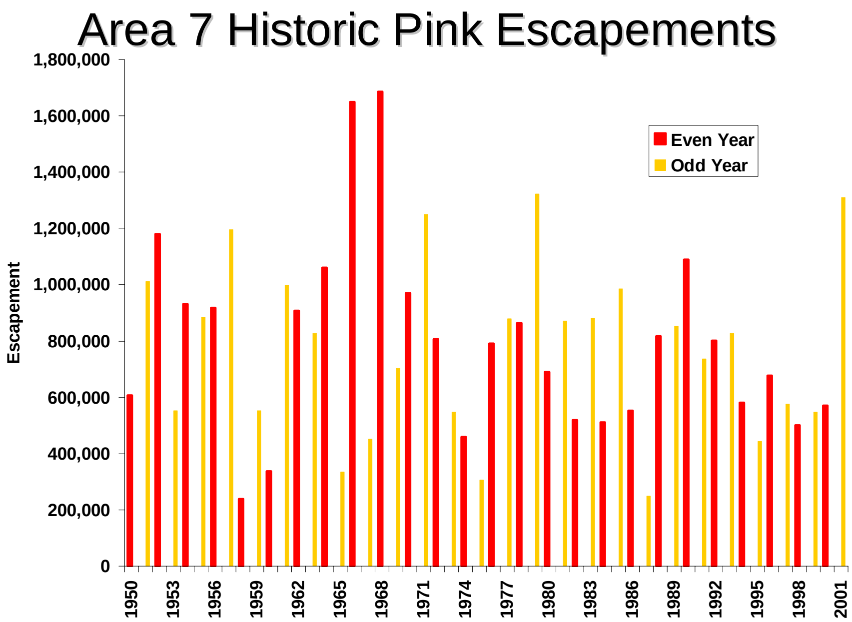


Annex #2 Slide 10. Messages from very preliminary look at 2002 pink salmon returns to study area

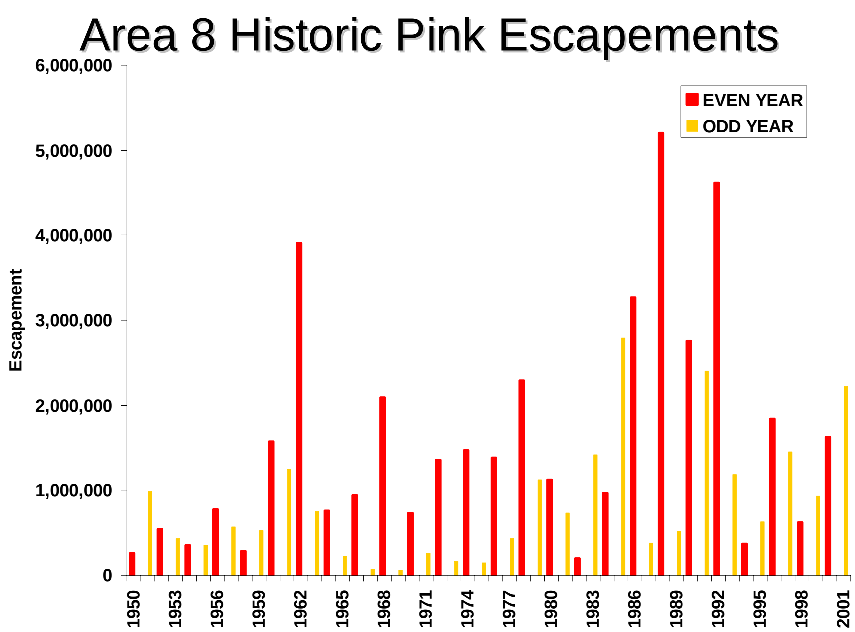
Messages from a very preliminary look at 2002 pink returns to the Study Area

- Escapements to streams in Kingcome, Bond and Knight Inlets were generally very low compared to recent levels and in many instances very low compared to historical levels as well.
- Recruits per spawner, a measure of life-cycle survival were also very low in these same areas.
- The low returns and poor survivals were seen in almost all systems within those areas.
- Escapements and survival appear to have been “normal” in systems to the south and north of those inlets.
- Poor survivals have generally but not always indicated large scale events most notably El Nino’s that have affected all streams within the study area (most of the Pacific NW in fact.) There is no evidence of such an event having occurred in the 2000 brood year (producing this year’s return).
- The localization of the phenomenon to these inlets and its appearance within most streams there strongly suggests that the search for the causal factor should begin in near-shore rearing areas shared by the smolts originating in the affected area during the spring and early summer of 2001.

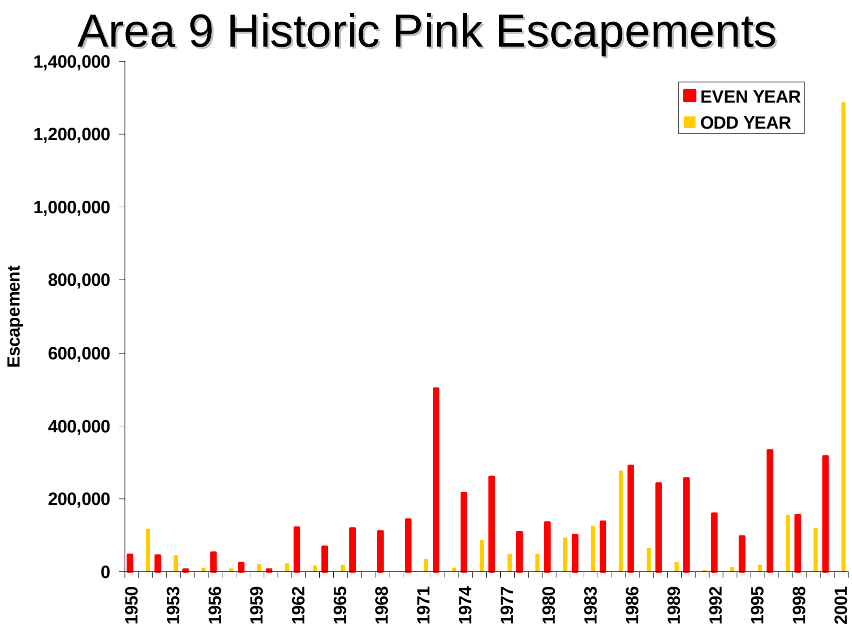
Annex #2 Slide 11. Area 7 historic pink escapements



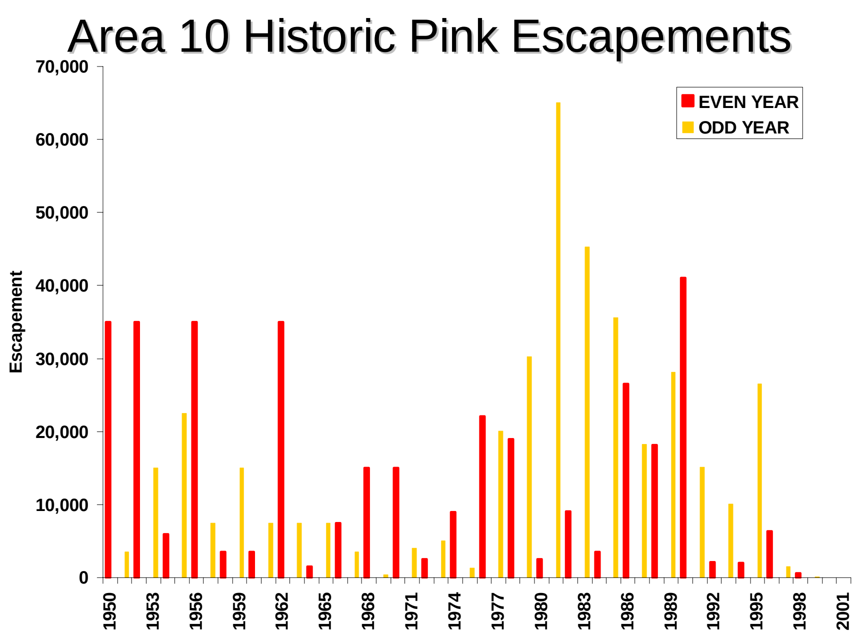
Annex #2 Slide 12. Area 8 historic pink escapements



Annex #2 Slide 13. Area 9 historic pink escapements



Annex #2 Slide 14. Area 10 historic pink escapements



ANNEX #3. REPORT ON THE SUMMIT OF SCIENTISTS ON SEA LICE WORKSHOP

Held at Simon Fraser University on July 22, 2002.

Facilitator*:* Craig Orr, Associate Director, Centre for Coastal Studies, Simon Fraser UniversityRapporteur: Michael Berry, ALBY Systems Ltd., Alert Bay, BC

Editors: Patricia Gallaugher, Director, Continuing Studies in Science, Simon Fraser University, Craig Orr, SFU Centre for Coastal Studies, Michael Berry, ALBY Systems Ltd, and Peter Broomhall, Chair, Watershed Watch.

Sponsors: Centre for Coastal Studies, Simon Fraser University; Vancouver Foundation; Watershed Watch.

Table of Contents

For full presentations please see website http://www.sfu.ca/cstudies/science/salmon.htm

Participants included scientists from academia, government, First Nations, aquaculture industry, and non-government organizations. Names of workshop participants are appended.

Background

In April 2000, Continuing Studies in Science at Simon Fraser University hosted a Speaking for the Salmon workshop and think tank, *Aquaculture and the Protection of Wild Salmon*. Scientists from Canada, USA and Europe described research on issues related to salmon aquaculture and together with representatives of the aquaculture industry, federal and provincial governments, First Nations, NGOs and other academics, made many observations and recommendations related to the sustainability of salmon aquaculture and the conservation of wild fish (see:www.sfu.ca/cstudies/science/salmon/aquaculture/aquaculture.htm). These recommendations are referenced in several recent publications, including the 2000 Auditor General's Report (http://www.oag-bvg.gc.ca/domino/reports.nsf/html/0030ce.html) and the 2001 report of the Royal Society of Canada Expert Panel on the Future of Food Biotechnology (http://www.rsc.ca/foodbiotechnology/indexEN.html).

One presentation at this workshop dealt with the occurrence and impacts of sea lice on Irish sea trout. Conversely, very little is known about the incidence of sea lice on salmon in British Columbia. In the spring/summer of 2001, Alexandra Morton, a biologist and resident of BC's Central Coast, documented and reported on an outbreak of sea lice on wild juvenile pink salmon (and other species) in the Broughton Archipelago, and sea lice entered the realm of public debate.

In March 2002, Continuing Studies in Science and the Centre for Coastal Studies hosted a meeting of scientists from academia, government and NGO groups as a follow up to the 2001 observations from the Central Coast. The purpose of the meeting was: to clarify impacts of salmon aquaculture including consequences of sea lice infestation on wild stocks of Pacific salmon; determine research needed to address the problems and risks to farmed and wild stocks; to identify sources of funding for the required research; and to discuss possible partnerships among government, academia, industry and NGOs to conduct this research.

The scientists subsequently identified several research priorities (Table 1).

Annex #3 Table 1. Sea lice and Salmon in British Columbia: Suggestions for Research Priorities

- Review information/literature on sea lice infestation, its relationship to salmon aquaculture, and the implications for BC
- Interview long-term participants in the fisheries, or others that may have relevant knowledge, to assemble anecdotal information on the history of sea lice impacts on wild salmon
- Monitor rates of louse infestation for baseline information in areas without salmon farms
- Monitor the movement and infestation rate of salmon runs from rivers near salmon farms to assess the correlation between encounter with aquaculture and infestation
- Research the life history of sea lice to understand modes of infection, range of hosts, and strategies for control
- Investigate the genetics of salmon and sea lice to evaluate strain effects and co-evolutionary trends
- Compare the behavioural and physiological responses of different species of Pacific salmon to sea lice
- Conduct experiments to assess the transfer of infection in a dose-response model and to test specific hypotheses about mode of infection
- Measure impacts of lice on non-salmonids.

The group agreed that the overall objectives are to determine the rates and conditions of parasite infestation, and whether these are correlated to salmon aquaculture; whether infections pose a significant risk to survival or commercial productivity of native species; and how effects of parasitism might be mitigated. Scientists agreed that research and management of sea lice would benefit from an open and transparent process of information gathering and sharing and that partnerships among government, academia, NGOs and industry would be vital in addressing research priorities.

This Summit of Scientists on Sea Lice (July 22, 2002) was largely organized to coincide with the visits of Dr. Bengt Finstad, Norwegian Institute for Nature Research, and Dr. Larry Hammell, University of Prince Edward Island, coincidentally in Vancouver for other meetings. At short notice, we expanded what was originally intended as a seminar to a full-day workshop on the ecology, impacts and natural history of the salmon louse (*Lepeoptheirus salmonis).* A discussion at the end of the workshop identified research priorities and ways to address the louse issue.

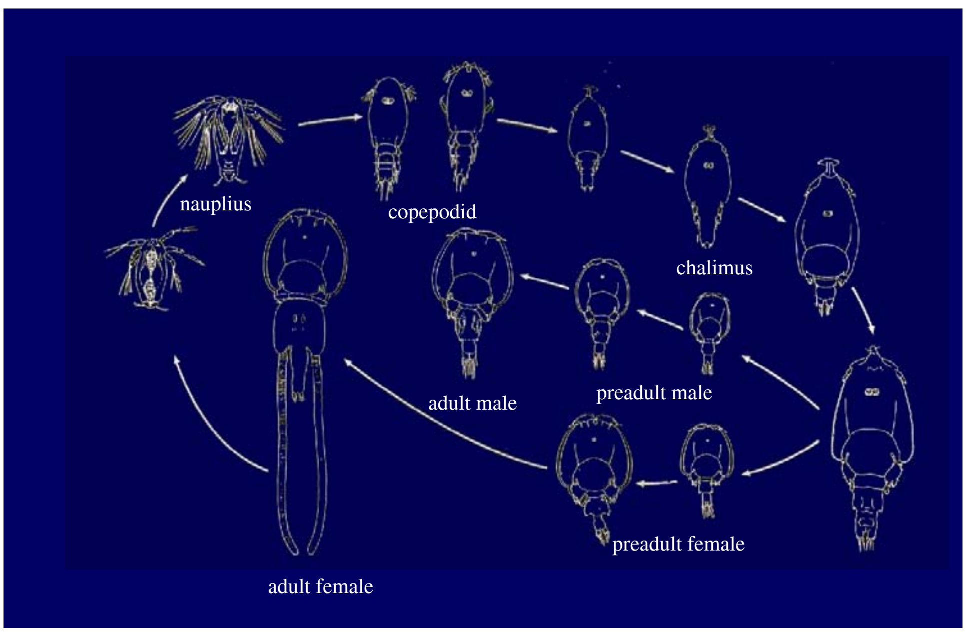
Presentations

The Physiological and Ecological Effects of Salmon Lice on Anadromous Salmonids

Bengt Finstad, Norwegian Institute for Nature Research (Appendix 2)

Dr. Finstad's presentation began with a review of the life cycle of the sea louse, *Lepeoptheirus salmonis*. Gravid females can produce up to 10 pairs of egg strings or 10M eggs. The typical development time is 38 days (@ 10oC) with females developing slower than males. Egg to adult survival is typically around 40%. Infection occurs at the copepodid stage with firm attachment to infested fish occurring at the chalimus stage (Figure 1).

Annex #3 Figure 1. Lifecycle of salmon lice



Dr. Finstad described the results of a 10-year research program that focused on sea lice infestations of farmed and wild Atlantic salmon, sea trout, and Arctic char in Norway and Scotland.

Table 2 describes the overall objectives of this research program.

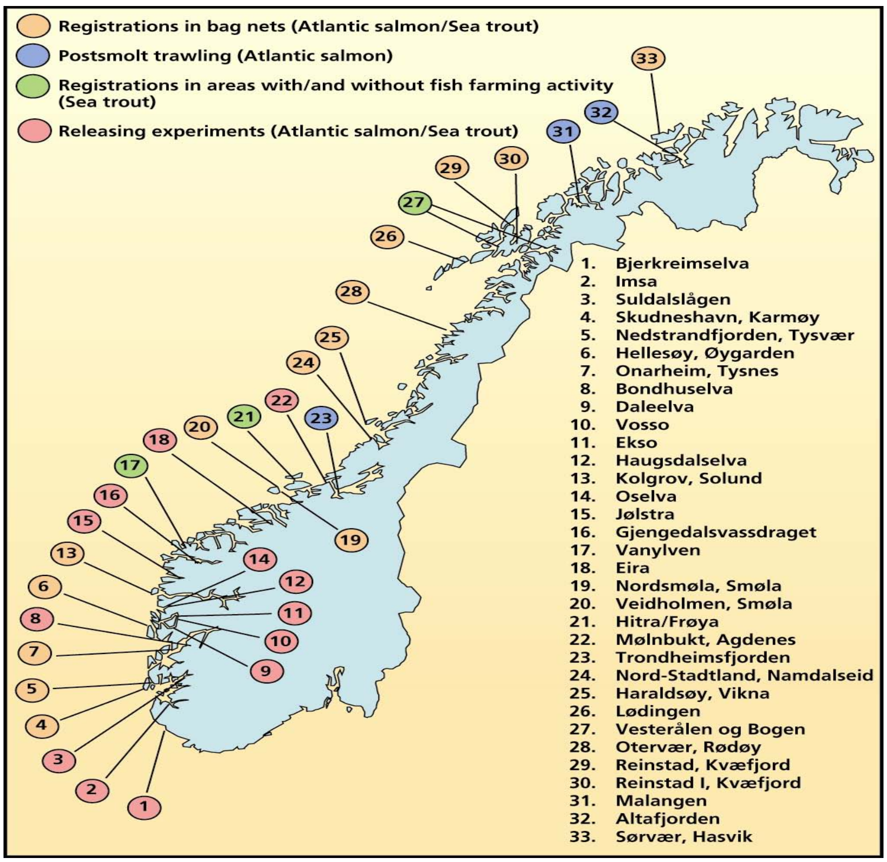
Annex #3 Table 2. AIMS (1993–1998)

- To test the survival time of salmon lice through a delousing process on fish in fresh water
- To describe the development, distribution on the host and pathogenicity of samon lice on sea trout
- To test the physiological effect of salmon lice on sea trout and Atlantic salmon post smolts
- To describe the salmon lice infection on post smolt wild Atlantic salmon, sea trout and Arctic char in areas with and without salmon farming activity, and to consider possible effects of the infection.

Objective: To test the survival time of salmon lice through a delousing process on fish in fresh water.

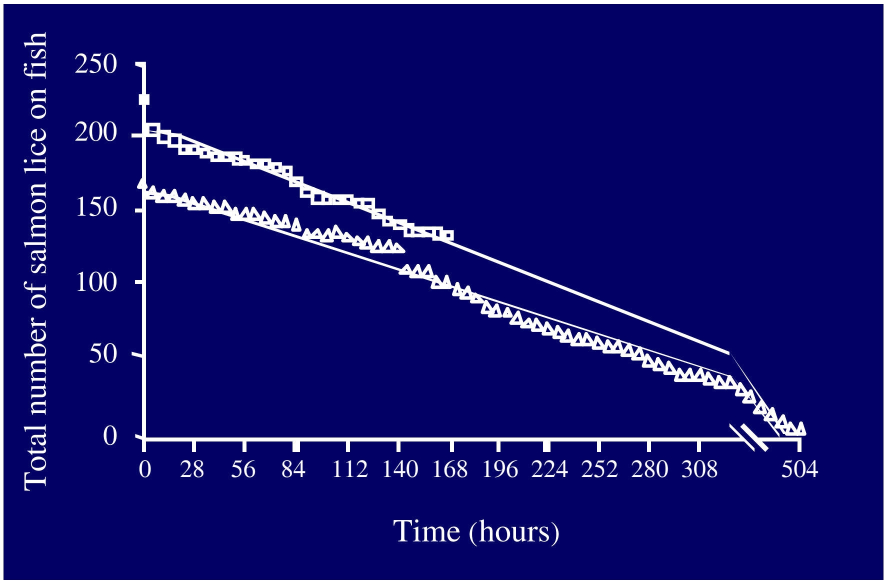
Figure 2 shows the locations of sea lice registrations for Atlantic salmon and sea trout in Norway.

Annex #3 Figure 2. Salmon lice registrations in Norway



In studies with Arctic char, Dr. Finstad demonstrated clearly that 60% of sea lice survive in freshwater for one week, and some survive for up to three weeks (Figure 3), although egg to adult development stops at salinities less than 16%. Thus, sea lice are potential threats, even in freshwater.

Annex #3 Figure 3. Survival of salmon lice on arctic char in freshwater



Objective: To describe the development, distribution on the host and pathogenicity of salmon lice on sea trout.

Table 3 describes some conclusions of these studies which demonstrate that the development rates, distribution, and pathogenicity of sea lice on sea trout parallel those observed on Atlantic salmon.

Annex #3 Table 3. Conclusions

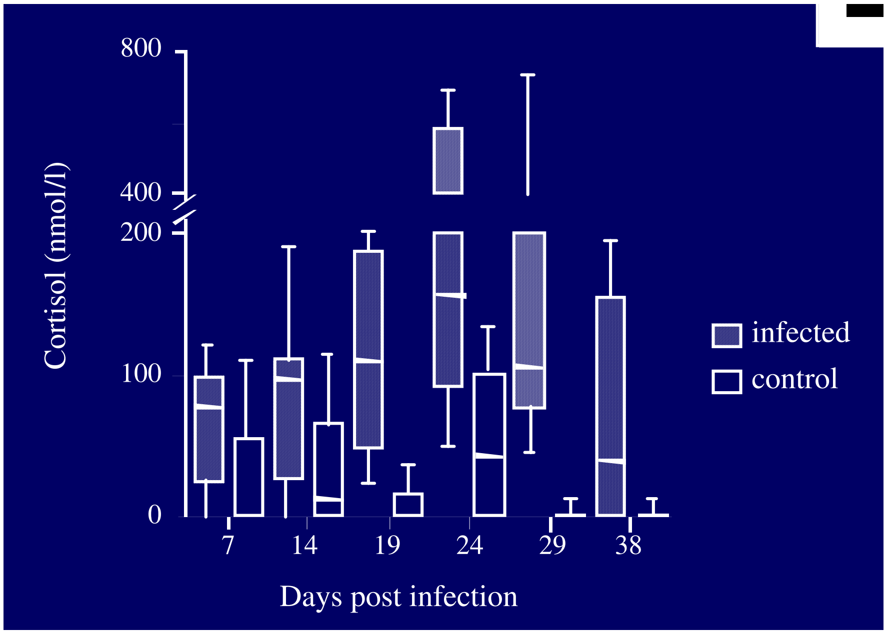
(Bjorn and Finstad, 1998. Can.J. of Zoology. 76:970–977).

- Male lice developed faster than female lice, taking 29 and 38 days, respectively, to reach the adult stage, but fewer than 40% of the lice reach the adult stage.
- The chalimus larvae preferred the gills and the fins, especially the dorsal fin, and caused minor skin damage.
- Preadult and adult lice stages preferred the head and dorsal areas of the fish, and caused severe skin damage.
- Salmon lice seem to have more or less the same developmental rates, distribution on the host and pathogenicity as seen in Atlantic salmon.

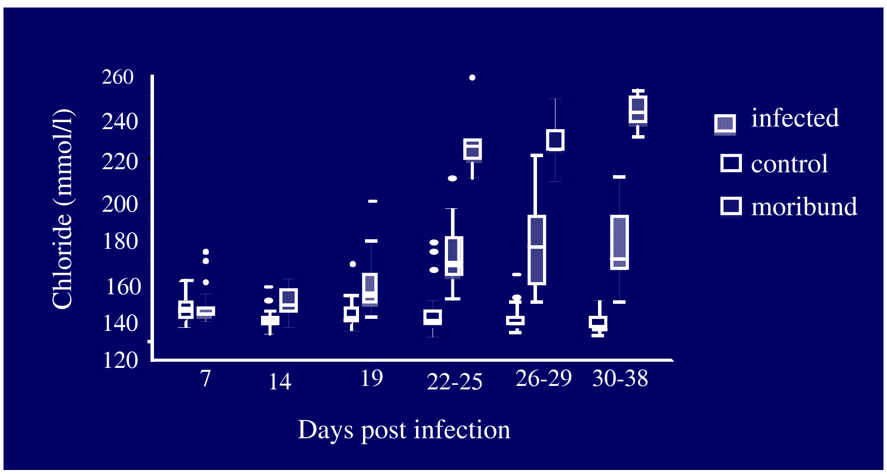
Objective: To test the physiological effect of salmon lice on sea trout and Atlantic salmon post-smolts.

This work demonstrates that heavy salmon lice infections can cause significant stress in salmonids, as measured by increased levels of plasma cortisol (Figure 4).

Annex #3 Figure 4. Plasma cortisol concentration in sea trout post smolts

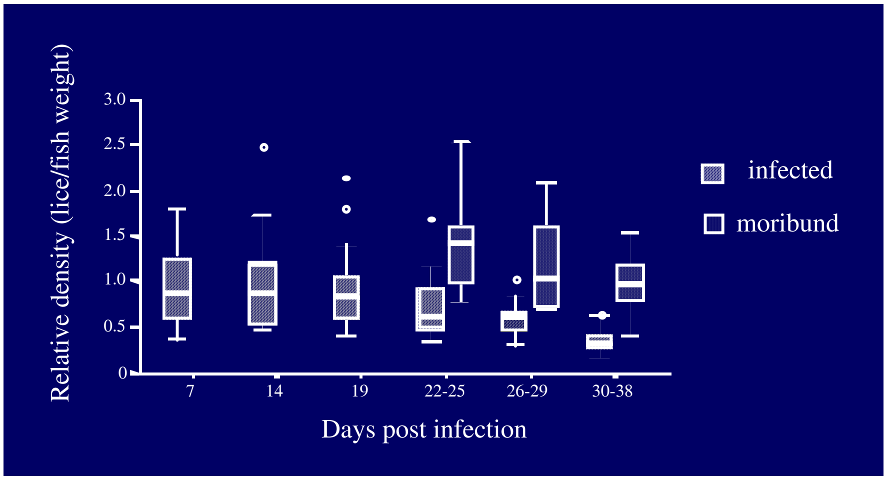


Annex #3 Figure 5. Plasma chloride concentration in sea trout post smolts



Significant osmoregulatory disturbances are apparent in infected fish (Figure 5), particularly at the pre-adult and adult stages of sea lice, and can lead to mortality in infected fish, depending on the relative density of sea lice; studies imply that a relative infection of between 0.75 and 1.6 lice larvae per gram fish weight can lead to mortality of Atlantic salmon and sea trout post smolts (see Figure 6).

Annex #3 Figure 6. Relative density of lice on sea trout post smolts



Objective: To describe the salmon lice infection on wild Atlantic salmon, sea trout and Arctic char post-smolts in areas with and without salmon farming activity, and to consider possible effects of the infection.

Assessments of sea lice on post-smolt Atlantic salmon in a number of different zones of Trondheimsfjorden from 1992 to 1998 suggest that these fish may become infected while migrating through fjords.

Studies also reveal correlations between degrees of infestation and presence of salmon farms—sea lice infestations were much higher on trout exposed to salmon farms compared to trout not exposed, (average numbers of lice per fish at 100 and 13, respectively, Figure 7).

Annex #3 Figure 7. Exposed and unexposed locality

Exposed locality

Sampling week	Hab	n	Prev	mean	min	max
26	SW	27	89	123	6	445
	FW	12	76	133	8	279
29	SW	27	96	203	11	471
	FW	11	91	206	1	532
32	SW	14	93	53	10	101
	FW	19	95	45	1	160
37	FW	1	100			13
	SW	3	33	0.3	1	1

Unexposed locality

Sampling week	Hab	n	Prev	mean	min	max
26	SW	21	61.9	1	1	4
	FW	3	0			
29	SW	11	54.5	6	1	13
	FW	2	0			
32	SW	9	88.9	6	2	12
	FW	0				
37	SW	16	68.8	13	1	36
	FW	1	100			

Heavy sea lice infections on wild sea trout were correlated with a significant stress response (see Figure 4) suggesting that sea lice can kill individual sea trout and might eradicate entire populations.

Discussion

In the discussion following Dr. Finstad's presentation the following points were raised:

- There is a need for a controlled study of sea lice infection of salmon in freshwater and seawater.
- Lice management on salmon farms in exposed areas involves treatment with 'x' which protects fish up to 16 weeks.
- Other physiological measures of stress could stem from bleeding from infection, or reduced oxygen-carrying capacity.

The Risk of Sea Lice Infestation

Scott McKinley, Centre for Aquaculture and the Environment, University of British Columbia

Dr. McKinley noted that sea lice are naturally occurring ectoparasites and that their occurrence in wild and farmed salmonids varies widely, both geographically and among species.

From physiological and behavioural perspectives, sea lice are known to impact osmoregulatory function, produce a stress response, and cause premature return of salmon to freshwater, with sea trout and Arctic char apparently being more susceptible than Atlantic salmon (see Bengt Finstad presentation above).

The purpose of this study was to determine if and at what levels sea lice infestations may affect the cardiac and swimming performance of Atlantic salmon. Adult Atlantic salmon were infected under laboratory conditions to two different levels (moderate, 0.13 lice per gram wet weight; low, 0.02 lice per gram wet weight) and their swimming performance, cardiac output and several blood parameters were compared with a group of uninfected control fish.

For fish infected at the moderate level, there was a significant reduction in swimming performance, and indications of stress and osmotic imbalance.

Discussion

Oxygen carrying capacity and swimming ability are positively correlated in salmonids. One explanation for the poor swimming performance in these Atlantic salmon could be that lice infestation led to a reduced hematocrit and anemic state, thereby reducing the oxygen carrying capacity.

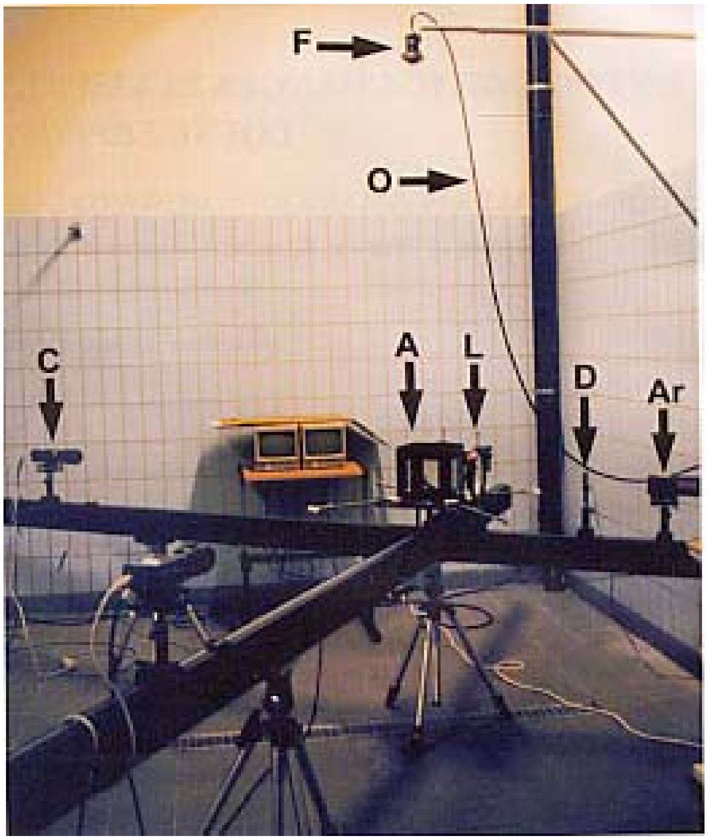
Visual Responses of the Parasitic Sea Louse

Inigo Novales-Flamarique, Biological Sciences, Simon Fraser University (Appendix 4). Dr. Novales-Flamarique described the methodology used to assess the spectral sensitivity of the sea louse (Table 4, Figure 8).

Annex #3 Table 4. Methodology

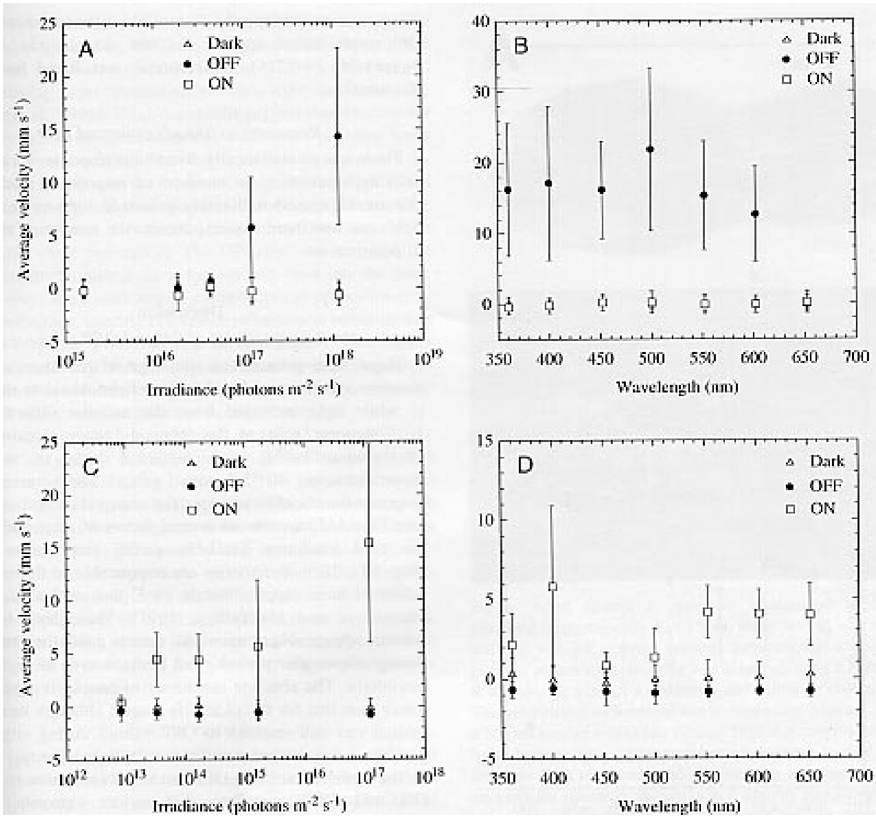
- Two cameras connected to computer
- Track nauplii in three dimensions
- Use special chamber—able to adjust filters and colours and monitor irradiance and water velocity in which nauplii are moving
- Monitor for response using on/off light source
- Vary intensity and colour of light
- Response to lights on or off recorded

Annex #3 Figure 8. Methodologies

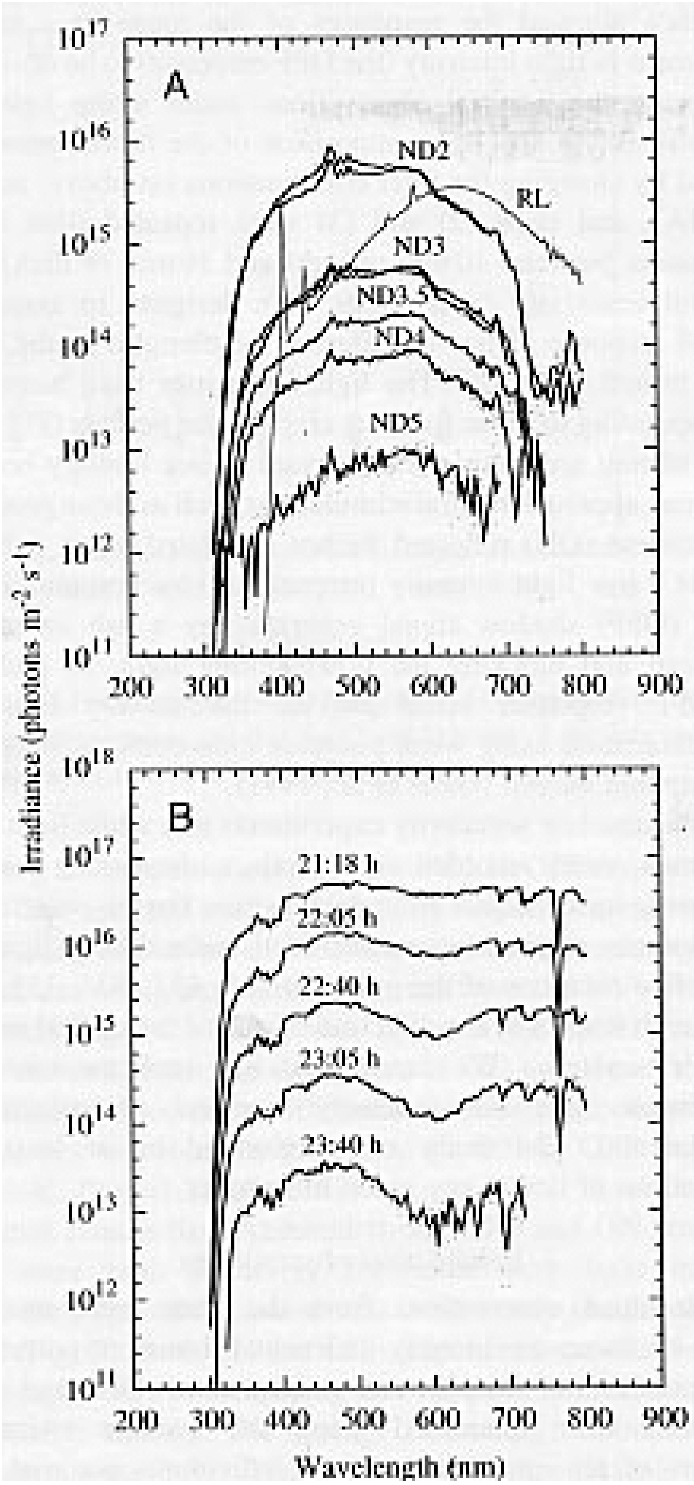


Results demonstrate different patterns of response to light for nauplii (2–3 day) and copepodid (3–4 day) stages. Nauplii dart upward quickly in response to the light being turned 'off' and sink when the light is turned 'on'. Note that the nauplii stage does not attach. Copepodids swim up when the light is turned 'on' and sink when the light is turned 'off'. They do not respond to specific colour changes (Figures 9, 10).

Annex #3 Figure 9. Nauplii and copepodids

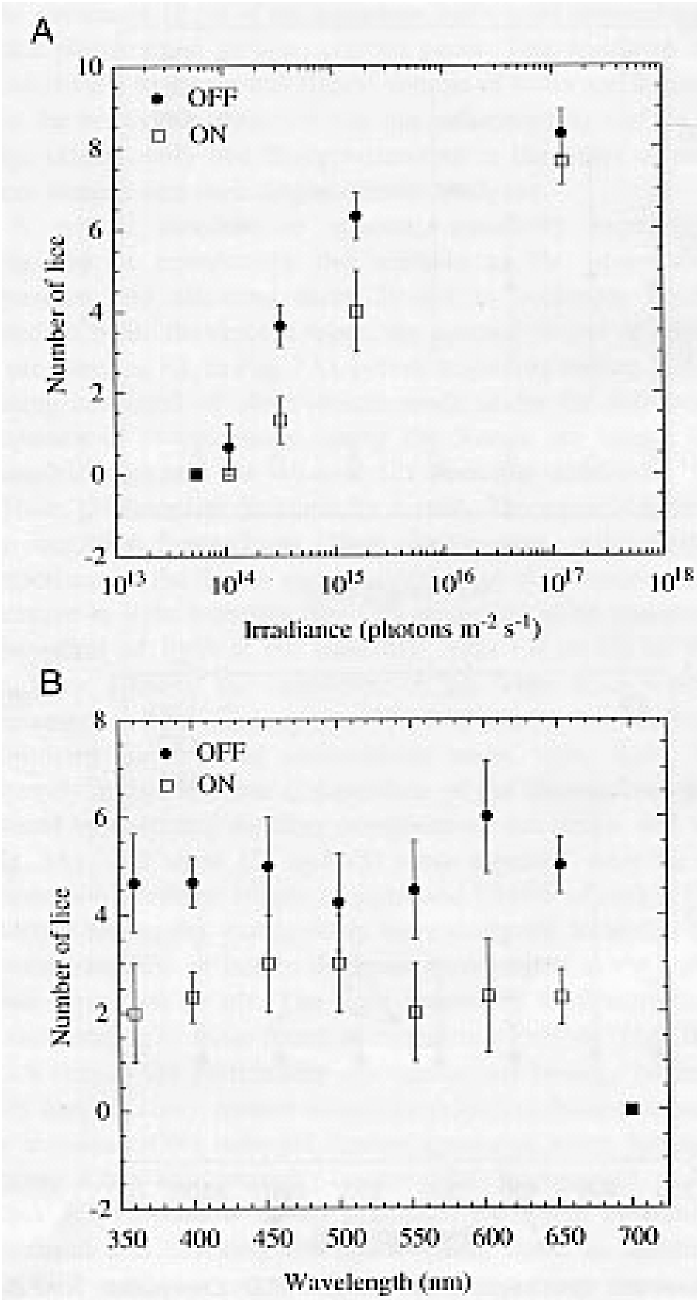


Annex #3 Figure 10. Lab natural light stimuli



Adult females show upward responses to both the onset and the termination of the light stimulus, but the 'off' response for vertical movement is always higher than for the 'on' response (Figure 11).

Annex #3 Figure 11. Adult female lice



Building on these results, Dr. Novales-Flamarique is currently working on designing a light trap for capturing larval stages of sea lice in order to reduce infestations and for monitoring and predicting infestations. It is critical to catch lice at the nauplii stage; that is, an early warning of impending infestation.

Discussion

The question was posed: Is there a behavioural (response) difference between *L. salmonis* nauplii and other (non-parasitic) copepods? Dr. Novales-Flamarique replied that the light trap enables monitoring of by-catch.

Life History of Lepeoptheirus salmonis

Lawrence Albright, Biological Sciences, Simon Fraser University

Two of the main issues with respect to Atlantic salmon culture in British Columbia are IHN (Infectious Haemopoietic Necrosis) and sea lice infection. Dr. Albright described experiments conducted in his laboratory since the late 1980s initiated in response to the introduction of Atlantic salmon for farming. It was suggested that the introduced Atlantic salmon might be prone to disease organisms that were not a 'normal' part of their environment in the Atlantic region of Canada (e.g., IHN). In addition, Atlantic salmon were known to be prone to sea lice infections when cultured in net pens.

With respect to sea lice, the main question is: Do the sea lice come from farmed or wild salmon?

Life Cycle

Investigations revealed that the sea louse has a ten stage life cycle: two free-living planktonic naupliar stages; one free-swimming infectious copepodid stage; four attached chalimus stages; two pre-adult stages; and one adult stage. The nauplius stages and the copepodid stage prior to attachment are non-feeding. Attached copepodids, chalimus stages, pre-adults and adults all feed on their hosts' mucous, skin and blood.

Factors affecting sea lice development

The tables below describe the mean development times for the various stages as a function of water temperature and salinity.

Annex #3 Table 5. Effects of temperature on the mean development times of the various stages of the sea louse.

	Temperature		
Determination	5°C	10°C	15°C
Mean time to hatch (h)	419.1	207.1	130.8
1st nauplius to infectious copepodid (h)	222.3	87.4	44.8
Egg to adult male (d)	–	40	–
Egg to adult female (d)	–	52	–

Annex #3 Table 6. Effects of salinity on development times for the various stages of the sea louse

Salinity (%)	Determination
10	No egg development occurred
	Copepodids survived for less than 24h
15	Eggs developed but failed to produce active nauplii
20–30	Active nauplii were produced but copepodids were only obtained at 30%
At salinities of 15 to 30 % and temperatures of 5, 10 and 15 ^{o}C average survival times of copepodids ranged from 2 to 8 days.	

There are species differences with respect to sea lice infection. The order of infection for open-ocean caught salmonids is chinook > steelhead > pink > chum > coho > sockeye and for farmed salmon in BC, Atlantic>chinook>coho. In experimental infections, coho were the most resistant to infection followed by chinook and Atlantic salmon. In general, copepods were lost from the gills of coho after 10 days post-infection and only a few remained on the fish at 20 days post-infection.

Immune responses and effects of stress

In terms of immune responses, coho salmon displayed well-developed epithelial hyperplasia and inflammatory responses to the presence of sea-lice while Atlantic salmon showed only minor gill and fin tissue responses. The chinook response was intermediate between these other two species. The data indicate that the main defense of the animals to sea-lice is non-specific and not a portion of the B-cellular specific immune system. The emphasis would be on epithelial hyperplasia, soluble or cellular factors of the inflammatory response and/or possibly serum enzymes or other proteins.

To investigate this rejection response corticosteroids were implanted in coho salmon. Corticosteroids increase the susceptibility of fish to a variety of parasitic diseases. Copepods were lost from the gills of control coho by 10 days post-infection and only a few remained on the body and fins at 20 days post-infection. Copepods remained attached to the gills, fins and body of the cortisol-implanted coho over the 20 day study period. There was a well-developed hyperplastic and inflammatory response in the control coho compared with a suppression of the inflammatory response and development of epithelial hyperplasia in the cortisol-implanted coho. These data support the hypothesis that non-specific factors are mainly responsible for protecting coho salmon against the sea-louse.

How to reduce the incidence of sea-lice infections

This information suggests several ways to maintain louse-free populations of salmonids in net pens:

- Cultivate species that are innately resistant to this sea lice (e.g., coho and sockeye salmon).
- Maintain fish in a low stress environment to minimize immune-suppression.
- Culture the fish in flowing waters to minimize horizontal infections within the cultured populations.
- Culture the fish in low salinity seawater to minimize growth of the ectoparasites.

The current knowledge of early life stages of sea lice make it possible to determine whether sea lice on newly infected wild salmon next to net pens came from farmed fish, or vice versa, partly because the heavy isotopes of carbon and nitrogen in naupliar and copepodid stages reflect the diet of host fish. Since the diets of farmed and wild fish are substantially different, their heavy carbon and nitrogen ratios are also likely to differ. By removing the copepodids from a salmonid shortly after it becomes infected, but before the louse substantially grazes on the host, one could analyze as few as ten copepods to establish the origin of the louse.

The following publications provide information on the life stages as well as the responses of various species of salmonids to *Lepeophtheirus salmonis* infections.

Johnson, S.C. and L.J. Albright (1991). The developmental stages of *Lepeophtheirus salmonis* (Kroyer), 1837) (Copepoda: Caligidae). Can. J. Zool. 69: 929–950.

Johnson, S.C. and L.J. Albright (1991). Development, growth and survival of *Lepeophtheirus salmonis* (Copepoda: Caligidae) under laboratory conditions. J. Mar. Biol Assoc. U.K. 71:425–436.

Johnson, S.C. and L.J. Albright (1992). Comparative susceptibility and histopathology of the response of naïve Atlantic, Chinook and coho salmon to experimental infection with *Lepeophtheirus salmonis* (Copepoda: Caligidae). Dis. Aquat. Org. 14: 179–193.

Johnson, S.C. and L.J. Albright (1992). Effects of cortisol implants on the susceptibility and the histopathology of the response of naïve coho salmon *Oncorhynchus kisutch* to experimental infection with *Lepeophtheirus salmonis* (Copepoda: Caligidae). Dis. Aquat. Org. 14: 195–205.

Discussion

Several questions were posed:

Is a sea louse a sea louse?

Dr. Albright responded that we need to think about the co-evolutionary response and the co-evolutionary perspective of studying both host and parasite.

Could you distinguish between farms using different feeds and ΔC as a tracer ?

Dr. Albright referred to the possibility of using stable nitrogen to distinguish between feeds.

Effects of Infestation on Behaviour of Young Pink Salmon, and its Potential Consequences

Lawrence Dill, Director, Behavioural Ecology Research, Biological Sciences, Simon Fraser University

Behavioural responses of hosts to their parasites is a subject of considerable interest in evolutionary ecology, because of the obvious evolutionary conflict involved (e.g., recent ISBE talks and book by J. Moore "Parasites and the Behaviour of Animals").

In some cases, the behaviours seem designed to increase the probability that the parasite is transmitted to the next host in its life cycle (e.g., tapeworms cause sticklebacks to spend more time near the surface, increasing their vulnerability to fish-eating birds). In such cases, the parasite appears to manipulate the behaviour of its host.

In other cases, the host's behavioural response seems designed to decrease parasite survival. There are several ways to do this. One is to enter an environment hostile to the parasite, e.g., behavioural fever (fish enter warmer water than usual).

Atlantic salmon and sea trout infected with sea lice might do something similar. Both species have been observed entering freshwater earlier in their life cycle than normal which, because sea lice cannot live long in freshwater, has been interpreted as an adaptive behavioural response (de-lousing).

Alexandra Morton has reported something similar for juvenile pink salmon in the Broughton Archipelago region of the Central Coast of BC. She has reported heavily infected pink salmon apparently aggregating in areas where waterfalls cascade into the inlets—possibly an attempt to rid themselves of parasites. Alternatively, the fish may be seeking out freshwater because stress, or their weakened condition, makes it difficult for them to pay the cost of osmoregulation, or because damage to the skin caused by the parasite increases the cost of osmoregulation. We will try to separate these experimentally.

Ongoing and proposed research

First of course, we will want to confirm and quantify Alexandra Morton's observations, to see if infected fish are, in fact, found in less saline microhabitats in the field.

Then, in the laboratory, we will see if this is due to a preference for less saline water, using experimentally infected fish (which will require a source of larval lice). It is important that the fish be experimentally infected, so that differences between individuals in susceptibility to parasitism do not confound results.

If we can experimentally shift the fish's salinity preference, then we will try to see how parasite load affects their behaviour, and determine if a threshold level of infestation is required to cause a change in salinity preference.

Testing the alternative hypotheses would require:

- Showing that there is an energetic benefit of entering freshwater, and seeing if the fish do so when their net energy balance is affected in other ways (e.g., by altering the energy content of their food), or when they are stressed by other means (e.g., handling)
- Measuring the impact of skin damage on osmoregulatory ability (here we need to collaborate with a physiologist), or damaging the skin in other ways to see if the fish alter their salinity preference in the same way.

If we can demonstrate an adaptive change in behaviour it will be of considerable interest to evolutionary and behavioural ecologists (as mentioned earlier).

Regardless of the causal mechanism, the findings will also have considerable applied significance. To estimate field infestation rates it is necessary to sample the fish in an unbiased way. It is also important to know about differences in the microhabitat preferences of infected and uninfected fish. If infected pink salmon are all near shore or in the freshwater lens near the surface, then mid-water trawling is not going to give a reliable estimate of infestation levels in the field, and may also influence susceptibility to predation.

This work is being supported by NSERC and by Watershed Watch Salmon Society, but additional funding is needed for field sampling and laboratory work (including graduate student support). Perhaps some collaboration with industry might be possible?

As mentioned, we also need:

- A supply of lice for experimental infestation
- Young, wild pink salmon (uninfected)
- Access to salinity preference apparatus
- A physiologist to collaborate.

Sea Lice Resistance to Chemical Therapeutants

Larry Hammell, Dept. of Health Management, Atlantic Veterinary College, University of Prince Edward Island (presenter), John Burka, Atlantic Veterinary College and Tors Horsberg, Norwegian Veterinary College (Appendix 5)

Dr. Hammell described the objectives of an ongoing collaborative study which examines factors involved in sea lice resistance to chemical therapeutants as:

To develop methods for monitoring the development of resistance to chemotherapeutants commonly used for treatment of *Lepeoptheirus salmonis* in Norway, Scotland, Ireland, and eastern North America.

The chemotherapeutants used include:

- Organophosphates, Pyrethroids and Avermectins
- Emamectin (SLICE) and Azamethiphos (the most recent (promising) treatments)

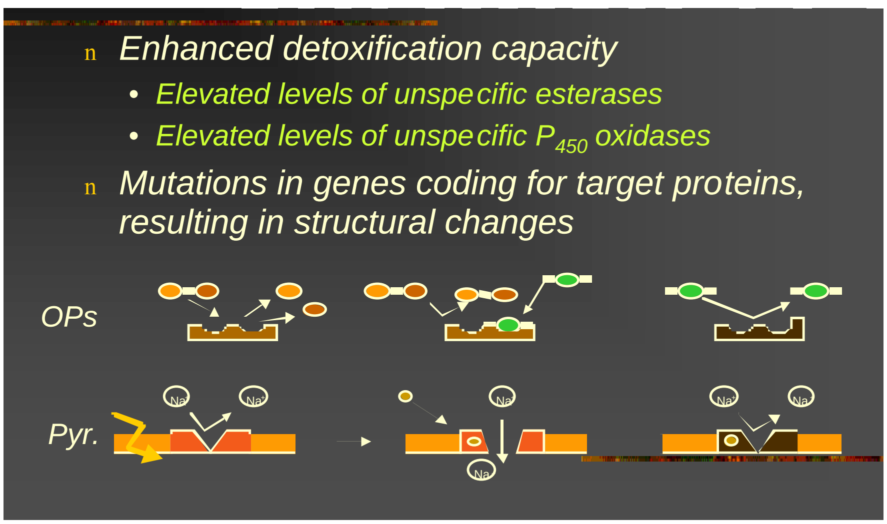
Only SLICE is currently authorized for use in British Columbia. The use of peroxide is not favoured as it causes increased stress in fish (ISA).

Relative treatment intensities are described in Figure 12.

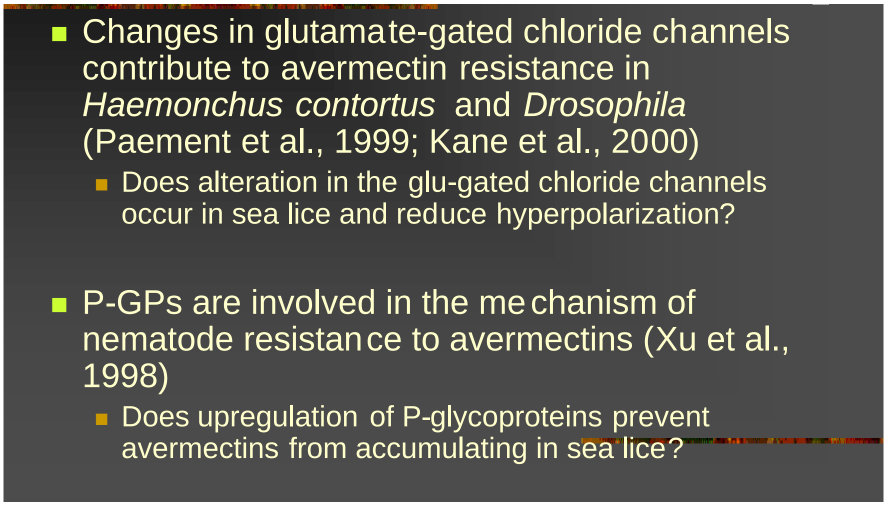
Annex #3 Figure 12. Relative treatment intensity.

Figures 13–14 describe the resistance mechanisms for organophosphates, pyrethroids, and avermectins.

Annex #3 Figure 13. Resistance mechanisms for organophosphates and pyrethroids

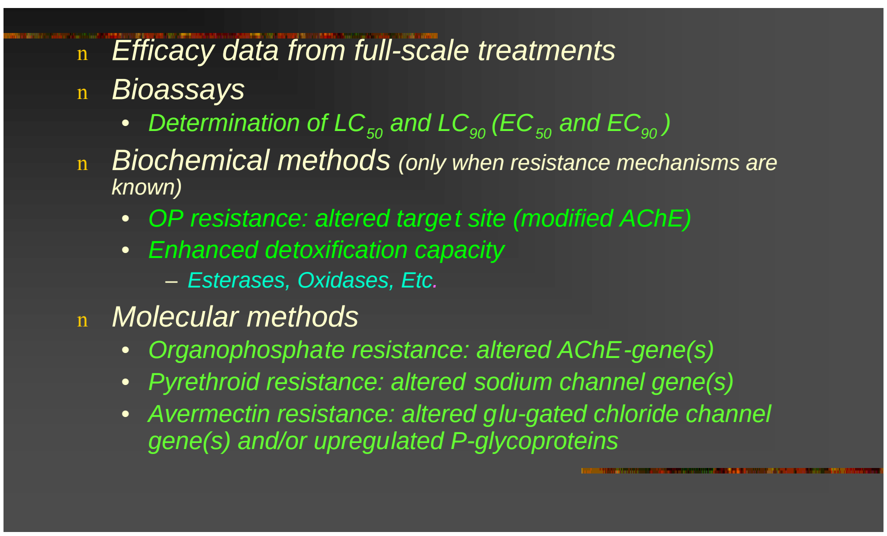


Annex #3 Figure 14. Resistance mechanisms for avermectins



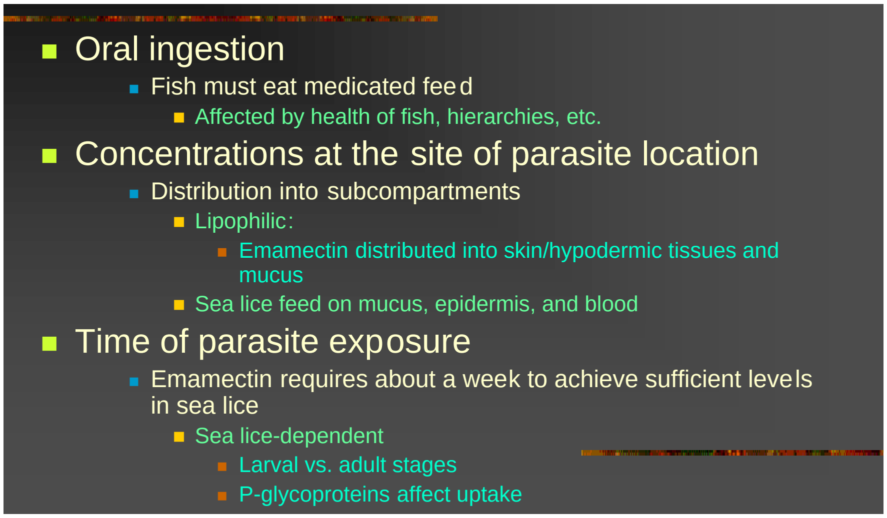
The approaches used to detect and verify resistance in these studies are described in Figure 15.

Annex #3 Figure 15. Approaches to detect and verify resistance



Factors affecting sea lice treatments with emamectin are described in Figure 16.

Annex #3 Figure 16. Factors affecting sea lice treatments with emamectin



The specific purposes for this project include:

- To develop bioassays capable of detecting resistance towards chemotherapeutants
    - Characterize underlying mechanisms for resistance
    - Develop rapid laboratory methods for diagnosis of resistance
    - Develop genetic markers capable of distinguishing between sea lice populations
    - Monitor patterns of gene flow between farms and regions
- To monitor the effectiveness of sea lice treatments
    - Monitor spatial and temporal distribution of sensitivity in sea lice populations
- To develop strategies for the control of resistance.

Preliminary results indicate the following:

- Bioassay for azamethiphos suggests an apparent high sensitivity of sea lice to azamethiphos in all samples collected in New Brunswick so far. Resistance to azamethiphos is known to occur
- Bioassay for emamectin indicates modification required—lice need to eat emamectin
- Emamectin is distributed into skin/hypodermic tissues and mucous—sea lice feed on mucous, epidermis, and blood
- Emamectin requires about a week to achieve sufficient levels in lice—effective on larval rather than adult stages—P-glycoproteins affect uptake
- There is a correlation between sea lice infestation and Infectious Salmon Anaemia (ISA).

Dr. Hammell described a number of research needs including:

- Need to understand mechanisms of resistance of other species
- Need a pesticide survey; # of treatments/ how often/ with what
- Need to determine reliability of counting methods
- Need to be more aggressive treating for lice.

Discussion

In the discussion following his presentation Dr. Hammell noted that sea lice are one of the possible vectors for ISA.

Case Study: A brief summary of how one member of the BC salmon farming industry approaches sea lice management.

Diane Morrison, Fish Health Manager/Veterinarian, Marine Harvest Canada

What follows is a brief summary of how Marine Harvest Canada approaches sea lice management in British Columbia. I try to be strategic in the timing of sea lice treatments, the goal being to minimize the number and optimize the efficacy of the treatments. I therefore try to ensure the fish go into the winter and the summer with low sea lice numbers. If the fish enter the winter with high numbers of juvenile lice, they will develop slowly throughout the winter and in the spring the fish will carry high levels of mature and gravid lice. In the summer, water temperatures are high, and the lice life cycle is therefore short. The fish very quickly acquire high numbers of mature and gravid lice. The goal is to minimize the number of gravid lice on the fish throughout their life cycle. The ultimate goal is zero gravids.

Integrated Pest Management (IPM) for sea lice is how MHC approaches sea lice management on salmon farms in British Columbia. What is IPM? It is an integration of a number of strategies with a goal of providing a sustainable production system with minimum inputs. I have taken the IPM approach developed in Norway and applied it to our situation in British Columbia. There are differences though, for example, number of treatments available, use of cleaner fish, and regulated allowable lice levels. The IPM approach for sea lice includes:

Pest identification

- Species, Lepeophtheirus or Caligus
    - Distinguish the basic life stages
    - Differences in the above affect management and treatment options
    - Timing of treatment depends on population and number
    - Staff capable of diagnosing and distinguishing species/stages

Management for prevention

- Prevention is key to an IPM strategy
- Therapeutants are not a substitute for prevention
- Management tools
    - Fallowing (not significant for Caligus)

  - Separation of year classes
  - Proper management of fish densities
  - Clean nets that maintain greater water circulation
  - Communication between companies
  - Co-coordinated, synchronous, treatments between neighbouring farms

Monitor populations and damage

- Monitor to ensure treatments occur at correct time
- Counting frequency e.g., Weekly > 10C, 2/3 weeks < 10C
- Establish threshold values on ovigerous lice not exceeded
- Identify impulses/waves of infection
- Predict peak infestation times for future years
- Determine the efficacy of therapeutic treatments

Reducing pest population

- Good husbandry / management techniques
- Use of wrasse, as cleaner fish (need to investigate whether there are any suitable species in B.C.)
- Therapeutic treatments (currently one therapeutant available in B.C.)

Optimizing therapeutic treatment (some of this does not apply to B.C., since we only have one treatment option, but the rationale is valid)

- Alternate products to reduce selection pressures and decreased efficacy
- Use correct method of application and dose
- Reduce selection pressure from products with long persistence
- Ensure applications do not result in sub-therapeutic dose
- Treat whole sites where possible
- Ideally treat all farms in the same water body
- Monitor efficacy of treatments
- Do not use a product once efficacy begins to decline
- Implement a Resistance Management Strategy.

Discussion

A Nutreco representative (another member of the BC salmon farming industry), said Nutreco monitors sea lice on its fish twice monthly at all sites, and said lice levels on Nutreco farms are much lower than on Norwegian salmon farms. At this time, data are proprietary and not available for scrutiny.

Industry participants were interested in collaborating with academic researchers on sea lice research in British Columbia.

Where Do We Go From Here?

Scott McKinley, Centre for Aquaculture and the Environment, University of BC

What Have We Learned?

- Studies to date are primarily restricted to Atlantic Salmon, Arctic Char and Sea (brown) trout
- Even moderate lice levels affect performance (swimming, reproduction, behaviour) of farmed and wild fish, but with differing consequences
- Susceptibility to sea lice varies according to the fish species involved and time fish spent in nearshore areas.

What Do We Need To Do?

- Understand the biology/natural life history of sea lice in Pacific coastal waters
- Initiate studies: on the effects of sea lice on Pacific salmon, on the rate of infection of wild salmon in areas with and without farms, and on the efficacy of existing treatments on Pacific salmon.

How Do We Do It?

- Establish strategic alliances (e.g., similar to the collaboration between UPEI, AquaNet and the EU)
- Develop appropriate sampling protocols (for lice and fish)
- Determine the level of infestation that affects performance of Pacific salmon
- Determine the role of fish farms in sea lice infestation and vice versa
- Determine the threat sea lice pose to wild stocks.

Wrap Up Discussion

Discussion led by Scott McKinley and Craig Orr

What Have We Learned?

- Sea Lice are a serious problem for both industry and wild salmon
- Anecdotal reports suggest lice have a problem in the past (1958 and 1970s). This was attributed to *El Nino*. Pink salmon especially showed high lice levels. Lack of historical data means getting baseline data is vital
- We know little about the natural life history of sea lice in Pacific coastal waters and their "normal" infestation patterns

What follows is a list of potential research projects

- Obtain baseline of current levels of sea lice on farms. Government could oblige the industry to release the numbers
- Examine behavioural responses to sea lice infestation in wild Pacific Salmon (both laboratory and field studies)

- Examine the rate/incidence of transfer of sea lice from wild to farmed and vice-versa (Δ C studies)
- Map wild salmon out-migration routes and timing
- Initiate comparative studies in areas with and without farms
- Assemble industry, and then baseline data (sampling must be uniformly done)
- Learn from Norway's data on threshold levels for # of lice per farmed fish. Similar thresholds are needed for BC.

What must be done?

- Initiate studies to determine the efficacy of existing treatments for farmed salmon (SLICE™ is the only approved method of delousing on the west coast)
- Identify ways to enhance innate protective mechanisms (e.g., immuno-suppressants)
- Identify environmentally-friendly methods for dealing with lice that do not affect the physiology of the fish.
- For the baseline studies, we need to look at regulatory alternatives (is industry adequate, what kinds of standards/oversight presently exist)
- Increase and improve on reporting.
- Search for ways to get wild smolts through high-risk periods and high-risk places. Reduce the risk to wild salmon.
- Establish a sea lice monitoring program at the Skeena gill-net fishery
- Map different localities, pick up monitoring sites
- Risk of infection: is it related to density of net pens and risk of infection within and outside of the farm? Is there research on this coming from Europe? Reports indicate that in one day from one farm you can get 2.3 billion sea lice larvae.

How do we do it?

- Establish/strengthen trust-based alliances with government, industry, First Nations. Some alliances have been formed—need to strengthen those (need to base this on trust and the realization that trust is not built overnight)
- Develop a list server
- Develop a Sea Lice Working Group, in which propriety information is not improperly or indiscriminately used, and in which participants are forthright and realistic.

Dr. Hammell raised the following questions: Do we need independent monitoring? Do we need regulations? Do we need third party monitoring? How can we get the baseline data we need?

Next Steps

- Establish a Sea Lice Working Group to ensure collaboration and avoid duplication. Plan for continued meetings/discussion.

- Develop proposals for submission to AquaNet (by October 2002), government agencies and, possibly, Foundations.

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ANNEX # 4. REPORT TO THE PFRCC ON INFESTATION OF THE SEA LOUSE IN THE BROUGHTON ARCHIPELAGO

Report to the PFRCC on infestation of the sea louse *Lepeophtheirus salmonis* (Krøyer) on juvenile pink salmon *Oncorhynchus gorbuscha* (Walbaum) in the Broughton Archipelago, British Columbia

Alexandra Morton—Raincoast Research

Based on research under review at ICES and research in progress with Dr. Rick Routledge (SFU), Aleria Ladwig (DFO) and Corey Peet (U.Vic.)

Introduction

The sea louse *Lepeophtheirus salmonis* is a common caligid parasite of salmonids throughout the Northern Hemisphere (Kabata, 1973; 1979). Low natural abundance and minimal host damage characterise the species (Boxshall, 1974; Wootten *et al.,* 1982; Berland, 1993; Nagasawa, 1987; Nagasawa *et al.*, 1993). Epizootics of *L. salmonis* on wild salmonids were rare (White, 1940; Wootten *et al.,*1982; Nagasawa, 1987) until 1989 when a series of outbreaks coincident with the presence of salmon farms occurred off the coasts of Ireland (Tully *et al.,* 1993) and Norway (Birkeland, 1996). Sea lice epizootics on marine net-cage salmon farms have followed the pattern of aquaculture development (MacKinnon, 1998). Due to the far greater densities of farmed hosts relative to wild hosts, lice populations become biomagnified in areas of intense salmon culture including Norway (Heuch and Mo, 2001), Ireland (Tully and Whelan, 1993), and Scotland (Butler *et al.,* 2001).

The Broughton Archipelago is a major natural production area for all native Pacific *Oncorhynchus* salmon species, except sockeye (*Oncorhynchus nerka* Walbaum). The pink salmon, identified as “Pacific Management Area 12 mainland pink stocks” are the most important commercial species in the archipelago (Towards a Salmon Stock Management Plan for Area 12 Mainland Inlets FOC 1990). It was estimated this stock could produce 4 million pieces (FOC 1990). There are currently 23 salmon farms distributed throughout the 406 km^2 archipelago on every waterway (Figure 1). Wild and farmed stocks share these confined waterways during both the wild adult salmon inbound migration and juvenile wild salmon out migration. Thus, if biomagnification of sea lice abundance occurs on salmon farms the native salmonid stocks will be exposed to unnaturally high lice abundance as they migrate through in waters where wild salmon occur. Wild salmonids appear to be adversely impacted by the unnaturally high sea louse levels near salmon farms everywhere there are salmon farms and wild salmonids in confined waters, but the oly studies on this phenomena have been in Atlantic waters.

Life histories of most Pacific salmonids differ from those of sea trout, Atlantic salmon and Arctic charr (*Salvelinus alpinus* L.), the three salmonid species to which virtually all *L. salmonis* literature pertains. For example, pink salmon enter the marine environment soon after emerging from the redd when approximately 3.5cm fork length (Heard, 1991), far smaller than the three Atlantic species. They form dense surface schools (Parker, 1965) with strong shoreward orientation (Healey, 1967, 1980). Juveniles from eastern Vancouver Island and central British Columbia river systems typically remain in shallow near-shore environments from April through early June (LeBrasseur and Parker, 1964; Healey, 1967; Healey, 1980). By entering the marine environment as very small individuals and remaining for extended periods in the near-shore environment (where salmon farms are sited), juvenile pink salmon may be at increased risk to be affected by farm-derived sea lice infestations.

Lepeophtheirus salmonis is not currently considered a problem species in the northeast Pacific (Pike and Wadsworth, 1999). The only recorded epizootic outbreak of *L. salmonis* on wild Pacific salmon occurred on adult sockeye in 1990. That spawning run was delayed in warm water at the head of Alberni Inlet, B.C., presumably awaiting freshwater levels to rise (Johnson *et al.,* 1996). This epidemic is thought to have been a result of high marine temperatures (speeding lice reproductive cycle) and temporarily high adult salmon density and abundance. It is not known what role, if any, local salmon farms in Alberni Inlet played in this outbreak.

Due to their small size, pink salmon fry and smolts residing in near-shore habitats are particularly susceptible to sea lice infections, yet smolt infestations are the least studied (Bakke and Harris, 1998). Here we report results (preliminary for 2002) of a survey of out-migrant pink and chum salmon smolts that were sampled extensively in 2001 and 2002 throughout the Broughton Archipelago and on single sample dates in the general area of Prince Rupert and Bella Bella in 2002. The survey was designed to investigate the incidence and prevalence of *L. salmonis* on juvenile pink salmon with respect to their proximity to salmon farms.

Methods

The primary study area, the Broughton Archipelago, encompasses two inlets (Kingcome and Knight), estuarine and archipelago environments and associated waterways. Collection sites were dispersed through the archipelago to include migration routes from eight major pink salmon-producing rivers (Embly, Wakeman, Kingcome, Ahta, Kakweikan, Glendale, Ahnuhati and Klinaklini) (Figure 1), the waters adjacent to 21 Atlantic salmon farm sites and the seaward edge of the archipelago at Queen Charlotte Strait. Sampling sites were divided into two categories; those where pink fry were "directly exposed" to salmon farms (60 sites) and "less exposed" sites where fry had yet to encounter a farm holding Atlantic salmon (5 sites). Note that fish sampled at the "less exposed" sites may have been exposed to farm-derived *L. salmonis* copepodids transported on tidal currents.

During the first weeks of the ocean phase, pink salmon remain in the top few centimetres of the water column and are common very close to shore (Healey, 1980). We observed juvenile pink salmon to be most abundant within a few meters of shore. From a 7.5m boat drifting with the current, schools of pink salmon fry were sampled using large dipnets (after Bailey *et al.*, 1975). Captured fry were placed individually in Whirl-pak™ specimen bags immediately after capture and placed on ice. Fish were weighed, measured (fork length) and the number and species of sea lice recorded using a 30x magnification stereoscope (Bjørn and Finstad, 1998). Sea lice were divided by life history stage: first and second chalimus stages (CH1), third and fourth chalimus stages (CH3), first preadult male (P1M), first preadult female (P1F), second preadult male (P2M), second preadult female (P2F), adult male ADM, virgin female (V), non-gravid female (NGF), gravid female (G), all adult females combined (ADF) (Bjørn *et al.*, 2001 after Johnson and Albright, 1991).

2001

On 41d from 5 June through 16 August, 2001, Juvenile pink salmon were collected from 65 sites along three wild salmon migration routes from Wells Pass to Knight Inlet (Figure 1). We first tested whether fish from our directly exposed and less exposed sites differed in mean fork length or mass due to inadvertent sampling bias, using the t-test with separate variance estimates in

STATISTICA v.5.0. We then compared lice abundance, prevalence and intensity between samples of fish directly exposed and less exposed to farm sites using the methods defined by Margolis *et al.* (1982). Abundance and intensity were calculated using log x+1 transformed data to control for over-dispersion and reported following back-transformation (Zar, 1996).

2002

Twenty juvenile pink and/or chum salmon were sampled weekly for 9 weeks beginning April 19 at each of three "less exposed" and three "directly exposed" sites. The sites, Glacier, Burdwood and Wicklow, near farms holding mature Atlantic salmon within months of harvest, were the three sites selected for the 2002 study to represent "directly exposed" sites. The site Betty Cove, near a farm holding young Atlantic salmon post-smolts not yet exposed wild adult salmon, was only sampled twice. The sites, Bond, Grappler and Kingcome were the three "less exposed" sites for the 2002 study. Moore and Double were also "less exposed" sites sampled infrequently and likely will not be part of the 2002 final report.

In addition 550 one time samples were taken from 21 locations in the Prince Rupert area and another 150 samples were taken from 4 sites in the Bella Bella area. While there are no salmon farms near Prince Rupert for collection of "directly exposed" samples, there are two salmon farms near Bella Bella and so samples from Bella Bella were divided into the same exposure categories as the Broughton Archipelago.

To provide maximal flexibility in the presence of multiple independent variables, the data were analyzed by generalized linear modelling—with function, *glm*, in Splus. The main analyses used a loglinear model with standard deviation proportional to the mean. Analysis of potential differences between left-side and right-side infestation rates used logistic regression with extra-binomial variation.

Results—2001

We collected a total of 872 juvenile pink salmon in June–August, of which both length and mass were recorded for 598 fish. The mean length of juvenile pink salmon was 5.8cm (± 0.033SE, n=598). No difference in mean fork length was observed between salmon sampled at directly exposed sites (mean=5.78cm ± 0.034SE, n=73) and less exposed sites (5.79cm ± 0.12SE, n=525) (t_{85} = 0.10, p = 0.92. NB—Degrees of freedom are approximated, since the t-test was computed with separate variance estimates (see Blalock, 1979).) No difference in mean body mass was observed between directly exposed sites (mean=2.02g ± 0.036SE, n=73) and less exposed sites (2.10g ± 0.12SE, n=525) (t_{86} = 0.78, p = 0.50. NB—t-test computed with approximated degrees of freedom and separate variance estimates.)

We counted 9,145 *L. salmonis* from 872 juvenile pink salmon, representing 96% of all lice recovered. An additional 356 *Caligus* (Müller) *spp.* were counted (323 chalimus, 22 ADM, 9ADF and 3 gravid females) but were not included in the analysis. Mean per capita number of *L. salmonis* (all stages) ranged from 0–68. First- and second-stage chalimus lice dominated the sample from June to August (Figure 2). Adult stages were observed on fish sampled from Day 21 onwards. Mean seawater temperature was 12.5°C.

Compared with less exposed sample sites, fish sampled from directly farm exposed waters had consistently higher lice burdens (abundance, prevalence and intensity) (Table 1; Figure 3). In samples taken near salmon farms, 78% of wild juvenile pink salmon were infected at or above levels reported as lethal to Atlantic salmon (1.6lice/g host weight, Bjørn *et al.* 2001) (Table 1).

Only 13% of juvenile pink salmon sampled at less exposed sites were similarly infected. *Lepeophtheirus salmonis* loads showed a bimodal peak at fish lengths of 4cm and 6cm. Beyond 6cm, the frequency of fish with more than 1.6 lice/g declined quickly to 0 at 9cm. (Figure 4). The majority of salmon less than 8cm exceeded the lethal dose 1.6 lice/g. However, the majority of salmon greater than 8 cm in length carried fewer than 1.6 lice/g and showed very few lice scars. These data may suggest a size-dependant relationship to host mortality (Bjørn and Finstad 1998).

The mean weight of salmon fry with less than 10 *L. salmonis* (another criterion commonly used to assess effects of sea lice infestation on *Salmo spp*. (Nolan *et al.,* 1999)) was 2.10g (SD=0.82), while salmon with 10 or more lice weighed on average only 1.86g, including lice, (SD=0.59), a highly significant difference ($t_{530} = 3.54$, $p < 0.001$) (Figure 4).

Other salmonid species were examined on an *ad hoc* basis, when samples were made available to us. Three chum (*O. keta* Walbaum) smolts averaged 51 sea lice/g, three coho (*O. kisutch* Walbaum) smolts averaged 24 sea lice/g, two chinook (*O. tshawytscha* Walbaum) smolts averaged 29 sea lice/g and four adult cutthroat trout (*Salmo clarki clarki* Richardson) averaged 53 lice/g (counts on the last species are likely underestimates since early chalimus stages can not be accurately counted on live fish).

Results—2002 (preliminary)

We collected 818 pink salmon and 247 chum salmon in the Broughton Archipelago. The mean number of sea lice (*Caligus* and *L. salmonis*) per fish (chum and pink) is clearly lower at the “less exposed” sites than the directly “exposed sites” (Figure 5) in the Broughton Archipelago. Overall, *L. salmonis* lice were approximately 10x’s more abundant on juvenile salmon from “directly exposed” sites and 3x’ more abundant at the post-smolt site compared to “less exposed” sites.

At other sites sampled on the coast, very few *L. salmonis* individuals were found (Table 2). Hence, it appears that *L. salmonis* abundance is abnormally high in the Broughton study area, particularly so in salmon caught near the adult salmon farms.

Of 4365 lice found, 4001 were *L. salmonis*. Furthermore of these 4001 lice, 83% were in either the copepod or chalimus stages

There was an increase in overall abundance of *L. salmonis* in the Broughton Archipelago to a peak at week 9 (Figure 6). The highest sea louse infection rates were at the three “directly exposed” sites, intermediate at the post-smolt site and lowest at all the “less exposed” sites (Figure 7,8).

Loglinear modelling with all these factors in the model confirms the significance of the overall time dependence ($p \ll 1\%$), of the differences amongst the three exposure categories ($p \ll 1\%$), and of differences amongst the locations within exposure categories ($p \ll 1\%$), but not of any species differences ($p = 81\%$). These conclusions apply whether or not salinity and temperature are included in the model. They therefore cannot be explainable as mere artefacts of confounding between exposure category and these other variables.

In the Broughton, the mean weight of wild juvenile salmon sampled was .87 g. The mean number of lice per fish across all exposure categories was 3.73. Eighty-six percent (86%) of salmon collected at “directly exposed” sites and 24% from “less exposed” sites were infected at or above the lethal level (1.6lice/g host weight). No (0) juvenile salmon from Prince Rupert, or the non-fish farmed areas of Bella Bella were infected at the lethal level.

Infection rates between chum and pink salmon were not significantly different.

Discussion

Our study was not designed to identify the biological cost of *L. salmonis* infestation on juvenile wild pink salmon, and we strongly recommend that this be addressed experimentally. However, the negative effects of *L. salmonis* infestation on juvenile Atlantic salmon have been sufficiently well documented to warrant concern about this previously unreported infestation of *L. salmonis* on juvenile Pacific salmon. Given the juvenile pink salmon's much smaller size when entering seawater, each sea louse could have even greater impact on pink salmon than on Atlantic salmon (Plate 1).

Infection by sea lice must occur near the larval louse source, since louse attachment must occur two to four days after hatching (Johnson and Albright, 1991; Tully and Whelan, 1993).

The source(s) of these lice infesting the pink salmon sampled in the present study were most likely from within the Broughton Archipelago as the fish sampled were moving generally west from freshwater at the heads of inlets and sounds towards the open ocean via Queen Charlotte Sound (Figure 1) and thus had not been exposed to water outside the archipelago. This is further supported by the occurrence of fish less than 3cm in length with visible yolks sacs and thus only recently emerged from river redds and almost certainly physically incapable of having migrated from outside the 406 km^2 Broughton Archipelago. From April–June, there are no large numbers of adult wild salmon migrating through the Broughton Archipelago to transport gravid female *L. salmonis* into the area (pers. comm. Glen Neidrauer Fisheries and Oceans Canada). There are, however, 27 salmon farm sites with up to 1,500,000 Atlantic salmon per site situated on the wild fry migration routes in the area.

While sea lice must initially be introduced to a sea-cage salmon population from wild salmon, once introduced, the stationary, high density sea-cage population appears to stimulate rapid, year-round sea louse production (Tully, 1989, 1992). It is possible, therefore, that L. salmonis larvae released from the farmed salmon are infesting wild pink salmon fry as they migrate through the Broughton Archipelago and account for the elevated sea louse numbers reported here.

Lice infections on farmed salmon are characterised by the concurrent presence of all developmental stages but consistent numerical dominance over time by chalimus larvae whereas lice populations continuously dominated by chalimus stages are 'unusual' in wild salmonids (Pike and Wadsworth,1999; Bjørn *et al.* 2001). In 2001 we found first and second stage chalimus lice accounting for over 60% of all lice, actually increasing in numerical dominance as the study continued (Figure 2), rather than declining as one would predict from a natural sea lice infestation. This lack of maturation of the infestation remains the most convincing evidence that the sea lice infestation may be linked to the presence of local fish farms. (This analysis not complete for 2002.)

Although surveys that compare sea lice infestation on hosts in areas near and distant from fish farms, such as the present study, can not provide causal linkage between farmed and wild hosts, or vice versa, they can provide strong circumstantial evidence and generate hypotheses that should be tested experimentally. Bjørn *et al.* (2001) found significantly higher sea lice infection rates in sea trout and Arctic char caught near salmon farms (mean intensity 100–200 larvae per fish) than fish caught distant from salmon farms. Nagasawa *et al.* (1993) found wild adult pink salmon in the open ocean averaged only 5.8 adult lice per fish.

Fish captured 2001 in the vicinity of two salmon farm sites in our study showed comparatively low sea louse infestation. One of these salmon farm sites was fallow, while the other held only first year smolts. It was only near farms in the second of a two-year production cycle where wild pink salmon fry showed peaks of sea louse infection rates. Lice infestation on farm salmon increases throughout the typical two-year production cycle (Bjørn *et al.*, 2001; Mackenzie *et al.,* 1998; Tully, 1993; Revie *et al.,* 2002). If salmon farms were not the causal factor for elevated lice numbers seen on pink salmon in this study, we would expect to see no difference between the fallow/smolt-only sites and those in the second year of production.

The higher occurrence of *Caligus* spp. lice near the Bella Bella salmon farms at Jackson pass raise the question whether this generalist species of sea lice, which can be present without a salmon host might, benefits immediately from the high density of hosts found on salmon farms.

In July 2001, Fisheries and Oceans Canada (FOC) sampled 523 juvenile pink and chum salmon (*Oncorhynchus keta*) in the waters immediately surrounding the archipelago study area, namely eastern Queen Charlotte Strait and western Johnstone Strait (Anon., 2001) (Figure 1). While the areas sampled do not have salmon farms, they would be subject to the same potential tidal transport of *L. salmonis* copepodids as the less exposed, eastern reaches of the Broughton Archipelago. Sea lice abundance from the FOC samples was reported as 1.7/fish, prevalence 58% and intensity 2.8/fish. In addition, FOC found a much higher proportion of preadult lice (18.9%) than this study (10%). These more mature, sparser lice loads are consistent with the less exposed sites in our study and serve to further define the boundaries of heavy infection as occurring only immediately adjacent to salmon farms.

Our data suggest that size-dependant mortality was likely a factor in the pink salmon population. Fish infested at levels reported as lethal to Atlantic salmon dominated the sample from 4–7.5cm, but fish infected at these levels became less frequent after 8cm. None of the larger fish were marked by accumulation of melanocytes, which suggests that heavily infested fish died prior to reaching ~8cm fork length (Bjørn and Finstad 1998). Even under normal conditions, predation on pink fry in the ocean is high, but decreases as individuals grow (Parker and LeBrasseur, 1974). Therefore, population viability in pink salmon is directly correlated with rapid growth rate through the fry stage. Grimnes and Jakobsen (1996) found "leaping and rolling" activity was six times greater in lice-infected *Salmo* spp. The disturbance and flashing associated with these behaviours would draw increased attention from both aerial and aquatic predators. Lice infection could therefore increase mortality directly or indirectly.

The external condition of the wild fish captured at directly exposed sites differed markedly from those caught from less exposed sites. While number of lice per fish increased slightly as sample sites approached the farms in the direction of the migrating salmon (likely due to movement of larvae in the tidal current), in 2001 92.5% of less exposed fish exhibited smooth, silver-bright skin. At directly exposed sites, however, 38% exhibited black lesions, pin-prick wounds and/or bleeding from eyeballs and base of fins. Black lesions caused by accumulation of melanocytes are symptomatic of heavy sea louse burdens (Grimnes and Jakobsen, 1996; Pike and Wadsworth, 1999). In addition in 2001, 56 fish (6.4%) from directly exposed sites bore signs of fish predation, parallel lacerations in paired occurrence on both sides of the fish, while only 1 (2.5%) was thus marked at the less exposed sites. The greater incidence of these marks on fish sampled at directly exposed sites suggests attack by Atlantic salmon as the fry pass through the pens, or perhaps by wild predator aggregations immediately adjacent to cages. In any case, where there were cuts into the skin, chalimus stage lice were lined up with their anterior ends in the exposed flesh. It is known that external physical damage promotes sea louse settlement (Pike and Wadsworth, 1999).

Four juvenile salmon in 2001 and three in 2002 were found with preadult stage lice in their mouths, suggesting the possibility these fish had been feeding on free-swimming lice. While transfer of preadult and adult stage lice between hosts is considered an insignificant route of louse infection, it has been observed (Bruno and Stone, 1990; Ritchie, 1997). If sea lice are transferring horizontally from farmed to wild salmon, this raises additional concern of disease transfer. Sea lice have been found to carry *Aeromonas salmonicida (*Lehmann and Neumann, 1896)*,* the causative agent for furunculosis (Nese and Enger, 1993). They are also considered potential vectors for other diseases, such as Infectious Salmon Anemia (ISA), which remains a threat to BC as long as importation policy allows for movement of Atlantic salmon to B.C. from ISA-infected areas (Håstein and Bergsjo, 1976; Wootten *et al.*, 1982; Nylund *et al.*, 1991, 1993).

Pink salmon biology predisposes juveniles of this species to high sea louse infection rates because; (i) pink salmon smolt in saltwater, in the same environment now heavily utilised by the salmon farming industry in BC; (ii) the smoltification process increases the fish's susceptibility to sea lice (MacKinnon, 1998) and (iii) pink salmon smolts are surface oriented, as are photopositive free-swimming lice nauplii (Johannessen, 1978), offering the potential for increased infection rates (Huse and Holm, 1993).

The juvenile pink salmon sampled in 2001, are the progeny of the adults which entered the rivers in the fall of 2000. A preliminary review comparing how many pink salmon entered certain rivers in 2000 and how many of their progeny returned in 2002 reveals a startling pattern of collapse (Figure 9). To the north of the Broughton Archipelago, the 2002 pink salmon returns were generally good to excellent, to the south they were fair to good, but in the Broughton Archipelago approximately 98% of the pink salmon that went to sea in 2001 failed to return to spawn. There is one anomalous river in the Broughton Archipelago, Embly River (Figure 1). The pink salmon sampled seaward of Embly River, in Wells Pass, had the lowest sea louse infections rates recorded in an area "directly exposed" to salmon farms (lice/g host weight $\bar{x}$=0.19; lice/fish $\bar{x}$=0.5). While there are two salmon farms in Wells Pass, the vast majority of juvenile pink salmon were found on the eastern shore, opposite the farms, likely pushed there by the tidal ebb out of Drury Inlet. This combined favouring of the non-farmed shore and the geographic placement of Embly River nearer to the open waters of Queen Charlotte Strait than other Broughton river could have contributed to the low infection rates and subsequent high returns of the pink salmon to that river.

The common practice of inadvertently siting salmon farms adjacent to salmon-bearing rivers results in outmigrant salmonid juveniles, including pink salmon, coming into close proximity to salmon farms immediately upon entering saltwater—the life-history stage when they are most vulnerable to the effects of sea lice infection due to the relatively small size of the host (Tully *et al.,* 1993; Tully and Whelan, 1993). The potential contribution of the salmon farming industry to this previously unreported sea louse infestation on juvenile pink salmon has to be considered because the geography and nature of the infection so closely match the better-studied sea louse infections in wild Atlantic salmonids exposed to European salmon farms. It should be remembered that salmon farms can act as "pathogen culture facilities" (Bakke and Harris, 1998) when siting salmon farms on juvenile Pacific salmon migration routes in coastal British Columbia. Given the strength of tidal currents within the relatively confined waters of the archipelago study area, there may be no areas truly unexposed to salmon farm effluent. Therefore we felt it was more accurate to consider our treatment categories as direct vs. lesser exposure to fish farms, rather than exposed vs. unexposed. Future work should expand the sampling protocol northward to include sites that are truly unexposed to fish farms. Our data suggest the precautionary principle should be applied to protect the wild salmon from farm-origin sea lice.

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Annex #4 Table 1. (2001 data) *Lepeophtheirus salmonis* burdens (all developmental stages) on pink salmon fry

Terms are defined as follows: Prevalence—percentage of fish with lice; Abundance—mean louse count per fish; and Intensity—mean lice per infected fish. Abundance and intensity were calculated using log x+1 transformed data to control for over-dispersion and reported following back-transformation (Zar, 1996).

	Directly Exposed to Farms	Less Exposed to Farms	P-value
Prevalence (%)	97.1	66.7	
Abundance (95% CI)	8.2 (7.8–8.7)	2.2 (1.8–2.8)	<0.001
Intensity (95% CI)	8.8 (8.3–9.2)	3.4 (2.8–4.0)	<0.001
% fish with > 1.6 lice / g body weight	77.9	12.8	
Mean length (cm±SE)	5.8 ±0.033	5.8 ±0.12	0.92
Mean Mass (g±SE)	2.0 ±0.036	2.1 ±0.12	0.50
n Fish	525	73	

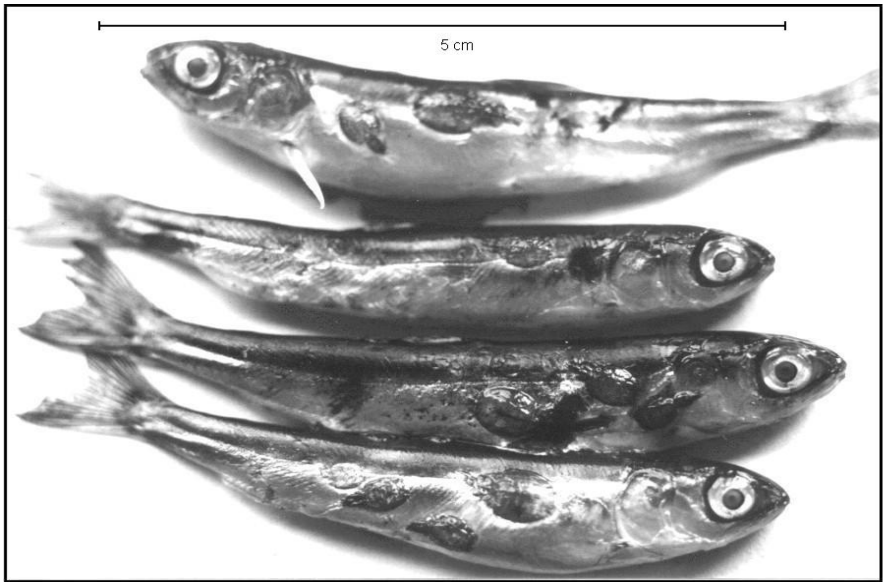
Annex #4 Table 2. The average number of lice (both species) per fish was greatest in the Broughton Archipelago where there are 23 salmon farm sites

Near Bella Bella the number of Caligus lice per fish was higher near the salmon farms at Jackson Pass than where there are no farms. There are no salmon farms in the Prince Rupert area. The samples from Rivers Inlet and Smith Inlet have not been analysed yet.

Area	Fish	*L. salmonis*		*Caligus* spp.	
		Total	Ave/fish	Total	Ave/fish
Broughton	1072	4001	3.73	364	0.34
Exposed/Adult	511	3494	6.84	264	0.52
Exposed/Smolt	37	79	2.14	79	2.14
Not Exposed	524	428	0.82	21	0.04
Smith Inlet					
Rivers Inlet					
Bella Bella	154	1	0.006	29	0.19
Exposed	118	0	0.000	28	0.24
Not Exposed	36	1	0.028	1	0.028
Prince Rupert	566	2	0.003	4	0.007

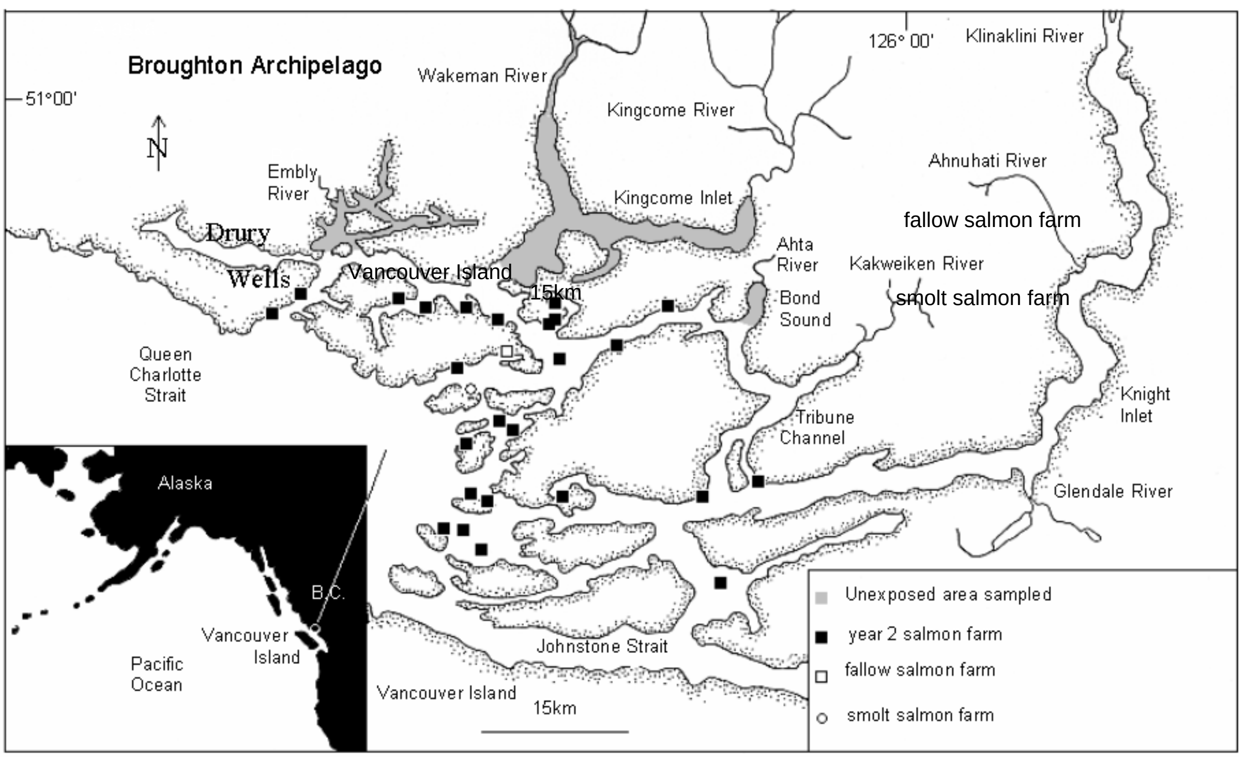
Annex #4 Plate 1. Four juvenile pink salmon infected with *Lepeophtheirus salmonis*

Sampled from Broughton Archipelago, B.C., June 2001



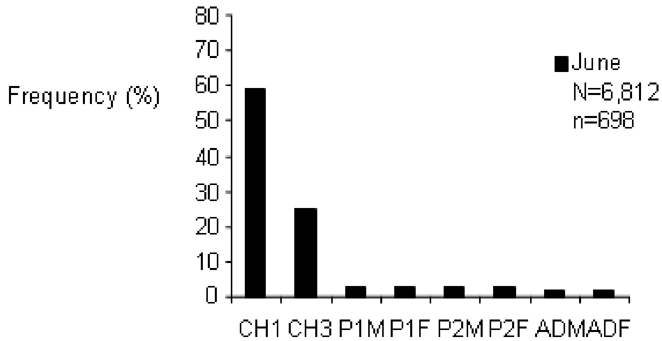
Annex #4 Figure 1. Map of the study area in the Broughton Archipelago

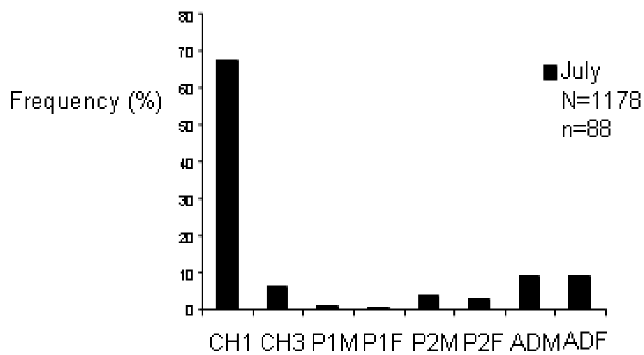
Showing major pink salmon-producing rivers, presumed migration routes of pink salmon and locations of salmon farms.



Annex #4 Figure 2. (2001) Frequencies of *L. salmonis* life history stages on juvenile pink salmon sampled from within the Broughton Archipelago in June and July 2001

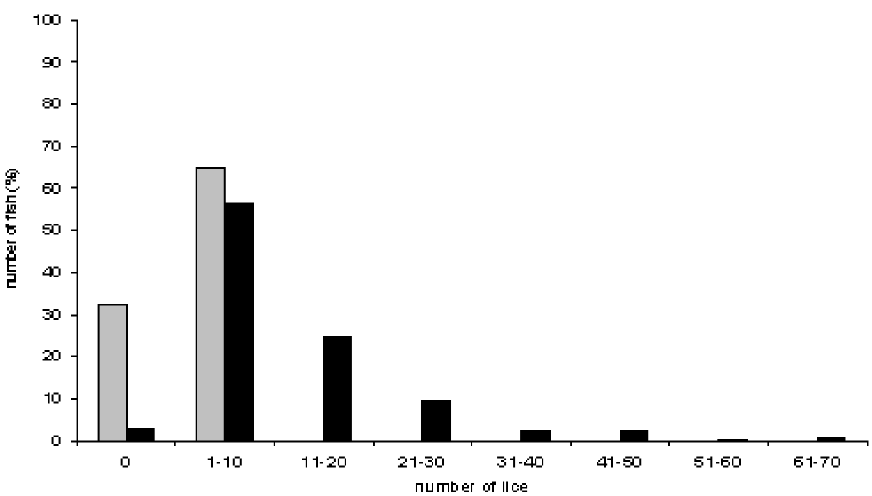
First and second chalimus stages (CH1), third and fourth chalimus stages (CH3), first preadult male (P1M), first preadult female (P1F), second preadult male (P2M), second preadult female (P2F), adult male ADM, all adult females combined (virgin, gravid, non-gravid) (ADF). The sustained dominance of early chalimus stages suggests local salmon farms as the dominant source of lice.

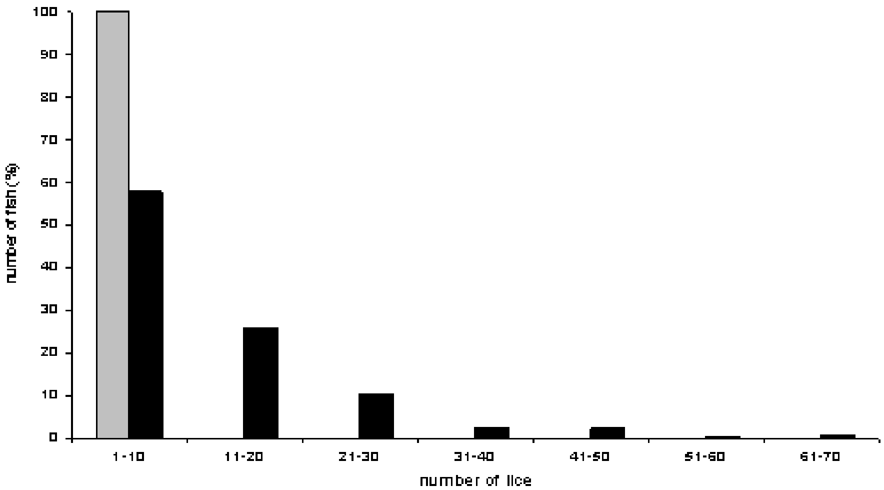




Annex #4 Figure 3. (2001 data) Profile of *L. salmonis* burdens (all stages) on pink salmon fry

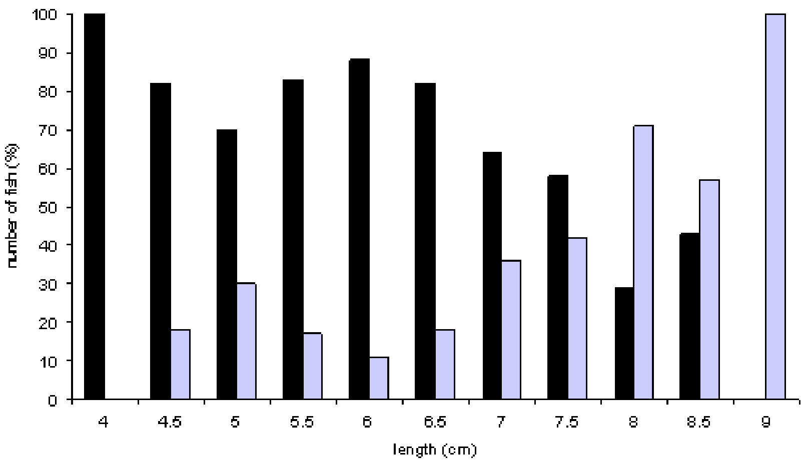
The upper figure depicts the abundance of lice per fish (%), whereas the lower figure shows the intensity of lice per fish. Grey columns represent "less exposed" hosts, black columns represent the burdens of the, "directly exposed" fish.





Annex #4 Figure 4. (2001 data) Length frequencies of pink salmon sampled (4–9cm) with *L. salmonis* burdens (all stages) equivalent to greater than (black), or less than (grey) 1.6 lice per g host weight

The decline of infected fish in samples of larger smolts suggests mortality of juvenile pink salmon infested with more than 1.6lice/g over time (Bjørn and Finstad, 1998).



APPENDIX 2. STUDY AREA PINK SALMON SPAWNING POPULATION SIZES

The PFRCC examined the frequency of progeny spawning population sizes (year t +2) relative to their parental population size (year t) for Study Area Pink salmon (Johnston Strait and Strait of Georgia) by brood lines. The fixed two-year life cycle of Pink salmon separates their production into two independent lines (even and odd calendar years). The 'Extent of Reduction' (below) is the progeny spawning population size expressed relative to their parental population size. For example, in the Even-year Line, in 3 of 1000 (0.3%) observations (stream & years), a progeny line would return a spawning population size less than 1% of the parental population size. The total number of observations for this table is based on all streams in the Study Area and all years with spawning escapements recorded by Department of Fisheries field staff since 1970.

Extent of Reduction in Progeny Year relative to Parental Spawning Year (i.e., the Brood Year)	Odd Year Line of Study Area Pink Salmon, 1969–2001 years. (519 observations)	Even Year Line of Study Area Pink Salmon, 1970–2000 years.* (582 observations)
Return was < 1% of brood	0.4%	0.3%
Return was < 2.5% of brood	2.3%	1.2%
Return was <10% of brood	10.0%	7.6%
Return was <25% of brood	21.3%	18.1%
Return was <50% of brood	30.8%	29.8%
Return was < than brood	41.0%	48.2%
Return was ≥ than brood	59.0%	51.8%

** The most recent year 2002 was excluded from the historical data, 2002 returns will be compared to the historical distribution based on 1970–2000 observations.*

No prior probability distribution is assumed in this data summary. The frequency of changes from the parental population (both positive and negative) is simply accumulated into categories of the degree of change and their frequency of occurrence estimated by category. Categories used are presented on the horizontal axis of Figure A2.1.

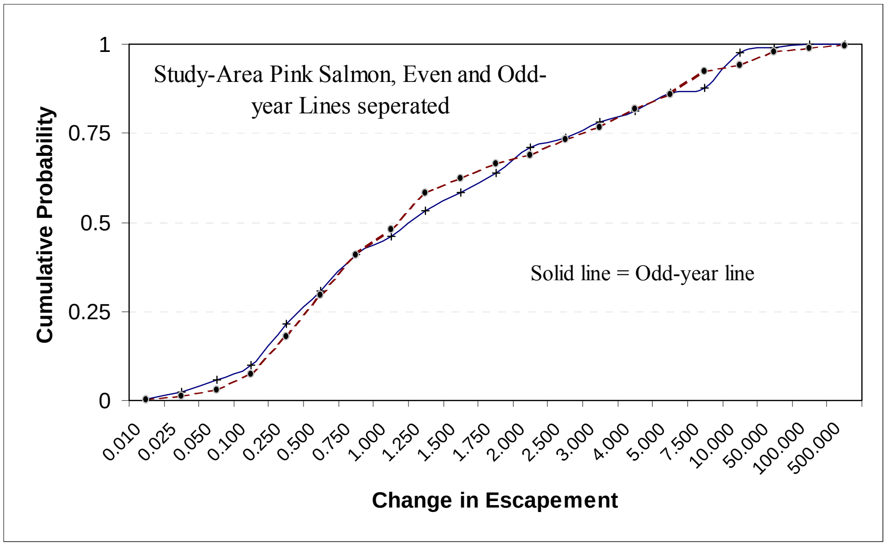
The observed changes between progeny and parental lines have similar frequency in the Even and Odd-year lines even though the size of spawning populations in these lines has changed significantly over the past 30 years. The recent PFRCC Annual Report (www.fish.bc.ca) documents this difference. The cumulative frequency of these changes between brood lines but within Even and Odd-year lines is presented in Figure A2.1.

During 2002, seven streams of 29 examined (24% of the streams) in the Study Area, had returns that were less than 2.5% of their parental population sizes. This frequency of reduction is much greater than expected based on the historical data for either Even or Odd-year lines as indicated from the above table. Reductions of the extent estimated in 2002 occurred less than 1.2% to 2.3% of the historical records by line. The 2002 surveys are based on many fewer observations than the historical record, but the occurrence of several serious reductions within one year and within a limited portion of the Study Area stocks, is unprecedented in the historical records for these pink salmon stocks.

Pink salmon production is reputed to be highly variable due to natural events. The natural variation in population size of Pink salmon is captured in these historical records with the exception that catch has not been allocated to individual streams. However, for the 2000 and 2002 comparison of escapement sizes there were no fisheries that could account for these changes in population size. However, the spawning stock sizes were at record high levels for two streams in 2002 (Kakweiken River and Glendale Creek). Extreme reductions were observed in these systems (0.6% and 2.1% respectively, 2002 compared to 2000 spawning population sizes), but these examples only account for two of the seven streams that demonstrated extreme reductions during 2002.

Appendix 2 Figure A2.1. Cumulative frequency of changes in spawning population sizes between the progeny (year t+2) and their parental year (year t)

All observations are grouped into categories (degree of change; values less than 1.0 indicate reductions from parental spawning year, and those greater than 1.0 indicate increased sizes) of change and are cumulative over the range. For example, ***any*** *reduction from the parental spawning population size (i.e., 'Change in Escapement' less than 1.000) would be expected to occur at slightly less than one half of the comparisons ('Cumulative Probability' of 0.5) during the past 30 years.*



APPENDIX 3. SEA LICE ON PINK SALMON JUVENILES OF THE BROUGHTON ARCHIPELAGO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