



THE UNIVERSITY OF BRITISH COLUMBIA

Science Forum

Sea lice

Review and Summary of Research Priorities

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Acknowledgements

This Science Forum was the first meeting of internationally recognised sea lice experts in Canada. The forum integrated local, national and international knowledge in sea lice and Pacific salmon biology. On behalf of the Forum's Steering committee, I am deeply grateful to all those scientists that participated in our forum on very short notice. The Science Forum would also not have been possible without the generous support and foresight of the Ministry of Agriculture, Food and Fisheries.

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Sea Lice Forum: Review and Summary of Research Priorities

Introduction

"Sea lice and their effects"

The copepod sea lice *Lepeophtheirus salmonis* and *Caligus elongatus* are the primary ectoparasites of farmed and wild salmonids. *L. salmonis* now is considered the most commercially limiting parasite in salmonid culture in northern Europe [8,9]. Sea lice feed on the mucus, skin, and blood of the host fish [2,9,22], and may debilitate or kill farmed [30,35] and wild salmonids [34,36]. Most work on the biology, pathogenicity and control of this parasite has focused on its impact on aquaculture and very little is known about the parasite in the wild [27]. The International Council for the Exploration of the Seas (ICES) Workshop on “Interactions between salmon lice and salmonids” (1997), identified several data deficiencies and research priorities, including: 1. The migratory routes and behaviour of wild post-smolts and older fish, 2. Post-smolt mortality at sea, following initial migration, 3. Sea lice dispersal and the distribution of the (larval, infective) planktonic stages, 4. The impact of farm management practices on sea lice on farmed and wild fish, and 5. Development of prophylactic treatments.

The salmon louse (*Lepeophtheirus salmonis* Krøyer), an ectoparasitic crustacean which is common on salmonids in the marine environment, represents one of the most serious pathogens of sea-farmed and wild Atlantic salmon (*Salmo salar*, [15], sea trout (*Salmo trutta*, [6,4] and Arctic charr (*Salvelinus alpinus*, [19]. Salmon lice also feed on the skin, mucus, and blood of fish, causing local oedema and haemorrhaging of the skin, seepage of blood, and osmoregulatory problems resulting in mortality [38]. This louse has been reported to infect wild species off the coasts of Canada [33], Ireland [7], Japan [26], Norway [15], and the United Kingdom [24].

It is clear that post-smolt salmon and sea trout are at their most vulnerable to stress during their first few weeks at sea, as they physiologically adapt to a saline environment. It is at this stage also that initial infestations of ectoparasites impact upon them and these undoubtedly will confer additional levels of stress on adapting fish.

The infective planktonic copepodid stage of *L. salmonis* attaches to the body and fin surfaces. Grazing of dermal tissue by vagile (so-called ‘mobile’) adult sea lice causes minor haemorrhages and skin erosion [2]. Because the epidermis is a physiological interface, ectoparasite infestation obviously may lead to osmoregulatory failure, as well as secondary infection by pathogens [1,34]. Parasites, by definition, place constraints on their hosts, which minimally concern their utilisation of nutrients and space provided by the host organism [31]. As a consequence, host species may evolve a variety of defence strategies, ranging from immunological responses to behavioural avoidance, which may themselves impose alterations in the life history of the host. Parasite-induced changes in an established life history will usually carry an associated fitness cost [17,32]. For a parasite such as *L. salmonis*, which is adapted to seawater, host migration to brackish or freshwater for extended

periods is fatal. Since fecundity increases allometrically with body size, sublethal levels of infestation may exert ecologically significant impacts on populations in a chronic, rather than acute, manner by compromising growth and reproductive potential.

Differences among post-smolts of salmonid species are likely to extend also to their physiological control systems and responses to stressors. Smolts are physiologically stressed in adapting to the environmental challenge of a saline medium; moreover, ectoparasite infestation during this period will be a significant additional stressful physiological challenge. A recent study [11] reported that attachment and survival of chalimus (post-larval) stages on the fins and body surface were significantly lower on Atlantic salmon than sea trout because of non-selective settlement and differential mortality. Furthermore, there may be a greater antibody response in Atlantic salmon to sea lice infestation as an immunological strategy to parasitic attack. Contrasting immunological responses are likely to be mediated by differences in the stress response to infestation between the two species, because stress and elevated cortisol concentrations can cause immunosuppression. Certainly, the obvious behavioural, ecological and demographic differences between these two species highlight the pitfalls of extrapolating findings based on research in Atlantic salmon to sea trout.

As few as 30 adult *L. salmonis* may cause significant osmoregulatory imbalance in plasma ion concentrations which are fatal to hatchery-reared Atlantic salmon and sea trout fully acclimated to seawater [12,28]. Furthermore, hatchery-reared sea trout smolts infested with high numbers of chalimus (post-infective lice) stages displayed high plasma levels of the stress hormone cortisol in advance of other indications of osmoregulatory imbalance [5]. In addition, prematurely returned wild sea trout often are emaciated and in osmoregulatory imbalance [4,34]. These are the only available (and limited) data on the impacts of sea lice infestations on smolt physiology and survival. Of particular relevance, therefore, is our need to understand the direct effects of this parasite on wild smolts at sea, and indirect effects after their return to freshwater, at what are likely to be sub-lethal levels of infestation. A comprehensive suite of well-established and state of the art physiological analyses of blood parameters, ionic fluxes, humoral and enzyme assays and tests of gill and skin epithelial integrity (SEM and TEM) will therefore be deployed in resolving these crucial questions.

Relatively low levels of sea lice infestation can result in perturbations in plasma electrolyte balance before physical damage to the smolt had occurred (unpubl. data). At smoltification, and during the period of adapting to seawater, smolt cortisol concentrations are temporarily elevated. In the present context it is therefore important to note that elevated cortisol concentrations have been reported to promote increased apoptosis (programmed cell death) in branchial epithelial cells in teleosts [37]. The increased additional stress of sea lice infestation may well have detrimental effects on osmoregulation due to cortisol-mediated effects on aging of gill cells at a stage before physical damage is evident.

"Wild/Farm Interactions"

Currently, there is a debate as to whether lice from mariculture facilities are contributing to a decrease in the survival of wild fish through increased risk to secondary infections, or these infections are a secondary attribute of a more complex problem, with little evidence to support either hypothesis [13]. Archival data of 'natural' sea lice loadings on returning wild adult salmonids prior to

the commencement of the salmon farming industry are lacking, hence the controversy as to the extent to which salmon aquaculture may contribute to this problem. Levels of lice infestation on mariculture and wild fish in the same near-shore waters are suggested to be consistently higher than on fish found offshore or upstream. However, the paucity of information on the prevalence and intensity of infestation among farmed salmon reported is still true today [30], making a comparison between farmed and wild lice infestation levels very difficult. For example, maricultured Atlantic salmon (*Salmo salar*) have been found to be heavily infested with lice (2 % of body covered), but this study did not include infestation numbers or a means to calculate them [21]. In another study, 2,000 lice were found on a single salmon, which likely is rare [8], but one report did find 305 lice on a single salmon, which they surmised had escaped from a mariculture facility [20]. Wild fish caught close to shore also are reported to have high levels of lice infestation. Estuarine Arctic charr (*Salvelinus alpinus*) caught in traps had a mean intensity of over 150 lice per fish [16]. Sea trout (*Salmo trutta*) released into estuarine waters with nearby fish farms also became infested with a median of 150 sea lice [3]. Another study found wild Atlantic salmon near Norway also were infected with lice, but at much lower levels than reared salmon [20]. They found long-line caught salmon had a lice prevalence of 99.2% and a mean intensity of 29.8. These fish were not in close proximity to shore-bound mariculture facilities. Lower intensity numbers ranging from 1 to 25, also have been reported for wild Atlantic salmon, sea trout, and all Pacific salmon with some lice prevalence well under 100% [7,25,33,38].

Levels of infestation may be highest inshore because of the proximity of wild fish to large mariculture facilities where sea lice generally are found in high concentration. Anadromous salmonids actually can be infected more than once as they leave the rivers to feed in the ocean and again travel upstream to overwinter or spawn. Infection during upstream travel is not thought to be as detrimental to the fish because the levels of lice have been reported to decrease due to their intolerance to low salinity [3,18,36]. There are conflicting reports as to the severity of louse infestation once in fresh water, however. One study found the majority of lice infecting Atlantic salmon were lost within 48 hours, and the few remaining attached lasted a maximum of only six days [24]. However, another study found the level of infestation on Arctic charr can remain above 50 lice per fish up to two weeks with exposure to fresh water [16]. These levels may be very detrimental to overwintering or spawning salmon. One study have shown as few as 30 salmon lice can cause osmoregulatory breakdown in Atlantic salmon once the lice reach the preadult stage [19]. Also, the same number of lice at the larval stages can significantly increase the cortisol levels of infected sea trout [5]. This increase in stress can cause immunosuppression leading to an increased susceptibility to secondary infection [14,23,29,38]. Currently, the perceived problem is both mariculture and wild salmon are being parasitised by lice at highly variable levels and these lice can continue to feed as the fish migrate into fresh water to overwinter or spawn.

Overall, several questions as to the risk and consequences of lice infestation on wild salmonids posed by aquaculture facilities remain unanswered. These include:

- what level of louse infestation pose a risk to the reproductive potential of salmonids?
- are downstream migrating smolts susceptible to increase risk of infestation from aquaculture facilities?
- what level of louse infestation affects the swimming performance of salmonids?

Studies conducted in the 1990s clearly showed that sea lice are considered a major factor limiting the production potential of wild and farmed Atlantic salmon and sea trout stocks. Measures adopted to reduce sea lice levels at aquaculture facilities remain controversial as well as the risk of infestation to wild stocks from increased production of farmed fish. The susceptibility of Pacific salmon to sea lice infestation, the role of fish farms in contributing to sea lice levels in wild Pacific salmon and the effectiveness of mitigative strategies to minimise sea lice infestation remains unknown. Evidence to date suggests that the amount of lice will increase as salmon production increases. Consequently, the present and future risk that sea lice pose to the productivity of salmon needs to be investigated. Identification of knowledge gaps and subsequent design of research studies to address these gaps are urgently required to minimise the risk of future anthropogenic impacts to wild salmon stocks.

Previous AquaNet (Network Centre of Excellence in Aquaculture) studies clearly demonstrated the effects of sea lice on swimming and reproductive performance in Atlantic salmon and sea trout and their susceptibility to sea lice during their respective downstream migrations. The role of aquaculture farms in contributing to sea lice infestation levels in wild stocks however still remains unknown. The incidence of sea lice is not limited to the East Coast of Canada and has recently been raised as a concern by regulatory agencies, First Nations and coastal communities as a limiting factor for increased aquacultural activity on the West Coast. Common to both coasts is the lack of information regarding the risk of sea lice from aquaculture facilities to the health and welfare of wild salmonid populations.

"the Science Forum's objectives"

The overall goal of the Science Forum was to integrate local, national and international knowledge and experience as related to sea lice and to develop short and long-term research objectives for the West Coast of British Columbia, particularly related to the Broughton Archipelago. Specifically, the objectives were:

- To review the biology of the sea louse and their host species and to review related management strategies
- Identify knowledge gaps
- Identify research required to address gaps and prioritise the research into short and long term action plans

The Science Forum recognised several overarching principles that would help frame the short and long-term research action plans for studies to be conducted on the West Coast. These included:

- Recognition of existing legal decisions
- Recognition of Aboriginal rights with respect to location of farms and species
- Involvement of First Nations in research and monitoring
- Incorporation of local/indigenous knowledge
- Need and evaluation of baseline data
- The requirement of a "**made in British Columbia**" approach

"the Forum's approach"

Our initial step was to invite national and international scientists whose work clearly designated them as leaders in the field of sea lice by their peers. Their knowledge and experience, along with local and indigenous knowledge helped frame the research required to address scientific gaps in sea lice biology and management in British Columbia. Scientists were assigned to one of several knowledge areas. These included:

1. *Biology of the Louse*
2. *Infestation Levels*
3. *Infestation Effects*
4. *Wild/Farm Interactions*
5. *Management Strategies*

Following the presentations, speakers and Forum attendees were assigned to one of several breakout groups. One of the invited speakers was assigned as Chair for each of the breakout groups. Each group was charged with the responsibility of formulating both short and long-term research requirements for the monitoring and management of sea lice. Particular emphasis was placed on addressing the short-term needs for the Broughton Archipelago. Suggested short and long term topics to be discussed included:

"short term (within the month)"

- Sampling procedures and protocols for wild and farmed fish
- Mitigative Strategies - fallowing periods, establishment of migration corridors

"long-term (over the next three years)"

- Establishment of sea lice triggers for treatment or mitigative strategy
- Determining the susceptibility of various Pacific salmon species to infestation levels
- Risk of infestation in wild and farmed fish
- Risk of sea lice transfer between wild/farm fish
- Evaluation of sea lice treatments (new and old), new approaches
- Evaluation of site selection criteria

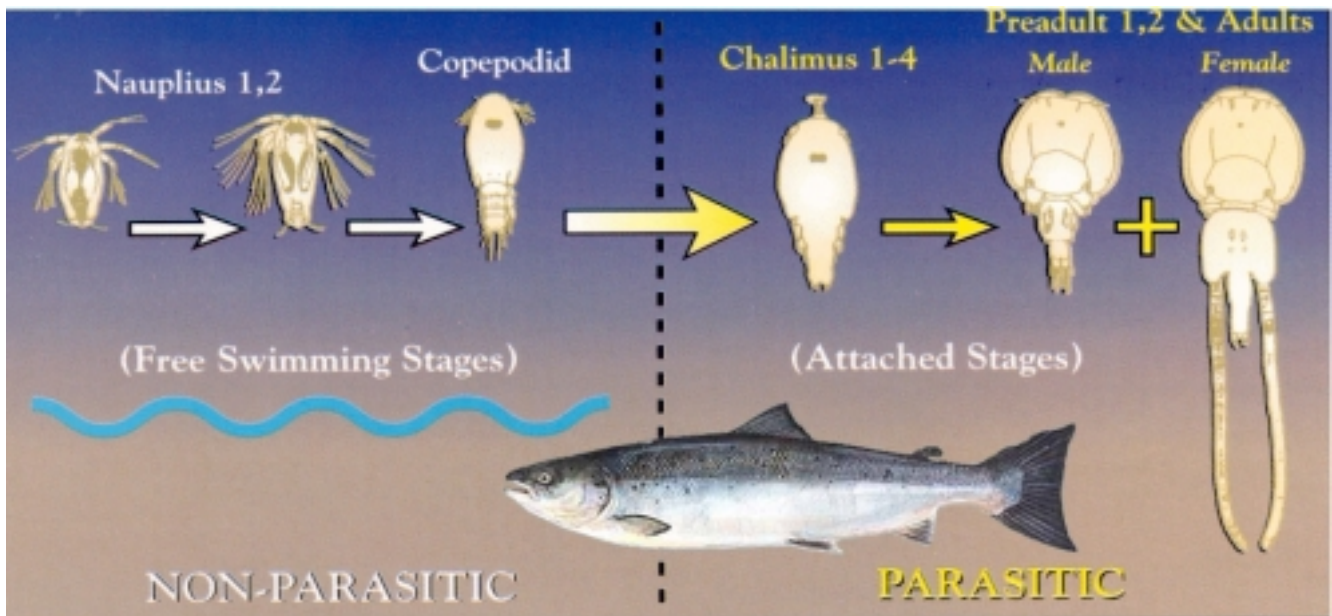
The integration of results from each breakout group was used to construct the short and long-term research action plans.

Research Area highlights

Biology of the Sea Louse

- Potentially 10 species of sea lice inhabit the West Coast
- Movement and distribution of free swimming stages likely related to ocean currents and flows
- Techniques and protocols to collect lice from smolt and post-smolts have been developed

Lepeophtheirus salmonis



Infestation Effects

- moderate levels of lice (0.13 lice/g fish) significantly lowered swim performance, altered cardiac output (especially heart rate), and upset osmo-regulatory balance
- high infestations (1.6 lice/g) impaired osmo-regulation, increased stress levels, decreased reproductive measures such as fecundity, and increased mortality in all three species (Atlantic salmon, sea trout, and Arctic charr), with greater effects on the latter two species.
- Downstream migrating smolts >10 cm can be tracked using telemetry to determine risk of sea lice infestations at various points along their respective migratory routes



Infestation Levels

- no apparent cause and effect relationship has been established between sea lice infection and wild fish stock abundance declines, and that there is likely a two way exchange of lice between farm and wild fish.
- sea lice are ubiquitous, infection rates are higher in bigger fish, resident salmon can perpetuate the infections of sea lice during the winter months, and that there was no clear cause and effect relationship between sea lice infection and fish farms as sea lice infections were found in areas without farms
- 86% of the pink salmon caught in the Broughton were infected with >1.6 lice/g, small fish were all infected, increases in size decreased infection, and that there appeared to be a spike in infection when sampling closer to fish farm
- response of sea lice to abiotic factors was determined, which, if combined with hydrological data could be used to develop a geographic model of sea lice dispersal and thus of potential infection zones

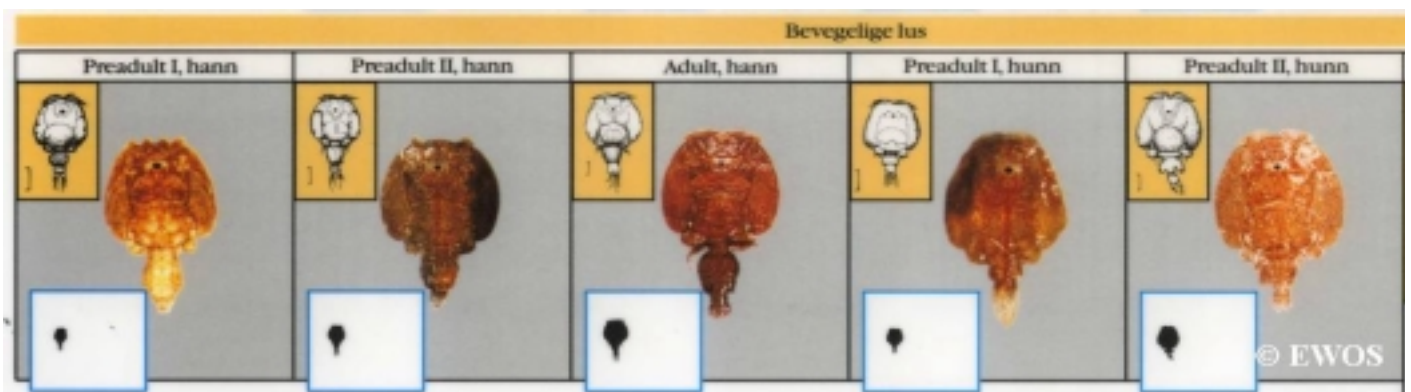
Wild/Farm Interactions

- high correlation exist in Norway between high infestation levels on free swimming fish in areas with farming activity than found in areas of low or no farming activity
- studies underlined the importance of accurate accounting of sea lice levels on both farmed and free swimming fish in Norway
- data were presented that demonstrated that correlation did not necessary equal causation

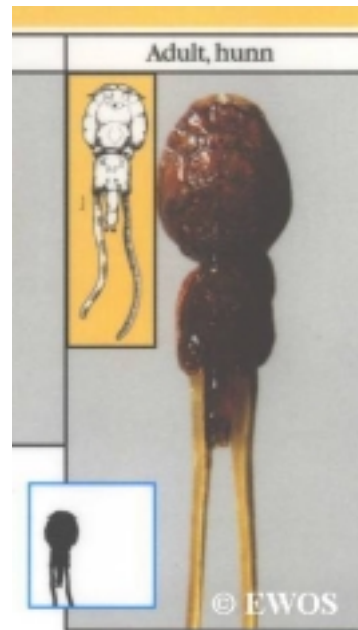
Management Strategies

- emphasised the importance of good co-operation between farms and regulator agencies, effective monitoring of wild and farm stocks and a diverse treatment regime
- no one treatment is completely effective, and that treatment options are extremely limited to in-feed treatments
- concern over the reliance on the one existing treatment and encouraged the approval of more treatments
- need for integrated pest management strategy and for increased numbers of sea lice treatments
- risk of sea lice developing resistance to chemotherapeutants
- outlined the existence of a fish health database for information storage and retrieval that could be adapted and expanded to include information on sea lice dispersal, infections, and treatment
- at sea temperature ≥ 4 °C the fish on fish farms are to be examined for salmon lice and recorded every 14 days in Norway
- Mandatory delousing is required when 0.5 adult female or more, or 5 or more adult female and mobile stages (in period 1.11 to 1.07; preadult and adult male) are recorded on average per fish per cage, and 2 adult female or more, or 10 or more adult female and mobile stages (in period 1.07 to 1.11) are recorded on average per fish per cage in northern Norway

Mobile stages



Adult female with egg strings



Results

Gaps in Scientific Knowledge - Environmental

All recognised scientific gaps are listed in Appendix 4. Scientific gaps were categorised as related to the environment, farming activities and wild fish stocks.

Scientific Gaps - Environment

- Treatment impact on non-target species and food chain in and outside areas of farming
- Identify migration routes of downstream migrating smolts
- Oceanographic modelling of currents and flows in and outside farm areas, year by year
- Ocean survival mortality factors, partitioning, variation of Pacific salmon
- Salinity in inlets, related to annual climate and hydrographic conditions
- Development of taxonomic keys for the various species of sea lice on the West Coast
- Susceptibility of Pacific salmon to lice and subsequent effects on swimming and reproductive performance
- Collate local and traditional knowledge into a database
- Identification of cause and effect for lice infestations between wild and farmed fish

Scientific Gaps - Farming Activities

- Evaluation of Prevention strategies
- Monitoring of lice in time and space

- Establishment of treatment triggers (*dynamic*)
- Evaluation of alternative treatments including availability
- Quicker regulatory approval of therapeutants
- Establishment of sampling and reporting protocols

Scientific Gaps - Wild Stocks

- Juvenile carrying capacity along migration routes
- Impacts of lice on wild pacific salmon/other species of concern
- Variation of lice in time and space
- Survival of lice after settlement on hosts
- Transport of lice to NE Pacific/SE Alaska
- Source of lice on wild fish? (ID by isotopes/DNA)
- Infection or infestation of non-salmonids
- Monitoring of fish health
- Dynamics of susceptibility

Recommendations

Recommended research studies required were divided into short and long-term needs. The short-term needs were viewed as particularly relevant to the Broughton Archipelago. The research actions/needs arose from the recognised research gaps and the Forum's overall arching principles.

Short term research actions/studies

- Meaningful consultation with First Nations
- Evaluation of "fallowing" as a mitigative strategy
- Establishment of a monitoring protocol for the out-migration of pink salmon smolts in the Broughton Archipelago, monitoring to include the enumeration/life stage/species of lice attached to smolts and a measure of fish health
- Evaluation and establishment of treatment protocols (to include the review and applicability of international protocols)
- Development of a taxonomic key for sea lice on the West Coast
- Establishment of communication protocols for the exchange of information (i.e. internet)

Long-term research actions/studies

- Monitoring of pink salmon populations (life history traits) in the Broughton Archipelago
- Determination of risk to out-migrating salmon smolts to sea lice infestation
- Determination of risk to swimming and reproductive performance of Pacific salmon

- Establishment of a cause and effect relationship for sea lice infestation between wild and farmed fish
- Risk to non-target fish species of sea lice infestations
- Evaluation of effects from treatments to non-target species

Summary

The Science Forum represented the first international meeting on the biology and management of sea lice outside Europe. The Forum integrated local, national and international knowledge on sea lice to address the unique environmental and socio-economic characteristics of British Columbia's West Coast. The meeting successfully identify scientific knowledge gaps in the biology of the louse, infestation levels and subsequent effects, wild/farm interactions and management strategies. The Forum clearly underlined the need for science based studies in both the short and long-term to address the risk posed by sea lice to both wild and farmed fish stocks.

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Appendix 1. Steering Committee Members

Bastien, Yves OCAD, Ottawa
Castledine, Al MAFF
Finstad, Bengt NINA, Norway
Jones, Simon DFO, PBS
Kent, Micheal OSC
Lash, Jennifer CAAR
McKinley, Scott (Chair) UBC
Morrison, Diane Marine Harvest Canada
Weinstein, Marty First Nations Representative

Appendix 2. List of Speakers and Topics

Biology of the Louse

1. Dario Stucchi, DFO, “*Oceanography and Circulation Models of the Broughton Region*”
2. Stewart Johnson, NRC, “*A review of the biology of sea lice species found in British Columbia waters*”
3. Jens Christian Holst, IMR Norway, “*Methods of live sampling of salmonids at sea*”
4. Blair Holtby, DFO, “*Returns of pink salmon to mainland inlets of British Columbia in 2002*”

Infestation Effects

5. Jens Christian Holst, IMR Norway, “*Relative differences in susceptibility to sea lice infections in estuaries between Atlantic and Pacific salmonids, in particular Atlantic salmon, European trout and Pink salmon*”
6. Scott McKinley, UBC, “*Effects of sea lice infestation levels on swimming performance in Atlantic salmon*”
7. Paal Arne Bjorn, Fisheries Institute, Norway, “*The Physiological and Ecological Effects of Salmon Lice Infections on Anadromous Salmonids*”
8. Jens Christian Holst, IMR Norway, “*Estimates of mortality of seaward migrating postsmolts of Atlantic salmon due to sea lice infestation in Norway*”
9. Eva Thorstad, NINA, Norway, “*Risk of infestation in sea trout and Atlantic salmon smolts*”

Infestation Levels

10. Alasdair McVicar, DFO, “*The international perspective on interactions of salmon lice infections in farmed and wild fish*”
11. Marc Trudel, DFO, “*Sea lice infection in Pacific salmon: results from the 2002 High Seas Salmon survey*”
12. Alexandra Morton, CAAR, “*Infestation of sea louse *Lepeophtheirus salmonis* (Kroyer) on juvenile pink *Oncorhynchus gorbuscha* and chum salmon *Oncorhynchus keta* in the nearshore marine environment*”
13. Karin Boxaspen, IMR Norway, “*Infection success of salmon lice related to temperature and it’s implication for infestation levels and regional salmon size of salmon production areas in Norway*”
14. Dick Beamish, DFO, “*Preliminary approaches to assess levels of sea lice on juvenile salmon in BC*”

Wild/Farm Interactions

15. Peter Heuch, NVI Oslo, “*Relationships between salmon lice on wild and farmed salmonids: A review of population dynamics, management measures and effects on wild salmonid fish stocks in Norway*” Part A.
16. Bengt Finstad, NINA Norway, “*Relationships between salmon lice on wild and farmed salmonids: A review of population dynamics, management measures and effects on wild salmonid fish stocks in Norway*” Part B.
17. Crawford Revie, U. of Strathclyde, Scotland, “*Epidemiological risk factors (environmental and management) affecting levels of sea lice (*Lepeophtheirus salmonis*) infestation on farmed Atlantic salmon in Scotland*”
18. Michael Kent, OSU, USA, “*Understanding transmission of pathogens between wild fish and farmed fish: science versus emotions*”

Management Strategies

19. Dave Jackson, Department of Marine Institute, Ireland, “*Sea lice monitoring and control on Irish salmon farms*”
20. Larry Hammell, UPEI, “*Sea lice management in Eastern Canada*”
21. Bill Heard, NOAA, USA, “*Elements of Pink Salmon Population Dynamics*”
22. Martin Iversen, Nordland Research Institute, Norway, “*Norwegian regulation in the treatment of sea lice*”
23. John Burka, UPEI, “*Studies on sea lice resistance to chemotheraputants (SEARCH): An international collaborative program*”
24. Murray Isman, UBC, “*Pest management and control procedures*”
25. Grace Karreman, “*Sea Lice Monitoring: a Proposed Solution for Information Management*”

Appendix 3. List of Abstracts

Oceanography And Circulation Models Of The Broughton Region

Dario Stucchi
Institute of Ocean Sciences
Fisheries and Oceans Canada
Sidney, B.C.

Off the BC mainland coast and east of Queen Charlotte Strait lies a scattered group of islands known as the Broughton Archipelago. Inland from the Broughton Archipelago, Kingcome and Knight Inlets penetrate deeply into the coastal mountain range. The oceanography of Queen Charlotte Strait and that of the adjacent high run-off fjords influences the large-scale water property variations and circulation through the archipelago. Tidal mixing is a key oceanographic process in Johnstone Strait and Queen Charlotte Strait. In winter, the waters of Queen Charlotte Strait are well mixed or weakly stratified, while in summer, increased run-off and solar heating result in a more stratified water mass. A striking feature of the climatology is the clear seasonal signal in the dissolved oxygen concentrations; lowest from late summer to early fall, and highest during the winter months. In Knight Inlet, the large peak in freshwater discharge caused by the summer melt of the interior snow pack is a major factor controlling stratification and circulation. The upper water column of the fjord is highly stratified in summer and only weakly stratified during the winter run-off minimum. The waters of the Broughton Archipelago are in the transition zone between the tidally mixed waters of Queen Charlotte Strait and the stratified waters of the adjacent high run-off fjords. Winter observations show well mixed conditions in the main passages (Fife Sound, Tribune Channel and Wells Passage) through the archipelago. However, in Kingcome Inlet the profiles are distinctly stratified reflecting the effects of the blocking sills and increased freshwater discharge in these more inland locations. The transition from well mixed to stratified profiles occurs abruptly across the sills separating Kingcome Inlet from Queen Charlotte Strait.

Over the last year, we have been developing numerical circulation models and undertaking a program of field observations to better understand the general circulation in this region and more specifically the circulation through the many passages through the Broughton Archipelago. A 2-dimensional depth-averaged tidal circulation model is nearing completion. The tidal model is presently being tested and compared to observations, and tools to display and extract information from the model results are also in development. Preliminary work has begun on a 3-dimensional model that will take into account the estuarine and wind driven components of the circulation.

A Review Of The Biology And Ecology Of Sea Lice Species From British Columbian Waters

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Sea lice are marine ectoparasitic copepods that belong to the family Caligidae. When present in high numbers sea lice can cause serious disease in both wild and farmed fish. Three species of sea lice have been reported on cultured and wild salmonids in the marine waters off British Columbia. These species include *Caligus clemensi*, *Lepeophtheirus cuneifer* and the salmon louse, *Lepeophtheirus salmonis*. In this seminar I will review what is known about the biology and ecology of *C. clemensi* and *L. salmonis*, as they are the species that are most commonly reported from salmonids in BC. Emphasis will be placed on aspects of their biology and ecology that will be important to consider during the planned discussion of research priorities and methods to potentially reduce their impact on wild salmonids.

Methods For Live Trawl Sampling Of Salmonids At Sea; The Ocean Fish Lift (OFL) And Salmon Trawl (ST)

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To obtain better quality of salmon caught in trawl and to optimise ship time in salmon trawl surveys a concept consisting of a live catching trawl device (OFL) and a trawl designed to maximize salmon catches (ST) has been developed.

A prototype of the OFL was developed in cooperation between the Marine Lab, Aberdeen and the IMR, Norway, in 1997 and tested the same year. The concept was further developed by the IMR in 1998 and onwards. Through a series of modifications the system today catches salmon at sea with varying but acceptable quality. A large portion of the fishes is caught live and has been subject to lab- and tagging experiments. The development of the OFL is still going on.

The ST was developed in cooperation between the IMR and Åkra Trålbøteri, Norway, in order to obtain an efficient way of sampling salmon at sea. Given the high prices of shiptime, efficient Dyneema (Spectra) trawls specifically designed to catch salmon is a good investment for optimising sea time.

Institutions in Norway, Ireland, Canada, USA, the Faeroe Isles, New Zealand, and Iceland currently use the OFL/ST concept. The system has been fitted to vessels from 200 HP up to 3400 HP with effective trawl widths up to 60 metres.

Returns Of Pink Salmon To The Mainland Inlets Of British Columbia In 2002

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Pink salmon (*Oncorhynchus gorbuscha*) are anadromous Pacific salmon. They have the simplest life history of the Pacific salmon and spend most of their two-year lifespan in the ocean. Eggs are laid in the lower reaches of coastal streams in the fall. The smolts enter the ocean soon after emerging from the gravel. The young fish migrate to the open Pacific over their first summer and occupy near-shore surface waters. Pink salmon are planktivorous throughout their lives. Pink salmon adults are enumerated in approximately 59 systems in the mainland inlets of British Columbia and adjacent areas of NE Vancouver Island (between 49.5°N to 51°N latitude and 124.5°W to 128°W longitude). In 2002 the number of spawning adults (called the “escapement”), recruitment (the total number of adults produced by the spawners two years previous) and especially recruits per spawner were depressed and in some cases severely depressed in most of the streams of Kingcome, Bond and Knight Inlets as well as the adjacent portions of Vancouver Island bordering Johnstone Strait. Streams to the east, west and south were not similarly affected even though many of those streams and especially those in the Loughborough Inlet to Bute Inlet sub-area are very similar in most respects to those affected. The analyses presented indicate that this recruitment failure was unlikely to have been caused by any of the usual factors that are thought to produce the inherently high variability in pink salmon abundance. It is suggested that the 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.

A First Attempt To Assess Relative Difference In Susceptibility To Sea Lice Infections In Estuaries Between Atlantic And Pacific Salmonids, In Particular Atlantic Salmon, Sea Trout And Pink Salmon

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While the Atlantic salmon postsmolt performs a relative rapid migration from its native river through the estuaries, lochs, and fjordic systems into the high seas, the sea trout and the Pacific pink salmon spends the summer following sea migration in the estuarine systems. With regard to sea lice infections sea trout have been shown to perform pre mature migrations into rivers in areas where heavy sea lice infections occur. In some areas the sea trout stocks may also reside in low salinity estuarine waters unsuitable for the sea lice, most typically inner fjordic areas. These behavioural traits probably lower the mean potential population effects of sea lice in sea trout stocks. Such behaviour has not been reported in pink salmon (to my knowledge).

Comparing the potential susceptibility to stock effects due to sea lice infections in these three species Atlantic salmon appears to be the potentially least affected stock given its short presence in the coastal areas affected by the salmonids farming. In many cases it also appears that this species go to sea during or before the period of maximum sea lice infection, thus avoiding the period of highest infection pressure. Due to its tendency to perform pre mature returns to fresh waters and ability to maintain populations in low salinity estuaries the sea trout is regarded the potentially second least affected species. Given its progressively seaward migration during the first summer at sea, with a potentially long period spent in the coastal zone and without the ability to perform premature returns, the pink salmon at this stage is regarded to be the potentially most susceptible species to sea lice infections. Its small size in the early marine phase may further indicate that the population effects may be more severe than in Atlantic salmon and Sea trout.

Simple theoretical models should be worked out to further elucidate these differences in potential susceptibility between these three species. It is recommended that specialists in all three species sit together to evaluate these thoughts further.

Physiological Impact Of Sea Lice On Swimming Performance Of Atlantic Salmon

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The number of sea lice required to compromise cardiac output and swimming ability of Atlantic salmon was determined. Fish were infected with two levels of lice (0.13 ± 0.02 lice g^{-1} ; 0.02 ± 0.00 lice g^{-1}). Once lice became adults, the ventral aorta of each fish was fitted with a Doppler cuff to measure cardiac output (\dot{Q}), heart rate (f_H) and stroke volume (V_s) during swim testing. Critical swimming speeds (U_{crit}) of fish with higher lice numbers (2.1 ± 0.1 bl s^{-1}) were significantly lower ($P < 0.05$) than fish with lower lice (2.4 ± 0.1 bl s^{-1}) and controls (2.6 ± 0.1 bl s^{-1}). After swim testing, chloride levels in fish with higher lice (184.4 ± 11.3 mmol l^{-1}) increased significantly (54 %) from rest and significantly were higher than fish with fewer lice (142.0 ± 3.7 mmol l^{-1}) or control fish (159.5 ± 3.5 mmol l^{-1}). The f_H of fish with more lice was 9 % slower than the other two groups at U_{crit} . This decrease resulted in \dot{Q} not increasing from resting levels. Sub-lethal infection by salmon lice compromises the overall fitness of Atlantic salmon. The level of lice infection used in the present study was lower than previously has been reported to be detrimental to wild salmon.

The Physiological And Ecological Effects Of Salmon Lice Infections On Anadromous Salmonids

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A series of laboratory studies have revealed the effect of salmon lice on host physiology, and the number of lice required to cause mortality has been estimated. These studies show that major physiological disturbances occur when the lice develop from the sessile chalimus 4 stage to the mobile first pre adult stage. Recent work from Canada support this conclusion, and demonstrate high levels of cortisol and glucose, reduced osmoregulatory ability and reduced non-specific immunity in the host after this molt. Sub lethal effects have also been recorded. In this case, the lice do not kill the host directly, but reduce growth and swimming performance, impair immune defenses and, hence, reduce likelihood of host survival. Physiological effects include increased blood cortisol concentration immediately after infection with copepodids, and damaged skin and gill epithelium and structural changes in chloride cells on infection with low numbers of adult lice. Recent research on Arctic charr has shown impacts on host reproduction: salmon lice infections may decrease the number of reproducing fish, delay maturation and reduce fecundity.

Field investigations support the above results. Negative correlations were found between the number of preadult and adult salmon lice and host plasma chloride levels on prematurely returned Arctic charr and sea trout in fresh water. In seawater, a positive correlation between the total number of lice, plasma cortisol and plasma chloride in sea trout has been observed. In summary, low lice numbers may give systemic negative effects, and severe osmoregulatory problems have been found on salmon louse hosts with heavy infections.

It has been estimated that wild salmon smolts would die from an infection of c.11 salmon lice. This threshold was also found in experimental work on naturally infected salmon smolts. Further support for this level comes from post-smolt monitoring in the North Sea, where no fish carrying more than 10 lice have been found. There is, however, still a need to scientifically determine the lice burden which has negligible physiological effects on hosts.

Mortality Of Seaward Migrating Postsmolt Of Atlantic Salmon Due To Salmon Lice Infection Norwegian Salmon Stocks

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Since the early 1990's premature returns due to heavy salmon lice infections have been observed in Norwegian sea trout stocks. Following these observations it was hypothesized that the salmon lice could cause serious problems and mortality also in seaward migrating postsmolts of salmon. However, due to the direct migration into the high seas of this species, evidence was hard to secure. In 1998 the Institute of Marine Research, Bergen, Norway in cooperation with the University of Bergen initiated fjordic trawl surveys aiming at estimating salmon lice infection and mortality in seaward migrating postsmolts of western Norwegian salmon stocks. Through the development of a live catching trawl device (Holst and McDonald, 2000), the Ocean-Fish-Lift, it has been possible to secure live samples of postsmolt salmon with its scales and salmon lice infection intact. Fjordic trawling has been carried out yearly during the period 1998-2002, the numbers of fjords sampled varying somewhat between the years. Sampling of postsmolts has also taken place in the open ocean later in the season when the salmon lice have grown to its most aggressive stages and mortality due to salmon lice infection have more or less ceased. It has also been possible to catch live postsmolts infected with sea lice the fjords and to run a controlled experiment to estimate mortal level of salmon lice infection on wild salmon postsmolts.

The mean infection levels of copepodits and chalimus stages on seaward migrating postsmolts in western Norway have been observed to vary from 0 to 104 per fish between years and fjords. The hydrographic features of the specific fjord and year appears to be a major factor governing the infection level, with much freshwater being unfavourable for the sea lice. There has also been signs of a general decreasing trend in infection level, possibly related to the efforts by the fish farming industry to lower its mean level of salmon lice on its fish. It is, however, premature to conclude on this matter and a longer time series is necessary for a conclusion. It is also too early to evaluate the limit set on the numbers of salmon lice allowed per farmed fish set by the Veterinary authorities. At present there are signs that the limit at 0.5 adult females are too high in densely farmed and narrow fjords.

The controlled experiment suggested a mortal level at 11 adult salmon lice on wild postsmolts. This number is in close accordance with the oceanic observations, where none of several thousand postsmolts taken in the Norwegian Sea during a period of 10 years (Holm et al., 200) have been observed to carry more than 10 adult salmon lice in July, after the fish mortality has ceased. Oceanic caught fish with close to 10 adult salmon lice are observed to be in a bad condition with almost no growth since sea entrance and typical haemoglobin levels below 20. Many of these fishes appear to be in a state where their chances of survival are small.

Based on the observed infection levels in the fjords and a conservative mortal limit at 15 adult salmon lice, estimates varying from 0% up to 95% mortality between years and fjords of western Norwegian postsmolts of salmon due to salmon lice infection have been presented during the period 1998-2002. In general mortality due to salmon lice infection have been observed to be a major factor regulating stock size in many western Norwegian salmon stocks in all these year except in 2002 when conditions improved.

Although the reported mean numbers of adult females in fish farms in the studied area is down towards the allowed level at 0.5 per fish in the spring, salmonids populations still appears to be negatively affected by salmon lice in many stocks in western Norway. At some stage the present Veterinary regulation on salmon lice in fish farms should be evaluated as to whether it is acceptable for securing a sustainable development in local salmon and sea trout stocks. As it seems unrealistic that the salmon lice levels in the fish farms will be further lowered in the near future, additional measures for critically affected rivers could be to treat the running wild smolts with a protective chemical against salmon lice infection or towing wild caught smolts out through the salmon lice belt into open waters. Such experiments are currently carried out on the Norwegian west coast.

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Smolt Migration And Salmon Lice Infection On Atlantic Salmon And Sea Trout In A Norwegian Fjord System

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The salmon lice (*Lepeophtheirus salmonis* Krøyer), an ectoparasitic crustacean commonly found on salmonids in the marine environment, represents one of the most serious pathogens of sea-farmed and wild Atlantic salmon (*Salmo salar* L.). Salmon lice epidemics on farmed fish have chronologically followed the pattern of the salmon aquaculture industry development. Similar epizootics have occurred subsequently on wild salmonids, especially sea trout (*Salmo trutta* L.), in all countries developing a major salmon aquaculture industry. Recent attempts by the aquaculture industry to reduce sea lice levels in the fjords do show promise but the risk of infestation to migrating smolts still needs to be determined.

In the present project we initiated telemetry studies to analyse the progression through fjord areas for Atlantic salmon smolts on their downstream migration from river mouth to the ocean in the following fjord systems Eresfjord, Langfjord and Romsdalsfjord in Middle Norway. In addition, we recorded time spent in fjord and inner coastal areas for sea trout.

So far the results from the preliminary analyses showed that Atlantic salmon migrated through the whole fjord system and were recorded even at the outermost monitoring station 70 km from the river mouth. Estimated time and swim speed of smolts to reach this point was 85 hours and 0.79 km/h, respectively. Sea trout smolts were not recorded at this point because they seemed to stay in the inner fjords. Estimated time and swim speed of sea trout smolts monitored 40 km from the river mouth were 242 hours and 0.16 km/h, respectively. These data will be connected to the hydrological conditions to map the migratory pattern of the smolts. The data will contribute to the development of site selection criteria by identifying sites that will minimise the risk of infestation for wild smolts.

The International Perspective On Interactions Of Salmon Lice Infections In Farmed And Wild Fish

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Salmon lice *Lepeophtheirus salmonis* have a natural circumpolar distribution in the northern hemisphere in wild salmonids, which are the initial source of infection to farms. The effect of lice from farms on wild salmonid populations has become the subject of controversy in several countries. Unfortunately, lack of historic data prevents determination of lice levels in the wild prior to establishment of fish farming. Although correlations have been found, cause and effect relationships have not been established. These correlations have become the source of extreme polarised views in both the scientific and non-scientific communities, with the same information being interpreted in different ways. It is recognised that variations in both the size of fish stocks and in the level of fish diseases are complex and multifactorial. Approaches taken in Europe to lice management in salmon farms are related to the current situation in British Columbia, but should be treated with caution because of the differences between these areas. The principles of a risk assessment approach need to be used to properly determine real hazard and appropriate management measures to address the objective of protecting the stock of wild salmonids.

Sea Lice Infection On Pacific Salmon: Results From The 2002 High Seas Salmon Surveys

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There is a growing concern in British Columbia that sea lice (*Lepeophtheirus salmonis*) are transmitted from salmon farms to wild stocks of Pacific salmon and could contribute to the decline of wild salmon stocks. This risk could be exacerbated with the anticipated expansion of the salmon aquaculture industry in British Columbia. To evaluate the potential impacts of sea lice associated with salmon farms, it is necessary to determine the species composition and background levels of sea lice infection on salmon, as natural epizootics of sea lice have occurred on wild salmon prior to the establishment of salmon farms both in the Atlantic and Pacific Oceans. In this study, we report spatio-temporal patterns of sea lice infection on Pacific salmon collected in 2002 with a surface trawl off British Columbia and Alaska. The prevalence of sea lice infection was generally higher in adult salmon, though sea lice infection rarely exceeded 4 lice per fish on either juvenile and adult salmon. The mean abundance of sea lice was generally below 0.5 lice per fish. There was no consistent pattern in sea lice infection with either space and time. Although sea lice counts were probably underestimated in this study due to scale loss, these data can be used to provide an initial reference for comparing other studies that use the same fishing gear.

Infestation Of The Sea Louse *Lepeophtheirus Salmonis* (Krøyer) On Juvenile Pink *Oncorhynchus Gorbuscha* And Chum Salmon *Oncorhynchus Keta* In The Nearshore Marine Environment

Alexandra B. Morton, Rob Williams, Richard Routledge, Corey Peet, and Aleria Ladwig

Sea louse (*Lepeophtheirus salmonis*) infestation was examined on 2,800 juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon in the nearshore marine environment of the Broughton Archipelago in 2001 and at five locations on the B.C. coast including the Broughton Archipelago in 2002. The range of sites sampled included active salmon farms, smolt farms, fallow farms, distances several km from farms and distances 100's of km from farms. There were approximately ten times more lice on juvenile wild salmon near salmon farms, and 3 times more lice near smolt farms, than on wild juvenile salmon distant from salmon farms. Chum and pink salmon were equally infected. Copepodid and chalimus stage lice dominated the population throughout the study. The percentage of fish sampled near salmon farms infected with more than 1.6lice/g host weight ranged from 81% to 94% between years.

Infection Success Of Salmon Lice Related To Temperature Infection Levels And Implications For Regional Size Of Salmon Production Areas

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The development rate for salmon lice larvae is highly temperature-dependent. Hence, the time from hatching of nauplii to an infectious copepodid will vary with the natural cycles in the sea and the copepodids life span is prolonged at lower temperatures. This has implications for dispersal of larvae in the environment and the subsequent decision of what is the sensible regional size of salmon farming areas.

The infection success of salmon lice as a function of copepodid age have been studied in controlled systems at high and low temperatures. Newly hatched salmon lice were collected every day from a hatching system and placed in holding units. Copepodid groups of specific and different age were used to infect salmon in a temperature controlled system and the successful moult to chalimus recorded. The salmon lice were as expected infectious for a longer time at lower temperature.

The Institute of Marine Research is working towards a numerical hydrodynamic model to visualise dispersal of larvae using the results described above. Examples will be given.

Preliminary Approaches To Assess The Impact Of Sea Lice On The Population Levels Of Pacific Salmon Stocks

R.J. Beamish and R.M. Sweeting

In 2001, DFO personnel carried out preliminary studies of sea lice levels on juvenile Pacific salmon and their impacts on fish health. As with most research, some preliminary work is needed to provide a focus for more detailed examinations. Our initial studies indicated that we could carry out long-term research to monitor sea lice levels on juvenile Pacific salmon and to begin to develop methods to assess the impact on recruitment of the various species of Pacific salmon.

Relationships Between Salmon Lice On Wild And Farmed Salmonids: A Review Of Population Dynamics, Management Measures And Effects On Wild Salmonid Fish Stocks In Norway. Part A.

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Norway is home to the largest populations of Atlantic salmon (*Salmo salar* L.), and the largest salmon-farming industry in the world. Salmon lice (*Lepeophtheirus salmonis* Krøyer) emerged as a problem soon after establishment of the industry in the 1970's. This parasitic copepod has been blamed for the collapse of sea trout (*Salmo trutta* L.) stocks in several countries, and is also perceived as a serious threat to Atlantic salmon smolts migrating through fjords and coastal areas in spring. The National Action Plan Against Salmon Lice on Salmonids (NA) was implemented in 1997 in Norway. Drawn up by the Animal Health Authority (AHA), fish health personnel and fish farmers, this was a consensus tool to reduce the impact of lice from farmed fish. Important measures in the NA were legal limits for the maximum mean number of lice per farmed fish, strategic regional treatments against lice, and compulsory reporting of lice numbers to the AHA. This review examines the implementation of the NA, and attempts to evaluate the success of the actions taken in terms of the lice loads found on wild salmonid stocks in 1998-2002.

Relationships Between Salmon Lice On Wild And Farmed Salmonids: A Review Of Population Dynamics, Management Measures And Effects On Wild Salmonid Fish Stocks In Norway. Part B.

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Effects of salmon lice on populations of sea trout and Arctic charr

If the proportion of fish carrying lethal levels of a parasite is known, population consequences of the parasite may be estimated. In the case of salmon lice, the damaging and lethal levels found in physiological studies should be combined with field data on wild salmonid infection. In the river the lice die and mobile lice fall off, and the fish reestablishes its physiological balance. Thus, catches of prematurely returned fish will not alone provide information of the consequences for fish remaining in salt water. A long-term study from the Vik watershed in Vesterålen, Northern Norway, shows that sea trout and Arctic charr in areas with intensive fish farming activity can be heavily infected with salmon lice. In 1997 the sea trout in the Vikbotten estuary had a mean intensity of 100-200 lice larvae on samplings in June-July, and fish with severe infections returned prematurely to the river. Such fish suffered from stress and physiological imbalance, and it was estimated that 30–50% of the smolts in the area would die or be greatly disadvantaged by their infections. In a nearby “control” area devoid of salmon farms, there was no premature return of sea trout. Monitoring in other dense salmon farming regions, especially in the south west and middle portions of Norway, similarly show premature return of heavily lice-infected fish to rivers. Taken together, these results suggest that this situation may be widespread in farming regions.

Long-term effects on wild populations of sea trout and Arctic charr are still uncertain, and it is not known whether the observed salmon louse epizootics may regulate host population size. The population dynamics of these two fish species are complex, as both anadromous and freshwater resident groups live within the same rivers. Population reductions may therefore be due to many other factors, both in fresh and salt water. Post-smolt feeding and growth is for instance dependent on local prey abundance and migration, giving high variability within river and between years. This underscores the importance of long-term studies of population variations.

Mortality as a consequence of lice may be additive or compensatory. To investigate this aspect, individually Carlin-tagged salmon and sea trout smolts have been protected against lice by an in-feed medication or bath treatment, and released in the vicinity of their native river. The substance protects the fish for several weeks, and provided it does not interfere with the fish in other ways, these experiments may provide estimates of population effects of lice. Data from Agdenes (Sør-Trøndelag County) and Daleelva (Hordaland County) show that in years with high salmon louse infection pressure, the returns of protected fish have been higher than returns of unprotected control groups. This suggests that lice mortality is additive, but more thorough experiments should be performed to validate these results.

Effects of salmon lice on running Atlantic salmon post-smolts

Results show large variations in salmon louse prevalence and mean intensity between years and between fjords. From zero to more than 100 lice per fish have been observed, giving mortality estimates from zero to over 90% of fish in the run. Sentinel cages have been used yearly since 2000 in some fjords. This method provides a relative measure of the infection pressure in a fjord, but systematic experiments to intercalibrate this with trawling have not yet been carried out. However, preliminary results indicate a relatively good correlation between infection level on the trawled fish and fish kept in sentinel pens in the same general area. These methods will be important tools to assess the suitability and effect of salmon louse limits in the future.

In conclusion, a significant amount of data now show high salmon louse infection levels in populations of sea trout, Arctic charr and Atlantic salmon, and several studies have predicted important negative effects on fish populations. Long-term field experiments and monitoring are required to assess the regulatory effect of salmon lice in these populations, and to estimate a “sustainable” infection pressure.

Epidemiological Risk Factors (Environmental And Management) Affecting Levels Of Sea Lice Infestation On Farmed Atlantic Salmon In Scotland

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This presentation provides an overview of the approach taken on a large UK government funded project (ENV12) to look for factors having an impact on the epidemiology of sea lice on commercial salmon farms in Scotland over the period 1996-2001. The findings were based on the compilation of an extensive database of sea lice recordings from over 40 farms and was undertaken in collaboration with an industrial partner. The investigation consisted of a systematic two-stage approach. In the first stage, experienced health managers from various coastal regions were used as an expert panel to identify a range of potentially relevant management and environmental factors suspected to have an effect on sea lice populations. In the second stage, the data pertaining to each of the factors were extracted from the database for statistical investigation and rigorous analyses undertaken using correlation and general linear regression models for confirmatory evidence of the role of each factor individually and in combination. These analyses led to a range of models relating mean mobile abundance to key environmental and management factors for each of the latter three six-month periods in a two-year production cycle.

From over 20 factors identified as being worthy of investigation by the expert panel, only a small number were subsequently found to be important. The models developed and the specific findings for the mobile stages of *L. salmonis* on Scottish sites will be presented. The results provide an insight into the epidemiological picture of infestation patterns on Scottish sites and identify type of treatment, level of treatment, cage volume, current speed, loch flushing time and sea lice levels in the preceding period to be key explanatory factors. Other factors cited in the literature as being possible correlates of risk, such as water temperature, stocking density and the presence of bad neighbours, were not found to be important. Despite evidence of an association between mobile abundance and certain key factors the models indicated that these factors could only explain at most 72% of the variation in mobile abundance and thus much of the variation in sea lice burden remains unexplained.

Interactions Between Infectious Diseases Of Wild And Farmed Fishes: Establishing Cause And Effect

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Two concerns associated with the development of aquaculture are the risk of importation and establishment of exotic pathogens, and amplification and transmission of indigenous pathogens. To date no exotic pathogens have been found in Atlantic salmon reared in British Columbia. There are many examples of transmission of disease from wild to farmed fishes. However, verification of spread of indigenous pathogens in farmed fish to wild fish, and subsequent disease in the latter, is difficult because sound knowledge of the disease status (e.g., prevalence, pathogen strains, geographic and host distribution) in wild fish is seldom available, particularly before an epizootic occurs. Causal inference that aquaculture is responsible for a disease in wild fishes must go beyond temporal and spatial associations. Criteria for making associations of causes relating to disease were proposed by A. B. Hill (1965, *Proceed Roy. Soc. Med.* 58: 295-300) and A.S. Evans (1976, *Yale J, Biol Med* 49: 175-195), and these will be reviewed. Extensive pathogen surveys of farmed fish and wild fish near and far from farms would be one important step for assessing the real and potential impacts of aquaculture on wild fisheries relating to disease transfers.

Sea Lice Monitoring & Control on Irish Salmon Farms

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Monitoring of lice infestations on Irish salmon farms commenced in 1991. By 1994, the programme had been extended to form a national monitoring programme covering all farm sites in the country. Today monitoring is carried out on each site fourteen times per year and the results of the monitoring programme are used to inform a control and management strategy. The programme has resulted in changes in husbandry practices which have been key to reducing lice infestation levels.

Sea Lice Management In Eastern Canada

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Although they have been present for many years in most areas, sea lice (*Lepeophtheirus salmonis*) have had very little impact on productivity in Nova Scotia or Newfoundland. However, lice have been a health management concern in New Brunswick since 1994. When salmon farms first faced increased burdens of sea lice, there were no approved treatments available to veterinarians or farmers, and no avenue to rapidly access chemotherapeutants. Since that time, management has evolved to include single year class sites and bay management areas, intensive monitoring, and strategic treatments. Lice management remains an important consideration for salmon farmers in New Brunswick, particularly as reliance on few chemotherapeutants reduces their ability to manage the possible development of resistance.

Elements Of Pink Salmon Population Dynamics

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Among Pacific salmon, pink salmon (*Oncorhynchus gorbuscha*) have a number of unique life history and population dynamic characteristics that differentiate them from other species. Pink salmon have a fixed two-year life cycle that completely separates stocks into odd-year and even-year runs, often with dramatic cyclic consequences. As adults, they are the smallest of Pacific salmon, the least fecund, yet are the most abundant species in both North America and Asia. Pink salmon life history is the least dependant on freshwater ecology. They normally spawn in groups in fast flowing riffles in short coastal streams, sometimes intertidally. Fry emerge from spawning gravels and migrate quickly to marine habitats where they form schools, actively feed and grow rapidly. Survival of eggs, alevins, and fry in freshwater and juveniles in early marine phases is highly varied, often fluctuating by orders of magnitude across a given brood line. Many factors, both environmental and biologic contribute to varied survivals. High variability in survivals, along with a short life cycle, cause wide fluctuations in pink salmon run strength that can go from very high to very low abundance levels in a few generations.

Research in Alaska demonstrates that excessive escapements (too many spawners) can lead to overseeding of eggs in spawning gravels which in turn leads to high density dependant mortality of eggs and alevins within the intragravel environment. Alevins that die shortly after hatching may place increased demands on available intragravel oxygen thereby creating a snowball effect causing accelerated mortality during the over winter period. In one instance of streambed overseeding 80 percent of live pink salmon that were present in the gravel in December had died by March.

These factors are reviewed relative to the dramatic decline in brood 2002 pink salmon returns to the Broughton Archipelago region of British Columbia. Early marine mortalities due to sea lice infestations on juvenile pink salmon in 2001 in the Broughton area have been implicated as the primary cause of the sever decline in 2002 adult returns. However, streambed overseeding of spawning gravels from record high escapements in 2000 may have dramatically increased density dependent mortality of eggs and alevins thereby greatly reducing fry production. The previous even-year Broughton-area cycle began with a more moderate escapement level in 1998. Spawning from that escapement resulted in sufficient fry to produce the record adult return in 2000. Were progeny from 1998 spawners exposed to similar levels of sea lice infestation when they migrated seaward in 1999 as were progeny from the 2000 spawners in 2001? If true, therefore, the main cause of the 2002 decline in adult returns was likely not sea lice infestation but the comparative levels of fry from the two broods. Sea lice infestation would have caused marine mortality in juveniles of both broods, but the main difference may have been dramatically different number of fry produced in freshwater by 1998 and 2000 spawners.

Streambed overseeding does not invariably occur at some precise level of spawners, but rather is a dynamic interaction between densities of eggs and alevins in the gravel, certain ecological features that define the fry production capability of the streambed, and the prevailing climatological conditions during the 6-to 8-month period eggs and alevins are in the intragravel environment.

Norwegian Management Of Sea Lice – Lice Control On Fish Farms

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In 1997, the Norwegian Animal Health Authorities established a national program for the control of sea lice in co-operation with the Directorate of Fisheries, Directorate of Nature Management, fish farmer's organization and private fish health services. In 1998 Norway got a law regulation (divided in 6 regional regulations) that included compulsory monitoring in farms, and of maximum levels of lice/fish. In 2000 (01.02.2000) the "Regulation of the fight against sea lice" was established, and replaced the 6 regional regulations.

The purpose of the regulation was to establish minimum measures of sea lice, intending to reduce the damage on Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) in farms and on wild species. At sea temperature ≥ 4 °C the fish on fish farms are to be examined for salmon lice and noted every 14 days. A lice report is expected to be delivered the 15th every month to local District Veterinary Officers by mail, fax or E-mail. Mandatory delousing is required in the region of Troms and Finmark when 0,5 adult female or more, or 5 or more adult female and movable stages (in period 1.11 to 1.07; preadult and adult male) are recorded on average per fish per cage, and 2 adult female or more, or 10 or more adult female and movable stages (in period 1.07 to 1.11) are recorded on average per fish per cage. In rest of the country the same limits applies, but the 2 period's are from 1.12 to 1.07 and 1.07 to 1.12. If the regulation is violated fines are most likely to be issued.

Studies of Sea Lice Resistance to Chemotherapeutants (SEARCH): An international collaborative program

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Infestations of farmed Atlantic salmon with sea lice have annually accounted for millions of dollars in losses due to mortalities and growth inefficiency, reduced carcass quality, and therapeutic costs throughout Northern Europe and Eastern North America. The development of sustainable methods of pest management must keep pace with the intensification of production and avoid excessive reliance on too few chemotherapeutants. Unfortunately, the effectiveness of chemotherapeutants (including the most novel products) may be eroded by the capacity of sea lice to develop resistance to these chemicals, particularly when alternative control options are lacking. Should resistance develop, it could substantially increase economical and environmental costs by reducing the scale of production, reducing the life span of well proven and safe treatments, forcing premature introduction of new chemicals, and forcing the industry to use antiparasitic agents lacking optimal efficacy. Use of higher dosing regimens due to resistance may also lead to greater toxicological effects on non-target organisms. The overall objective of the project is to develop methods to detect the emergence and monitor patterns of resistance in sea lice against chemotherapeutants in Norway, Scotland, Ireland and eastern North America. The results will be used to issue recommendations to the authorities, fish health veterinarians and the aquaculture producers on how to reduce the risk of resistance developing and to address any resistance problems that may have already arisen.

This project is addressing the following:

- 1) Development of biological test methods (bioassays) capable of detecting sea lice populations with reduced sensitivity towards chemotherapeutants.
- 2) Characterization of the underlying resistance mechanisms and development of high throughput laboratory methods for screening sea lice strains for the presence of these mechanisms.
- 3) Development of sufficiently detailed protocols for monitoring the effectiveness of sea lice treatments in salmon farms in all participating countries.
- 4) Description of the spatial and temporal distribution of sea lice infestations and sensitivity to chemotherapeutants within and between participating countries.
- 5) Arranging contact meetings and issuing written material for authorities, fish health services and the fish farming industry.

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Management of sea lice: Some ideas for new products and strategies

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Management of sea lice on farmed salmonids to date depends on therapeutic administration of a small number of parasiticides. Dependence on these raises concerns of resistance development in the target pests. In this presentation I will discuss some newer pesticide products, currently in use for insect control in veterinary or crop protection contexts, that may have applicability for the management of sea lice. These include a number of chemicals used for systemic flea management on dogs and cats and some reduced-risk botanical insecticides used to mitigate pests in organic crops. Oral and topical delivery methods will be compared with respect to efficacy and impacts on the environment and fish health. Product registration likely poses a significant barrier to the introduction of new products, and environmental testing will be key factor in regulatory decisions. In addition, some alternative strategies (bait fish, pheromones, genetic modification of host attraction) for the future will be discussed.

Sea Lice Monitoring: A Proposed Solution For Information Management

Grace A. Karreman, VMD

All relevant stakeholders in the marine environment in BC, including industry, Fisheries and Oceans Canada (DFO), BC MAFF, NGO's and First Nations groups have been drawn into the sea lice debate. While DFO has records of sea lice cases in Pacific region wild species since the 1970's, to date there has been no integrated, global approach to monitoring sea lice populations in both farmed and wild fish in Pacific waters.

A proposed mechanism for housing this information is the provincial Fish Health Database, which currently tracks fish health information on the farmed sites, DFO fish culture facilities and (in the near future) BC WALP sites. It is proposed that a module be added to this system on a pilot basis to capture information on sea lice on farms plus lice information from DFO – directed work on wild fish.

Appendix 4. Scientific Gaps

1. Establishment of baseline Data
 - A. Biology/ecology of all salmonids (geographic and temporal variability)
 - Migration timing (down/up)
 - Numbers (down/up)
 - Quality Index (Condition factor)
 - Growth rates
 - Inshore Feed
 - Migration route (down/up)
 - Mortality/stage
 - Inshore Behavior
 - Egg survival rates
 - Marine carrying capacity
 - Local and traditional knowledge
 - B. Biology/ecology of Sea Louse (geographic and temporal variability)
 - Lice abundance levels
 - Lice life cycles
 - Larval dispersion strategy
 - Overwintering strategy
 - Predators of Sea louse stages
 - Survival of lice after settlement
 - C. Oceanography (DO, temp., salinity, currents, etc.) of different regions (farmed areas, non-farmed areas, important ecology areas) start in Broughton Arch.
2. Treatment Methodologies
 - Trigger levels/Max. levels/Min. levels
 - Impacts on surrounding biota (crustaceans especially)
 - Development of new and alternatives treatments
 - Development of mitigative strategies
 - Development of preventive strategies
3. Model for salmon farm management and the effect of loading on sea lice in the environment
 - Siting strategy
 - Allowable density of farms/region
 - Allowable density of fish/farm
 - Season management
 - Fallowing
 - Treatment intervention
4. Interaction of Sea Lice and wild/farmed salmon
 - Physiological impact of lice on fish
 - Lethal load levels of lice on fish
 - Data on lice infestation parameters in wild and in farmed salmon
 - Sources of lice
 - Juvenile carrying capacity along migration routes
 - Proportion of impact on wild fish due to farms
 - Development of adequate sampling techniques
 - Infection/Infestation of non-salmonids

Spatial and temporal overlap

Research

Measurement of hydrology
Mark-Recapture studies
Measurement of geographical/temporal variability
Trawl/netting studies
Trapping studies
Tagging studies to monitor movement, migration etc.
Develop taxonomic keys (field keys) for Sea Lice spp. identification
Sentinel Cage Studies in various regions of infestation
Lice Gene Flow
Modeling of movement, hydrology and farm information to est. safe sites for cages and corridors
LC50/EC50 studies on salmonids with all lice
Lice loading studies (lab)
Oceanographic and hydrologic measurements
Collate local and traditional knowledge
Collate international and historic data
Develop and test new treatments
Development of mitigative strategies
Development of preventive strategies
Conduct impact assessments of treatments on non-target species
Establishment of sampling protocols
Establishment of analysis and reporting protocols
Treatment response experiments
Fallowing experiments
Over/Under-seeding experiments
Sea-Lice dispersion studies (in lab)
Modeling
Development of communication tools (Websites)
Lice settlement experiments
Host-preference studies

Short

Start with Pink Salmon
Start with Broughton Archipelago region
Start with Lepeophtheirus
Encourage co-operation between all stake holders and first nations

Long term

Expand to all salmonids (and other key species)
Expand to entire BC coast
Expand to all lice
Continue to foster co-operation
Develop SOP and strategies for Area management