SEA LICE AND SALMON FARMS: A SECOND LOOK

AN UPDATE OF "SCIENCE AND SEA LICE: WHAT DO WE KNOW?"

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Author's note

In late 2007, the B.C. Pacific Salmon Forum engaged me to create an independent overview of recent research on the interaction between sea lice and juvenile Pacific salmon in the Broughton Archipelago. An annotated bibliography was chosen as the best way of providing an impartial summary of the available scientific research. The responsibility for which papers to include in the bibliography, what information to include in each entry, and for any mistakes in interpretation, were mine.

The bibliography was called Science and Sea Lice: What Do We Know? and was completed in early 2008. The present review brings the science up to date as of February 2009.

I did not formally interview any of the cited researchers during the preparation of this bibliography, although I am grateful to many colleagues, and to all the people at the Pacific Salmon Forum, for alerting me to publications I might otherwise have missed.

Brian Harvey

February, 2009

COMMENTARY

Science and sea lice: has anything changed?

In February 2008, I summarized a hundred or so peer-reviewed scientific studies on the unholy love triangle involving farmed salmon, wild salmon and sea lice. My client was the Pacific Salmon Forum. My job was to look for consensus on the following question: How much of an impact are the sea lice from salmon farms having on wild salmon populations in the Broughton Archipelago?

Hard as it is to put anything to do with salmon and sea lice in plain language, I'll try to paraphrase the answer I came up with back then: Scientists did *not* agree on the big-picture population effects of infections caused by lice that came from salmon farms. So my conclusion a year ago was "The science isn't clear." This didn't mean there wasn't evidence that lice from the farms caused harm, just that scientists didn't agree on how big the effect was. It certainly didn't mean that we should wait for consensus before taking action (although quite a few people interpreted it that way).

Now, a year later, I've reviewed 31 more scientific papers on the same topic. More than 31 papers were, of course, published on that very big subject during the year, but I concentrated on the most relevant ones. (Not that the irrelevant papers, like the one on freshwater baths to rid cultured puffer-fish of lice, weren't interesting, but multiple freshwater baths aren't a practical option for salmon in seawater cages.) As usual, such a review suffers from the need to ignore papers in the publication pipeline, as well as valuable findings that may get presented at meetings but are never published. So it's still an analysis based on the published scientific record, and that record still reflects the enormity of the biological puzzle that researchers are trying to sort out.

The scientific and social backdrop for this update had, however, changed from the previous year. Here are some changes that have, in my opinion, reduced the regrettable polarization that was for years such a feature of the whole sea louse field:

- In the fall of 2008, even though total Pacific salmon catch was at an all-time high, dramatic declines in returns of many Pacific salmon populations presented such a chaotic picture of salmon survival that experts were often at a loss to explain why some stocks were healthy and others (including the enhanced Glendale River pink salmon stock in the Broughton Archipelago) collapsed;
- Louse prevalence on wild juvenile salmon in the spring in the Broughton also declined in 2008, as it has been doing since 2004 – although spikes later in the summer were still confusing;
- The scientific literature on fish in general contained more references to climate change in 2008, the long-term effects of which on Pacific salmon may overwhelm concerns about sea lice;
- Interestingly, the rate of expansion of global aquaculture continued to decline;

- Finally, exposure of fatal weaknesses in the global economy had people thinking about how everything is connected to everything else, so they may be more receptive to the idea that complex systems can never be fully understood.

Some legal developments in early 2009 will also affect the way people fund and carry out sea louse research: First Nations in the Broughton Archipelago filed a class action suit against the B.C. government for damages caused to wild salmon by fish farms; and the Supreme Court of B.C. ruled that salmon farming is a fishery, and thus falls within the jurisdiction of the federal government, not the province. One possible outcome of the latter ruling is a complete changing of the guard for salmon farm regulation within twelve months of the ruling.

My strategy for reviewing the scientific literature was the same as before, with the same search criteria, and I used the same format for the short summaries of each paper that follow this introduction. Once again, the summaries were simply a description of what the scientists said they found; editorializing was confined to the "Commentary" you are reading now. This time, however, I grouped the papers in categories. They are: *Big Picture*; *Physiology of Infection*; *Infection in the Wild*; *Thrust and Parry* and *Treatment with SLICE™*.

When you look at these categories and the numbers of papers in each, two things are clear. One is that the different sea louse research fields are fairly well balanced. There are people who work on the physiology of infection, there are people who sample lice or fish or both in the wild (and sometimes create models for infection), and there are people who confine themselves to the chemicals used to kill lice. These are all different fields, and there's more consensus in some than in others.

The second interesting thing is that there were enough "Big Picture" publications to warrant their own section. It's the inclusion of those far-sighted papers that makes me think researchers have agreed to disagree on how much damage the lice from farms cause, and that some of these researchers are starting to formulate useful what-ifs about the way forward. That's new, and it's welcome.

Some notes on the research

The interaction between sea lice and salmon is still a contentious subject. In the summaries that follow, *Infection in the Wild* and *Thrust and Parry* are where you find the most controversy, probably because the field research is so hard to do. I created the "Thrust and Parry" section because the sea lice literature is unusually afflicted with strings of papers in which the authors take pot-shots at each other. Maybe they're the scientific equivalent of a blog. When the exchanges get so drawn-out that they have titles like "Comment on comment on comment…" then I think it's best to read them as a sequence, because the give and take tells us something important about the science.

It's hard to read a sequence like the one following Butterworth et al. (2008a), on louse infestation on the Central coast, and conclude that the science is clear. There isn't even agreement about how to sample in the field and interpret the data. Or the back and forth related to Krkošek's 2007 paper on declining wild salmon populations in the Broughton: one person's "association" is another's "cause and effect." There are just too many ways to use the same spotty data, and the fewer data there are, the more your conclusion rests on assumptions— which can always be argued about. This is the most frustrating area of sea louse research, because scientists are trying to tie the available data into a grander mechanism that accounts for all the observations on sea lice, their movements, and their hosts. They're like the learned physicians of the Dark Ages who struggled to account for human disease in the absence of adequate observation and experimentation, and came up with all manner of schemes, from vital humours to mysterious life forces residing in the ventricles of the brain. Seven hundred years separates these two groups of scientists, but they're caught in the same trap, reduced to arguments about assumptions and statistics and flaws in the other guy's reasoning. We shouldn't expect any sudden clarity here.

Infection in the Wild is where you find the hard-core field work, with all its frustrations. It's here, using beach seines and plankton tows and farm records, and comparing louse levels at different locations, that biologists are looking for associations between numbers of sea lice and other factors – including but not limited to farms. The design of such a field study is terribly important (is a particular spot "close" to a farm, or "remote" from one?) and both the lice and their hosts are moving targets. Some progress was reported in the new literature I reviewed, with several new studies of B.C. coastal areas outside the Broughton Archipelago, with and without farms, and a few new ones from Europe. Coupled with data from DFO's continuing annual field studies of louse levels on wild juvenile salmon, these studies seem to confirm existence of a number of poorly understood wild sources of infection on young salmon, with the effects of lice from salmon farms added to this background level. The association of salmon farms with abundance of larval sea lice in the water is clearly seen in as yet unpublished results of plankton tows throughout the archipelago. The source of the winter spike in louse numbers on the farms remains controversial.

It is now becoming clearer how the farm effects can be modified by various management actions, especially the periodic use of emamectin benzoate (SLICE™) to control infestation on farmed fish. Is SLICE™ the reason louse infestation on wild salmon in the Broughton continued to drop in 2008? Certainly it's one of them, and it may also be related to later spikes in the summer. A long-term study from Europe shows how well SLICE™ can work, although the timing of its use in B.C. seems to be critical. In other words, when and how often you treat has immediate practical importance; where the farm infestations actually originate is still being sorted out. Modelling of louse movements and infections, already a cumbersome process, now has to account for the ups and downs caused by SLICE™. A number of papers in the *Treatment with SLICE™* section also point out the potential for the sea louse *L. salmonis* to develop resistance to the chemical, present new ways of measuring resistance and propose treatment regimes to minimize it.

Research on the *Physiology of Infection* continues to add vital insights that can be plugged into the grander scheme. One reason for progress is the relative ease of getting reliable data in the lab, where a lot of this kind of research is done. Advances include the greater attention now paid to infections on very small wild salmon, to low level infections, and to sub-clinical effects – in other words, more closely approximating conditions in the wild. Studies at the molecular level are providing rational explanations for earlier observations (for example, how different species respond to louse attack). Studies that point to a vulnerable period in the young salmon's life may have practical application in managing salmon farms. Unfortunately, there's still a big hole in our understanding of louse behaviour – how a louse senses a fish host and attacks. Preliminary studies suggest it will be a fascinating field.

The bottom line

The question everyone wants answered is: Have we still just demonstrated a lot of *associations* between salmon farms and the lice on wild salmon, or do we have proof of *causation* (what some call the smoking gun)? In my opinion, research is still at the association stage. But the general attitude among researchers seems to have changed, so maybe we need to ask a different question.

What would happen if you asked a roomful of scientists (say, all the scientists involved in the papers summarized here): *Are the sea lice produced on farmed Atlantic salmon causing the decline of wild salmon in B.C.*? After reading this latest batch of research papers, I believe scientists' convictions still range from "all's well on the farm" to "populations are going extinct." However – and this is the significant change from my first review — I doubt you'd find anyone who would claim that lice from the farms *aren't* a factor in wild salmon survival. Whether farm-origin lice are the *main* source of infection for wild juveniles in the spring, as many scientists believe, will have to wait a little longer, but in my view the agreed-on link to farms is significant progress. It's another way of saying, OK, there *is* a problem, let's keep working at the science but let's start making practical changes too. The paper by Krkošek (2009) captures this shift, because it actually contemplates policies that take the current state of knowledge into account. At a time when B.C. salmon populations are behaving chaotically, some plunging and some doing well, with the certain influence of oceanic events we simply don't understand, doing what we can to minimize an identifiable threat like sea lice from salmon farms makes sense.

How do we do this? There's good evidence from this research that emamectin benzoate (SLICE™), when fed to farmed Atlantic salmon, reduces the number of lice that can infect young wild salmon. We already knew this from European studies, but the B.C. data now clearly show the spikes and slides in louse numbers related to SLICE™ use in the Broughton, even on top of still-puzzling "natural" variations in the numbers of lice. These data, including as yet unpublished information on the timing of waterborne louse numbers in relation to SLICE™ use, have much practical use. If society accepts the idea of using medicated feed and feels its drawbacks are well enough known and can be

managed, then we have a tool. Other management tools have been shown to work too, especially the timing of stocking and harvest, and their coordination with known wild salmon migratory patterns. Relocation of farm sites is another option. Unlike the unraveling of the various survival strategies used by lice in the Broughton (the *Infection in the Wild* work), this isn't rocket science.

The ultimate "management solution" would of course be to close the farms down. If, however, market forces were to take the farms elsewhere, the problem might simply be shifted to another hemisphere. For a society that claims to believe more and more in "ecosystem thinking", this makes no sense. A much shorter migration of the farmed salmon would be the proposed one to closed containers; this is the "solution" that's often advanced in B.C. Here again, though, we should look out for unintended consequences. The 2009 paper by Ayer and Tyedmers, in the *Big Picture* section, is instructive, because it looks at the energy costs and resource use for three kinds of closed containers as well as the traditional net cage. Their findings are not the last word on the subject, but should be enough to ensure that people take the environmental impact of *any* kind of container into account. Otherwise, solving a local problem (sea lice) may perversely add to a global scale problem (energy use).

The fact that "farm management solutions" are more or less agreed on as the way forward (including by scientists) just reinforces the fact that the sea lice issue in B.C. has gone beyond science. One reason is the role played by media, which is why the paper by Amberg and Hall (2008), on American newsprint representation of farmed salmon, is relevant. If media in B.C. tend to favour stories about salmon farming that elicit feelings of dread, then where will balance come from? Maybe, if research on sea lice continues to be funded, it will actually come from the scientific community itself. Which is, after all, the way science is supposed to work.

SUMMARIES OF PEER-REVIEWED ARTICLES

The Big Picture

Krkošek, M. 2009. **Sea lice and salmon in Pacific Canada: ecology and policy.** Front. Ecol. Envir. 7: in press.
Geographic area: Pacific coast of Canada
Sea lice topic: biology; infection routes; effects on wild populations; policy
Kind of research: desk study
Kind of document: review article
Funder(s): NSERC Graduate Scholarship; National Centre of Excellence, Mathematics of Information Technology and Complex Systems Post Doctoral Internship with the David Suzuki Foundation.
Rating: Must read
Question: What does recent research tell us about the interaction between farmed Atlantic salmon and wild Pacific salmon, and what kinds of policies are needed to reduce the sea louse threat?
Main message: Wild-origin sea louse *L. salmonis* populations are sufficiently amplified on farmed Atlantic salmon to disrupt the natural ecology of sea lice and Pacific salmon. Continued high exposure to farm-origin lice can cause infestations in wild juvenile salmon that have been shown to be associated with declines in some wild salmon populations. While our understanding of the natural ecology of sea lice continues to improve, mathematical models are becoming more sophisticated, and we are learning more about the relative importance of sea lice in comparison to other factors that affect Pacific salmon population dynamics. But we already have enough evidence to provide a strong basis for a sea lice policy for Canada that goes beyond the current provincial level. This policy must be able to accommodate scientific uncertainty and should reflect lessons learned from European policies. Management options that need to be considered in the policy include relocating farms away from rivers and migration corridors, spring fallowing, reducing stocking density, chemical treatment and closed containers. Coordination of several of these options may be a good approach.
Importance to Broughton: A forward-looking argument for policies and regulations that reflect what we know (and don't know) about the impact of farm-origin sea lice on wild Pacific salmon.
See also: relevant to all current research.

Cubitt, F., K. Butterworth, and R. S. McKinley. 2008. **A synopsis of environmental issues associated with salmon aquaculture in Canada.** In: Aquaculture, Innovation and Social Transformation. Culver, K. and D. Castle. Springer.
Geographic area: Canada
Sea lice topic: basic biology; differences between North Pacific and Atlantic; impacts on salmon health; interactions between farmed and wild populations
Kind of research: desk study

Kind of document: review chapter in a book
Funder(s): not stated
Rating: Should read
Question: Are sea lice having a significant impact on parasite loads on wild Pacific salmon?
Main message: Sea lice and their impacts are reviewed as part of a more extensive chapter that also treats escaped farmed Atlantic salmon, the environmental footprint of salmon farming, use of antibiotics and therapeutants, and biological waste from salmon farms. All these topics are considered in the light of the relevant legislation, policy and regulations in B.C. As far as the threat from sea lice is concerned, the strong influence of temperature and salinity, the potential for alternate local hosts like stickleback, and lack of information on health effects of sea lice on wild salmon, it is still not possible to say that the sea lice produced on B.C. salmon farms have a significant impact on parasite loads on wild Pacific salmon.
Importance to Broughton: An example of the polarization in interpretation of research results on sea lice, this review comes to conclusions that are at odds with a number of other papers.
See also: A good contrast to the review by Krkošek (2009), which makes policy recommendations while reaching different conclusions about the contribution of salmon farms to the sea louse load on wild salmon. Observations on the environmental costs of closed containment aquaculture recall some of the points made by Ayer and Tyedmers (2008).

Amberg, S.M. and T. E. Hall. 2008. **Analysis of US newsprint representations of farmed salmon.** J. World Aquaculture Society Vol. 39, No. 2.
Geographic area: United States
Sea lice topic: media response to research
Kind of research: desk study
Kind of document: peer reviewed journal article
Funder(s): not stated
Rating: Can read
Question: How is scientific research on the health and environmental effects of salmon farming represented in US media?
Main message: Stories published in US media between 2000 and 2005 relating to health and environmental effects of salmon farming were quantitatively analyzed for content. Based on a review of media articles on the health effects of eating farmed salmon, the study showed that reporting followed an already recognized trend of emphasizing negative effects. Media provided a largely uniform message about the effects of eating farmed salmon based on the conclusions from two scientific studies, and paid little attention to subsequent studies.
Importance to Broughton: If media attention does indeed favour stories that elicit feelings of dread, any balance in the sea lice controversy is more likely to come from the scientific community itself, not the media.
See also: No similar study has been done for Canadian media and the Broughton.

Ayer, N. W., and P. H. Tyedmers. 2009. **Assessing alternative aquaculture technologies: Life cycle assessment of salmonid culture systems in Canada.** Journal of Cleaner Production Volume 17(3): 362-373.
Geographic area: Canada
Sea lice topic: closed containment culture systems
Kind of research: desk study
Kind of document: peer reviewed journal article
Funder(s): Dalhousie University; Pew Charitable Trusts
Rating: Must read
Question: What are the environmental advantages and disadvantages of open-net and closed containment culture systems?
Main message: Life Cycle Assessment (LCA), an environmental accounting method for quantifying resource use over the production cycle of a product, was applied to traditional open-net cages, a floating bag system and two land-based operations for growing Atlantic salmon. Data were collected from actual operating examples of each system. By replacing the "free" ecosystem services exploited by open net systems with external inputs to circulate, aerate and clean the water, energy inputs increased for all three closed containment systems tested. The bag system had a life cycle environmental impact similar to open net cages; both land-based systems had much greater energy use. An apparent environmental advantage of hydroelectric power over coal and natural gas did not consider the potential environmental impacts of hydroelectric generation on wild salmon habitat. By substituting industrial, energy-driven services for natural ecosystem services, closed containment may shift environmental problems from immediate and local (like sea lice) to global scale concerns.
Importance to Broughton: While the study does not consider economic costs, and the bag system tested was a flexible plastic construction (there are other options), the comparison highlighted the increased energy demands of closed containment, especially land-based systems. Closed containment systems promoted as solutions to sea lice infestation will need to minimize energy use and related global impacts.
See also: Many published articles on sea lice refer to closed containment as a solution.

Liu, Y., and U. R. Sumaila. 2008. **Can farmed salmon production keep growing?** Marine Policy 32(3):497-501.
Geographic area: global
Sea lice topic: Future of salmon farming
Kind of research: desk study
Kind of document: peer reviewed journal article
Funder(s): AquaNet; Sea Around Us Project (Pew Foundation).
Rating: Can read
Question: Will global output of farmed salmon keep increasing?
Main message: The global *rate of increase* in farmed salmon production peaked in 1984. While overall production continues to increase, the *rate of increase* has continued to decline since 1984. There is no difference in the trend in the growth rate of farmed and wild-caught fish.

Importance to Broughton: Expansion of salmon farming, if it occurs, will be at a slower rate than before.

Thrust and Parry

Riddell, B.E., R. J. Beamish, L.J. Richards and J.R. Candy. 2008. **Comment on "Declining wild salmon populations in relation to parasites from farm salmon."** Science 322 (www.sciencemag.org).
Geographic area: Broughton
Sea lice topic: population effects
Kind of research: desk study
Kind of document: technical comment
Funder(s): not stated
Rating: Must read
Question: Are pink salmon in the Broughton on a trajectory of rapid local extinction?
Main message: The conclusions of a 2007 mathematical analysis of trends in pink salmon populations in the Broughton area would be different had different data been selected. Among other issues, the choice of the starting point for analysis of population trends (2000) and the decision to exclude the contribution of the enhanced Glendale River stock mean that conclusions should have referred to extirpation in some streams but not extinction in the Broughton. The risks presented by sea lice from salmon farms are thus overstated because they result from highly selective use of the available data.
Importance to Broughton: Since the ultimate evidence of harm to a population is actual population numbers, scientific debate over interpretation and analysis of pink salmon population dynamics in an area of salmon farms can be expected to remain intense. This is one installment in such a debate (a reply, from the authors of the paper being criticized, follows).
See also: The paper being criticized here is Krkošek, M., Ford, J.S., Morton, A., Lele, S., Myers, R.A., and Lewis, M.A. 2007b. **Declining wild salmon populations in relation to parasites from farm salmon**. Science 318: 1772-1775. For an earlier criticism of these findings, see Brooks, K.M, and Jones, S.R.M. 2008. **Perspectives on pink salmon and sea lice: scientific evidence fails to support the extinction hypothesis.** Reviews in Fisheries Science 16: 1-10. This criticism raises several of the same technical issues.

Krkošek, M., J. S. Ford, A. Morton, S. Lele and M.A. Lewis. 2008a. **Response to comment on "Declining wild salmon populations in relation to parasites from farm salmon."** Science 322 (2 pp). www.sciencemag.org.
Geographic area: Broughton
Sea lice topic: population effects
Kind of research: desk study
Kind of document: technical comment
Funder(s): Watershed Watch Salmon Society; Wilderness Tourism Association; Finest At Sea; National Geographic Society; David Suzuki Foundation; Canadian Sablefish Association; NSERC; University of Alberta; Tides Canada; Lenfest Ocean program.

Rating: Must read
Question: Are the criticisms of Riddell et al. 2008 (previous paper) justified?
Main message: A response to a number of technical criticisms raised by Riddell et al. (2008), which take issue with conclusions first published in 2007 (Krkošek, M., Ford, J.S., Morton, A., Lele, S., Myers, R.A., and Lewis, M.A. 2007b. **Declining wild salmon populations in relation to parasites from farm salmon**. Science 318: 1772-1775). Two potential non-louse factors on pink salmon population dynamics (density-dependent mortality and environmental variation in survival) were in fact controlled for in the mathematical model. If some non-louse factor has changed negatively for louse-exposed populations, nobody has identified it yet. Excluding the 2000-2002 pink salmon collapse data does not invalidate our conclusions, although time to 99% population decline would be extended to five generations. Including the Glendale River data only slightly reduces the predicted decline. The only common factors that explain recent differences in fluctuation of pink salmon abundance in the Broughton (relative to unexposed populations) are sea lice and fallowing. Prevention of sea lice infestation is a management and policy option that may help restore these populations.
Importance to Broughton: see previous paper.
See also: The paper being criticized here is Krkošek, M., Ford, J.S., Morton, A., Lele, S., Myers, R.A., and Lewis, M.A. 2007b. **Declining wild salmon populations in relation to parasites from farm salmon**. Science 318: 1772-1775. For an earlier criticism of these findings, see Brooks, K.M, and Jones, S.R.M. 2008. **Perspectives on pink salmon and sea lice: scientific evidence fails to support the extinction hypothesis.** Reviews in Fisheries Science 16: 1-10.

Krkošek, M., J. S. Ford, A. Morton, S. Lele and M.A. Lewis. 2008b. **Sea lice and pink salmon declines: A response to Brooks and Jones.** Reviews in Fisheries Science 18(4); 413-420.
Geographic area: Broughton
Sea lice topic: population effects
Kind of research: desk study
Kind of document: technical comment
Funder(s): NSERC; Canada Research Chair.
Rating: Must read
Question: Are the criticisms of Brooks and Jones (2008) justified?
Main message: The assessment by Brooks and Jones (2008) is thoroughly mistaken. For example: Klinaklini River data that were advanced as an example of wide natural population variation are low quality data and reflect inconsistent field surveys. Including the Glendale River (and excluding Kakweiken River) shifts the decline timeline but does not invalidate the main conclusion. Glendale River was excluded because increased productivity due to spawning channels prevents evaluating recent trends relative to historic abundance. Claims of high mortality after louse infection are for less than 1-gram pink salmon, which is more relevant to the field situation. Lack of "cause and effect demonstration of a relationship between louse release from salmon farms and infections on pink salmon fry" is countered by many studies showing spatial and temporal associations. There are adequate data to show that alternate natural hosts cannot account

for the vast majority of sea lice infecting wild juvenile salmon in the Broughton. Salinity effects are less important than claimed. The Ricker model is the appropriate one, and has numerous advantages over the one proposed by Brooks and Jones (2008), for which a suitable dataset would be hard to imagine. Summing escapement estimates for all rivers tends to obfuscate ecological processes, so that the processes responsible for variation cannot be seen, nor can trends in individual populations. The conclusion that Broughton pinks are in fact recovering assumes that all data points are independent and does not stand up to analysis.
Importance to Broughton: More back and forth on how to treat the available data for Broughton pink salmon, and what conclusions about population dynamics can responsibly be drawn from various kinds of mathematical analysis.
See also: Brooks, K.M, and Jones, S.R.M. 2008. **Perspectives on pink salmon and sea lice: scientific evidence fails to support the extinction hypothesis.** Reviews in Fisheries Science 16: 1-10.

Butterworth, K., F. Cubitt and R. S. McKinley. 2008a. **The prevalence, density and impact of *Lepeophtheirus salmonis* (Krøyer) infestation on juvenile pink salmon (*Oncorhynchus gorbuscha*) from the central coast of British Columbia, Canada**. Fisheries Research 91: 35–41.
Geographic area: Central B.C. coast
Sea lice topic: role of salmon farms in infection of wild salmon
Kind of research: field
Kind of document: peer reviewed journal article
Funder(s): B.C. Science and Innovation Council
Rating: Must read
Question: Is the situation on the Central coast different from the Broughton?
Main message: Based on the belief that more conclusive evidence is needed to show cause and effect between salmon farms and the sea lice infection levels on wild Pacific salmon, six sites believed to be on the out-migration route of juvenile pink salmon on the central B.C. coast were sampled by beach seine in early June. Each site was sampled once. Two sites were close to salmon farms, two were on the seaward side, and two were on the headwaters side. There was no significant increase in sea louse prevalence, in either of the two channels studied, on juvenile pink salmon sampled on the headwater side of the farms, near salmon farms or seaward of the farms. The mean prevalence (18.4%) was low in relation to the numbers previously reported for adult pink salmon in Smith and Rivers Inlets. The number of juvenile pink salmon with louse intensities over 1.6 lice/g was much lower than reported for the Broughton Archipelago. Condition index (an indication of health) was estimated using a method that was not skewed by the added weight of any lice on the fish, and was not significantly different in headwater-side, seaward-side or near-farm sampling sites.
Importance to Broughton: The findings of this study are at odds with some of those from the Broughton in that they do not appear to associate sea louse prevalence with sampling area (near farm, seaward of the farm, or headwater side of the farm). A critical response from researchers working in the Broughton is cited below.
See also: Morton and Routledge (2008), the following paper.

Morton, A., and R. Routledge. 2008. **Comment on Butterworth, Cubitt, and McKinley (2008).** Fisheries Research 92(2-3):345-346.
Geographic area: B.C. Central coast
Sea lice topic: role of salmon farms in infection of wild salmon
Kind of research: comment
Kind of document: comment in scientific journal
Funder(s): not stated
Rating: Must read
Question: Are the conclusions of Butterworth et al. (2008) justified?
Main message: First, the weight of lice on a juvenile pink salmon is under 1% and cannot thus skew the measurement of condition factor. Second, sampling each of six sites only once provides a very limited data base which does not account for any changes over time and allows for little statistical power in analysis. Moreover, the statistical tests used were flawed; a more appropriate statistical treatment of the same data reveals significant differences in louse prevalence among the six sites. The possibility that salmon farms play a role in the observed spatial patterns of infection was not adequately considered, even though louse abundance was highest at the two farm sites. Finally, the literature referred to is incomplete, and ignores extensive research from Europe which shows evidence of fish farm impacts on wild salmon.
Importance to Broughton: This comment was written by researchers with extensive field experience in the Broughton
See also: Butterworth et al. 2008a.

Butterworth, K., K. F. Cubitt, and R. S. McKinley. 2008b. **Response to "Comment on Butterworth, Cubitt and McKinley (2008)" by Morton and Routledge [fish. res.(2008)].** Fisheries Research 92(2-3):347-349.
Geographic area: B.C. Central coast
Sea lice topic: role of salmon farms in infection of wild salmon
Kind of research: comment
Kind of document: comment in scientific journal
Funder(s): not stated
Rating: Must read
Question: Are the comments of Morton and Routledge (2008) justified?
Main message: Morton and Routledge's assertion that lice weigh around 1% of fish weight is incorrect. It should be around 7% for two adult lice per fish, and up to 45% at the mean abundance of 13.2 lice/fish. Their re-analysis of the data to show evidence of differences in prevalence among the six sampling sites is statistically invalid. In response to Morton and Routledge's statistical concerns, we performed an additional test (Levene test); it confirmed out earlier conclusions. The very low levels of infestation observed in our study (compared to those seen in the Broughton), plus the lack of effect of infestation density on condition factor, support the reasoning that there is not enough evidence to speculate on the origin of the lice in our study. Finally, European literature was deliberately excluded because of the difference in host salmonid species, different

prevalence on different species of Pacific salmon, differences in the relative numbers of wild and farmed salmon in B.C. and Europe, and the presence of alternate potential hosts on which sea lice could over-winter in B.C., including wild coho and chinook salmon, and stickleback.
Importance to Broughton: Continues the debate about the contribution of sea lice by farmed salmon.
See also: Morton and Routledge 2008**.**

Dill, L.M., C.J.C. Losos, B.M. Connors and P. Mages. 2008. **Comment on Beamish et al. (2007) "A proposed life history strategy for the salmon louse, *Lepeophtheirus salmonis* in the subarctic Pacific."** Aquaculture 286 (3-4):154-155.
Geographic area: subarctic Pacific Ocean
Sea lice topic: louse hosts and sources
Kind of research: desk study
Kind of document: letter to the Editor
Funder(s): not stated
Rating: Should read
Question: Is the life history strategy for *L. salmonis* proposed by Beamish et al. (2007) well-argued and supported by the available data?
Main message: The claim that juvenile Pacific salmon would be infected by lice from over-wintering wild Pacific salmon almost immediately after they entered the ocean is not supported by the available data. Important literature was ignored in arriving at this speculative conclusion, and the life strategy proposed by Beamish et al. is not evident in the coast-wide patterns of louse infection that vary depending on the presence or absence of salmon farms.
Importance to Broughton: a not unexpected argument in favour of further research to clarify the roles played by non-farm sources of sea lice that are present at the time of juvenile pink and chum out-migration.
See also: Beamish et al. 2007 for the original arguments in favour of an infection role for resident Pacific salmon.

Physiology of infection

Wagner, G. N., M. D. Fast, and S. C. Johnson. 2008. **Physiology and immunology of *Lepeophtheirus salmonis* infections of salmonids.** Trends in Parasitology 24 (4): 176-183.
Geographic area: global
Sea lice topic: physiology of infection
Kind of research: review
Kind of document: peer reviewed journal article
Funder(s): not stated
Rating: Should read

Question: What is our understanding of the physiology and immunology of the louse-salmon interaction?
Main message: This is a review of scientific literature from the mid-1990s to 2007. It summarizes what we know about the physiological consequences of louse attachment and feeding, pointing out the limitations of laboratory studies and providing solutions to some of the technical problems encountered in studying the louse-salmon interaction. We know less about the actual interaction between *L. salmonis* and its salmon hosts than is known about many other economically important parasites. Much of what we know comes from laboratory studies that are not comparable (different salmon species, different life stages, different levels of infection and environmental conditions) and are hard to relate to life in nature. Laboratory methods need to be much refined. Subclinical effects are poorly known, as are immunological responses to infection. Studies that use high infection levels make it hard to differentiate between response to the parasite and general stress. In general, reliance on high levels of infection in laboratory studies makes it hard to distinguish the host response to the parasite from a generalized stress response. The current construction of salmon genomes will allow more important insights into host physiological responses, and may even lead to development of vaccines and alternate breeding strategies for the aquaculture industry.
Importance to Broughton: Many conclusions about the effects of a given louse load in nature are currently derived from laboratory studies; unfortunately, those studies still have limitations.

Jones, S.R.M., M. D. Fast, S. C. Johnson and D. B. Groman. 2007. **Differential rejection of salmon lice by pink and chum salmon: disease consequences and expression of proinflammatory genes**. Dis. Aquat. Org. 75: 229–238.
Geographic area: B.C.
Sea lice topic: susceptibility to infection in different salmon species
Kind of research: laboratory
Kind of document: peer reviewed journal article
Funder(s): B.C. Innovation Council
Rating: Should read
Question: How do pink and chum salmon differ in the way they respond to *L. salmonis* infection?
Main message: Juvenile pink and chum salmon exposed to two different concentrations of *L. salmonis* copepodids responded differently to infection. While both Pacific salmon species were more resistant to lice than Atlantic salmon, pink salmon had lower prevalence and abundance of lice that did chum, and the reduced hematocrit (red blood cell count) and weight that was seen in chum did not occur in pinks. Coupled with the faster activation of an inflammatory response in pink salmon (confirmed by measuring expression of proinflammatory cytokine genes), the evidence argues for higher resistance to *L. salmonis* infection in pink salmon.
Importance to Broughton: Much of the research on salmon-louse interactions in the Broughton concentrates on pink salmon; these results confirm earlier studies suggesting that effects on chum may actually be greater than on pinks.

See also: Wagner et al. (2007) places this paper in context of other research on louse-salmon interactions, including problems of interpreting measured stress responses and the significance of gill infestation.

Jones, S.R.M., M. D. Fast, and S. C. Johnson. 2008. **Influence of reduced feed ration on *Lepeophtheirus salmonis* infestation and inflammatory gene expression in juvenile pink salmon.** Journal of Aquatic Animal Health 20:103–109.
Geographic area: Pacific coast
Sea lice topic: factors influencing severity of infection
Kind of research: laboratory
Kind of document: peer reviewed article
Funder(s): B.C. Science and Innovation Council
Rating: Should read
Question: Does reduced feed availability affect infestation level and the expression of genes that promote the inflammation response to infection?
Main message: Based on laboratory infection of pink salmon juveniles, there were no significant effects of temporarily reduced ration on prevalence or abundance of *L. salmonis*, even though growth was impaired in the salmon on reduced ration. As already seen in earlier experiments, most lice were lost within 21 days, without fish mortality. This "rejection mechanism", believed from earlier work to be mediated by pro-inflammatory gene expression, may have been temporarily compromised by reduced ration; this idea needs to be tested further. Expression of inflammatory genes after louse infection, while confirmed here, needs to be further explored.
Importance to Broughton: Sheds a little more light on the complex response of juvenile pink salmon to sea lice by exploring what might happen to their resistance to sea lice under different ecological conditions (in this case, food availability).
See also: the previous paper goes into more depth on the pro-inflammatory response to infection.

Connors, B.M., E. Juarez-Colunga and L. M. Dill. 2008. **Effects of varying salinities on *Lepeophtheirus salmonis* survival on juvenile pink and chum salmon.** Journal of Fish Biology 72: 1825–1830.
Geographic area: Broughton
Sea lice topic: effects of environmental conditions (in this case, salinity) on severity of infection
Kind of research: field
Kind of document: peer reviewed journal article
Funder(s): Watershed Watch Salmon Society; Sierra Club of BC;NSERC; private donors.
Rating: Must read
Question: Does reduced seawater salinity affect survival of sea lice on juvenile pink and chum salmon?
Main message: Nearshore salinity in the Broughton can fluctuate, but previous research isn't conclusive on how a range of salinities could affect lice on young pink and chum

salmon. Using wild-caught, infected juveniles of both species, and assuming that lice not recovered in the experimental tanks actually died as a result of lowered salinity, 7-day exposure to salinities of 21,14, 7 and 0 ppt indicated rapid louse mortality in fresh water (0 ppt) but short-term toleration of the other salinities tested. Differences from previously published research may reflect species and host size, as well as experimental design. The salinities normally encountered in spring in the Broughton nearshore (20-30 ppt) are thus not likely to dramatically affect motile sea louse survival.
Importance to Broughton: Salinity is an environmental factor in sea louse survival that is incorporated into mathematical models for dispersal and infection. Real-life data on effects of salinity are essential if the models are to be relied on.
See also: For an earlier discussion about the importance of salinity, see Brooks, K.M. and Stucchi, D.J. 2006. **The effects of water temperature, salinity and currents on the survival and distribution of the infective copepodid stage of sea lice (*Lepeophtheirus salmonis*) originating on Atlantic salmon farms in the Broughton Archipelago of British Columbia (Brooks, 2005) – A response to the rebuttal of Krkošek et al.** (2005a). Reviews in Fisheries Science 14: 13-23.

Jones, S., E. Kim and W. Bennett. 2008. **Early development of resistance to the salmon louse, *Lepeophtheirus salmonis* (Krøyer), in juvenile pink salmon, *Oncorhynchus gorbuscha* (Walbaum).** Journal of Fish Diseases 31(8): 591-600.
Geographic area: Broughton
Sea lice topic: susceptibility of young pink salmon to sea lice
Kind of research: laboratory
Kind of document: peer reviewed journal article
Funder(s): Fisheries and Oceans Canada; Marine Harvest Canada
Rating: Must read
Question: How do small, post-emergence pink salmon respond to laboratory infection with *L. salmonis*?
Main message: In contrast to previous laboratory studies using 3-20 g juvenile pink salmon, smaller fish (from 0.3 to 2.4 g, a range likely to be found shortly after entry into seawater) responded to laboratory infection with some mortality at the smallest size tested (0.3 g). Mortality was lower in 0.7 g fish, and zero in 2.4 g fish. Bigger fish had less abundant sea lice and less mortality. Juvenile pink salmon thus appear to have an innate resistance to *L. salmonis* that develops in fish heavier than 0.3 g and is functional at 0.7 g. How the resistance works is unknown; no inflammation was seen, and lice were rejected whether the fish had developed scales or not. While more work is needed to determine this mechanism of resistance, these results point to a window between 0.3 g (average size at sea-entry) and 0.7 g, during which encounters with sea lice in the wild will cause mortality.
Importance to Broughton: Better knowledge of louse resistance in relation to size of juvenile salmon allows management of Atlantic salmon farms to accommodate the period of susceptibility.
See also: Jones et al. (2007), which uses a similar laboratory infection protocol on much larger (20 g) fish, without attendant mortality.

Skugor, S., K. Glover, F. Nilsen abd A. Krasnov. 2008. **Local and systemic gene expression responses of Atlantic salmon (*Salmo salar* L.) to infection with the salmon louse (*Lepeophtheirus salmonis*)**. BMC Genomics 9:498 (18 pp).
Geographic area: Norway
Sea lice topic: Physiological effects of lice on Atlantic salmon
Kind of research: laboratory
Kind of document: peer reviewed journal article
Funder(s): National Research Council of Norway
Rating: can read
Question: What is the underlying genetic basis for the high susceptibility of Atlantic salmon to lice?
Main message: The activity of several hundred genes involved in the response to salmon louse infection in skin, spleen, head kidney and liver was measured using micro-arrays that showed the level of gene activation at various periods after infection. The observed switching on or off of various genes was consistent with the delayed wound healing, restricted inflammatory response, and slowly repairing injuries commonly noted in Atlantic salmon.
Importance to Broughton: Provides a molecular-level insight into the high susceptibility of Atlantic salmon farmed in the Broughton area.
See also: Jones, S.R.M., M. D. Fast, S. C. Johnson and D. B. Groman. 2007. **Differential rejection of salmon lice by pink and chum salmon: disease consequences and expression of proinflammatory genes**. Dis. Aquat. Org. 75: 229–238 provides some contrasting gene expression data for two Pacific salmon species that are more resistant to sea lice than Atlantic salmon.

Connors, B.M. Krkošek and L. Dill. 2008. **Sea lice escape predation on their host.** Biology Letters 4(5):455-457.
Geographic area: Broughton Archipelago
Sea lice topic: louse behaviour
Kind of research: field
Kind of document: peer reviewed journal article
Funder(s): Watershed Watch Salmon Society; Sierra Club of BC; National Geographic Society; David Suzuki Foundation; Canadian Sablefish Association; Pacific Salmon Forum; NSERC; individual donors.
Rating: should read
Question: When juvenile pink and chum salmon get eaten by larger Pacific salmon, what happens to their sea lice?
Main message: Experimentally caught pink and chum juveniles, if placed in an enclosure with larger coho and cutthroat juveniles, get eaten. If those pink or chum are carrying sea lice, a high proportion of the male lice are able to jump to the predator. This male-biased trophic transmission makes evolutionary sense by increasing encounters with female lice. Health consequences for the predators (in this case, coho and cutthroat trout) are harder to judge, but suggest another indirect consequence of raised louse numbers in the vicinity of salmon farms.

Importance to Broughton: A fascinating life-history observation that reminds us that biological systems are full of surprises, even if we don't yet know quite what they mean.

Yazawa, R., Motoshige, Y., Jong, L., von Schalburg, K.R., Cooper, G.A., Beetz-Sargent, M., Robb, A., Davidson, W.S., Jones, S.R.M., and Koop, B.F. 2008. **EST and mitochondrial DNA sequences support a distinct Pacific form of salmon louse, *Lepeophtheirus salmonis.*** Mar. Biotechnol. 10: 741–749.
Geographic area: Pacific Ocean
Sea lice topic: Relevance of European experience to Pacific sea lice
Kind of research: field and lab
Kind of document: peer reviewed journal article
Funder(s): Genome B.C., province of B.C., Microtek International, Mainstream, Marine Harvest and Grieg Seafoods.
Rating: Should read
Question: Are the *L. salmonis* that parasitize Pacific salmon genetically different from Atlantic lice; if so, can that explain observed differences in their behaviour?
Main message: Based on genetic analysis of salmon lice collected from nine sites in Japan, Alaska and B.C., these lice are sufficiently different from those collected in the Atlantic Ocean to justify separation of the species into two distinct forms, and possibly two subspecies. The level of genetic separation and the amount of time it reflects support the idea that *L. salmonis* originated in the Atlantic, was introduced into the Pacific with the opening of the Bering Strait 5 million years ago, and then co-evolved with Pacific salmon.
Importance to Broughton: The considerable genetic differences between Atlantic and Pacific forms may account for observed differences in behaviour, such as salinity tolerance and incidence of disease caused by *L. salmonis*. The strongest understanding of sea lice in BC will thus probably come from local research.

Infection in the wild: patterns, mechanisms and models

Gottesfeld, A.S., B. Proctor, L.D. Rolston and C. Carr-Harris. 2009 in press. **Sea lice, *Lepeophtheirus salmonis*, transfer between wild sympatric adult and juvenile salmon on the north coast of British Columbia, Canada.** J. Fish. Dis. In press.
Geographic area: North coast B.C.
Sea lice topic: source of lice on juvenile pink salmon
Kind of research: field
Kind of document: peer reviewed journal article
Funder(s): B.C. Aquaculture Research and Development Committee; Pacific Salmon Forum; Pacific Salmon Commission
Rating: Must read
Question: In an area distant from salmon farms, where is the most likely source of *L. salmonis*?

Main message: Juvenile pink salmon were sampled by dip net and surface trawl in nearshore areas in Chatham Sound in 2004-2006. In 2006, adult coho and Chinook were also sampled in nearby areas (by hook and line). The levels of *L. salmonis* on juvenile pink salmon increase through the spring; by May and until July, returning Chinook and coho adults share the same habitat. In the absence of salmon farms, few stickleback and few resident coho and Chinook, returning coho and Chinook appear to be a major source of transmission to juvenile pink salmon. Much of the *L. salmonis* reproduction must occur at sea, and transfer in the coastal zone may be a relatively minor part of the louse reproductive strategy. The levels of *L. salmonis* on the North coast were found to be one or two orders of magnitude lower than in the Broughton.
Importance to Broughton: Uncertainty about the role of resident Chinook salmon notwithstanding, the most dramatic contrast between the North coast data and those from the Broughton would appear to be lower louse levels in the north, where there is an apparently exclusive reliance on natural transmission from incoming adult salmon.
See also: Beamish et al. (2007) for evidence of a role for returning adult salmon as a source of *L. salmonis*.

Penston, M., C. Millar, A. Zuur, and I. Davies. 2008. **Spatial and temporal distribution of *Lepeophtheirus salmonis* (Kroyer) larvae in a sea loch containing Atlantic salmon, *Salmo salar* L., farms on the north-west coast of Scotland.** Journal of Fish Diseases 31 (5): 361 - 371
Geographic area: Scotland
Sea lice topic: Dispersal patterns from farms
Kind of research: field
Kind of document: peer reviewed journal article
Funder(s): not stated
Rating: Must read
Question: How are louse larvae distributed in two lochs in relation to salmon farm location, season and depth?
Main message: Based on plankton sampling over two years in several locations in Loch Torridon and Loch Shieldaig, significant trends in density over the farm production cycle could be accounted for by the stocking and harvesting of salmon in farms. Copepodids were more widely distributed than nauplii, suggesting larval transport for several kilometers. The greatest density of nauplius larvae was at sampling stations near farms; spikes in abundance were assumed to be at least partially related to SLICE™ treatment on the farms. Invoking the results of mathematical models for louse transportation, especially those that account for the effects of wind strength and direction, could explain the appearance of farm-origin lice upstream of the farms (in other words, a wild source of these “head of inlet” lice is not their only possible explanation). The fact that louse densities rise and fall with the farming cycle argues for the farms as their source.
Importance to Broughton: As in the Broughton, interpretation of such point-source sampling studies still relies heavily on mathematical models to suggest how the lice are moving.
See also: Jones and Hargreaves (2007) is also a long term field survey, but in this case lice were counted on fish, not free-swimming.

Frazer, L.N. 2008a. **Sea-cage aquaculture, sea lice, and declines in wild fish.** Conservation Biology. Published online: 10.1111/j.1523-1739.2008.01128.x
Geographic area: Europe and Broughton
Sea lice topic: predator-prey equilibria and host-density effects
Kind of research: desk study
Kind of document: essay
Funder(s): Pure Salmon Campaign of the National Environmental Trust
Rating: Can read
Question: What is the basic physics of the exchange of lice between wild and farmed fish?
Main message: Mathematical treatment of the host-density effect suggests that a treatment threshold of 0.5 lice per farmed salmon is not low enough to reverse decline of wild salmon. Basic physics dictates that wild fish will decline wherever protected farmed hosts and sympatric (same-area) wild hosts have a common parasite. You don't need difficult mathematics to see that louse abundance on farmed fish has to be kept to less than a few percent of their abundance on wild fish.
Importance to Broughton: A contribution to the development of models.
See also: Frazer 2008b.

Frazer, L. N. 2008b. **Sea-lice infection models for fishes**. Journal of Mathematical Biology 57(4):595-611.
Geographic area: global
Sea lice topic: mathematical modeling of infection
Kind of research: Desk study
Kind of document: peer reviewed journal article
Funder(s): not stated
Rating: Can read
Question: Does host mortality affect estimates of larvae production? What are the effects of louse clumping?
Main message: Describes a three-stage mathematical infection model that includes host mortality and louse clumping. The model provides new insights into previous mathematical studies concerning infection of juvenile salmon passing a salmon farm.
Importance to Broughton: A contribution to the development of models.
See also: Frazer 2008a.

Jones, S. R.M and N. B. Hargreaves. 2007. **The abundance and distribution of *Lepeophtheirus salmonis* on pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon in coastal British Columbia.** J. Parasitol. 93(6):1324–1331.
Geographic area: Broughton
Sea lice topic: variation in abundance and prevalence of sea lice on wild pink and chum juveniles by year and by region
Kind of research: field

Kind of document: peer reviewed journal article
Funder(s): DFO
Rating: Must read
Question: How many lice were found on wild juvenile pink and chum salmon in the Broughton in 2004 and 2005?
Main message: Approximately 4,000 juvenile pink salmon and an equivalent number of chum were collected within eleven zones in the Broughton Archipelago over three time periods during May and July of 2004 and 2005. Declines in abundance over the spring and summer, for both years, coincided with an increase in motile lice stages. Although there were some differences in abundance, prevalence and intensity of lice on each species during a given year, the most obvious finding was that all three measures of infection were higher, for both species, in 2004. Infestations were not uniform throughout the study area in either year. Records of surface salinity and temperature at each collection site suggest that abundance was lowest in areas where surface salinity was lowest. Comparison with records for previous and subsequent years identifies 2004 as a peak year for sea louse abundance (2006 was similar to 2003). The fourfold reduction in abundance reported for most zones in 2005 is not likely related to fallowing (there was no coordinated fallowing in Tribune Channel in that year). Lower abundance in 2005 may reflect treatment of farmed salmon with SLICE™, but this factor is unlikely to act alone. Common environmental processes involving salinity and temperature probably also play a role in regulating abundance on both captive and wild populations.
Importance to Broughton: Adds another two years of analyzed data to field sampling in the Broughton, and provides vital continuity in the year to year picture. However, the coincident variation in environmental variables, and trends in management practices like fallowing and chemical treatment, still can't be assigned quantitative roles in influencing the abundance, prevalence and intensity of louse infections on wild salmon.

Morton, A., R. Routledge and M. Krokosek. 2008. **Sea louse infestation in wild juvenile salmon and Pacific herring associated with fish farms off the East-Central coast of Vancouver Island, British Columbia.** North American Journal of Fisheries Management 28:523–532.
Geographic area: Discovery Islands, BC
Sea lice topic: sea louse infestation on wild fish outside the Broughton area
Kind of research: field
Kind of document: peer reviewed journal article
Funder(s): Tides Canada Foundation; David Suzuki Foundation; BC Wilderness Tourism Association
Rating: Must read
Question: How severe is louse infestation on wild fish outside the Broughton area, and how is infestation related to salmon farms and physical environmental variables?
Main message: An area in northern Georgia Strait (the "Discovery Islands") was sampled for juvenile salmonids by beach seine in spring and early summer of 2005 and 2006. Sampling sites were designated "exposed to farms" or "peripheral" based on assumptions about the direction of migration of wild juvenile salmon and the likelihood that they would be directly exposed to some salmon farms in order to reach the sampling

sites. Farms contained either Atlantic or chinook salmon. Their production status during sampling was determined from farm company records in 2005, and by observation from a boat in 2006. Overall production status showed fewer sites with older (that is, more likely to amplify sea lice) farmed fish in 2006. Two of 15 sites were also sampled specifically for juvenile herring and sockeye salmon in 2005. Sea louse abundance was lower for "peripheral" sampling sites. Louse abundance was greater in 2005. Juvenile salmon in the "peripheral" area may also have been exposed to sea lice, but the natural baseline level of abundance is not known. Assumed probability of exposure to farms was the only factor consistently explaining the data; salinity and temperature were not significant factors, and the effect of any SLICE™ treatment on the farms was not considered. The influence of salmon farms may overwhelm any influence of environmental factors like temperature and salinity (which affect the behaviour of sea lice). The limited data from juvenile sockeye salmon and herring provide preliminary evidence that sea lice from farms may affect these species as well.
Importance to Broughton: This is the first observation in Pacific Canada of an association between salmon farms and sea lice on wild salmon outside of the Broughton Archipelago.
See also: Gottesfeld et al. 2009 (in this section).

Treatment with SLICE™

Lees, F., M. Baillie, G. Gettinby, and C. W. Revie. 2008. **The efficacy of emamectin benzoate against infestations of *Lepeophtheirus salmonis* on farmed Atlantic salmon (*Salmo salar* L) in Scotland, 2002-2006.** PLoS ONE 3(2):e1549.
Geographic area: Scotland
Sea lice topic: chemical control
Kind of research: field and laboratory
Kind of document: peer reviewed journal article
Funder(s): not stated
Rating: Should read
Question: How well has emamectin benzoate worked over a four year period?
Main message: Farm records of *L. salmonis* infestations before and after SLICE™ treatment at 56 Marine Harvest sites in Scotland were analyzed using an epi-informatics method. 108 treatment episodes were analyzed between 2002 (when SLICE™ was first used in Scotland) and 2006, in order to look for evidence of a decrease in efficacy that might indicate development of resistance. While analysis of data from a commercial setting was complex, most of the SLICE™ treatments reduced infestation – but efficacy was not uniform between years or geographic regions. Ineffective treatments appeared to become more common in later years. Comparisons of findings with the situation in BC are hard to make, but SLICE™ may not be as effective on Scottish farms as it once was (for a variety of reasons. Further monitoring by all users in all countries is crucial.
Importance to Broughton: SLICE™ is the only anti-louse chemical available for BC salmon farms, and forms part of the current integrated management approach. Any indication of reduced efficacy needs to be factored into management.

See also: Reports of reduction in *L. salmonis* in the Broughton in 2005 have been related to the use of SLICE™ (Jones and Hargreaves 2007; Lees et al. 2008a).

Lees, F., G. Gettinby and C. W. Revie. 2008. **Changes in epidemiological patterns of sea lice infestation on farmed Atlantic salmon, *Salmo salar* L., in Scotland between 1996 and 2006**. Journal of Fish Diseases 31(4): 259-268.
Geographic area: West coast of Scotland
Sea lice topic: patterns of infestation on Atlantic salmon farms
Kind of research: field study
Kind of document: peer reviewed journal article
Funder(s): MAFF (UK); Marine Harvest (Scotland)
Rating: Must read
Question: What is the long term abundance of sea lice on farmed Atlantic salmon in relation to treatment?
Main message: Sea louse abundance data collected at 54 salmon farms operated by Marine Harvest (Scotland) between 1996 and 2006 were analyzed in relation to farm management practices, especially the use of emamectin benzoate (SLICE™). The sites account for around 20% of Scottish production during that period. There was a statistically significant drop in louse abundance during the summer months of the second production year after 2002, coinciding with the availability and use of SLICE™ (with some regional variation). To avoid development of resistance in lice, various ectoparasitic medications may need to be used in rotation.
Importance to Broughton: SLICE™ is an important part of louse management on farms in the Broughton.
See also: A good discussion of principles for sampling lice in farmed salmon cages can be found in Revie, C.W., Gettinby, G., Treasurer, J.W., and Wallace, C., 2005. **Evaluating the effect of clustering when monitoring the abundance of sea lice populations on farmed Atlantic salmon.** Journal of Fish Biology 66: 773-783.

Westcott, J. D., H. Stryhn, J. F. Burka, and K. L. Hammell. 2008. **Optimization and field use of a bioassay to monitor sea lice *Lepeophtheirus salmonis* sensitivity to emamectin benzoate.** Diseases of Aquatic Organisms 79(2):119.
Geographic area: Bay of Fundy
Sea lice topic: development of resistance to emamectin benzoate
Kind of research: laboratory
Kind of document: peer reviewed journal article
Funder(s): AquaNet; Atlantic Innovation Fund
Rating: Can read
Question: Is bioassay a useful tool for tracking sea louse sensitivity to SLICE™?
Main message: The potential for *L. salmonis* to develop resistance to SLICE™ means that we need a way of unequivocally monitoring any changes in louse sensitivity. The new bioassay protocol described here would allow early detection of changes in sensitivity of preadult stages of *L. salmonis*. The bioassay, which exposes lice to SLICE™ concentrations covering the range they would be expected to encounter when feeding on

SLICE™ -medicated Atlantic salmon, shows that females were more susceptible than males (so sex will influence bioassay results). The bioassay is currently most useful as a research tool and is not yet practical for monitoring resistance in the field.
Importance to Broughton: Adds to the list of tools needed to monitor for SLICE™ resistance.
See also: Tribble et al. (2008) for a molecular-level tool to judge development of resistance.

Olsvik, P.A., K.K. Lie, E. Mykkeltvedt, O.B. Samuelsen, K. Petersen, A-K. Stavrum and B.T. Lunestad. 2008. **Pharmacokinetics and transcriptional effects of the anti-salmon lice drug emamectin benzoate in Atlantic salmon (*Salmo salar* L.).** BMC Pharmacology 8:16.
Geographic area: Norway
Sea lice topic: physiological effects of SLICE™ on Atlantic salmon
Kind of research: laboratory
Kind of document: peer reviewed journal article
Funder(s): not stated
Rating: Can read
Question: What are the molecular signs of the physiological effects of SLICE™ administered orally to Atlantic salmon?
Main message: Using molecular techniques (micro-array and qPCR), the effects of orally administered SLICE™ (50 ug/kg body weight) were measured in liver, muscle and skin. This standard 7-day treatment had only modest physiological effects based on evidence of gene regulation: a temporary stress response that affected protein stability and folding, and a secondary inflammation.
Importance to Broughton: Depending on the SLICE™ treatment levels used in the Broughton, this research provides molecular evidence of relatively minor physiological effects on juvenile Atlantic salmon.

Tribble, N., J. Burka, F. Kibenge, and G. WrightT. 2008. **Identification and localization of a putative ATP-binding cassette transporter in sea lice (*Lepeophtheirus salmonis*) and host Atlantic salmon (*Salmo salar*).** Parasitology 135(2):243.
Geographic area: global
Sea lice topic: resistance to emamectin benzoate (SLICE™)
Kind of research: laboratory
Kind of document: peer reviewed journal article
Funder(s): Aquanet; NSERC; Elanco Animal Health
Rating: Can read
Question: Does *L. salmonis* have the molecular machinery for developing resistance to SLICE™?
Main message: A gene and its product that are known to be involved in the development of resistance to emamectin benzoate in other invertebrates have now been identified in *L. salmonis* using molecular methods. This shows that sea lice have at least one proven mechanism of resistance development.

Importance to Broughton: Analyzing the level of expression of this gene could be a way of corroborating field observations of resistance to SLICE™ used on Atlantic salmon farms.
See also: Lees, F., G. Gettinby and C. W. Revie. 2008a. **Changes in epidemiological patterns of sea lice infestation on farmed Atlantic salmon, *Salmo salar* L., in Scotland between 1996 and 2006**. Journal of Fish Diseases in press.

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Cubitt, F., K. Butterworth, and R. S. McKinley. 2008. A synopsis of environmental issues associated with salmon aquaculture in Canada. In: Aquaculture, Innovation and Social Transformation. Culver, K. and D. Castle. Springer.

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