Some considerations on organic certification of farmed salmon from the perspective of infectious disease

prepared for

The National Organic Standards Board
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by

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Specific NOSB Question 1:

How can net pens be ecologically responsible? What requirements need to be included in the proposed regulation to assure this? How can the issues of water flow and rotational locations be included? What are the other issues?

Summary

I have addressed these questions from the perspective of disease interactions between wild and farmed fish.

- Disease threats to farmed and wild salmon include a multitude of pathogens and open net pen salmon farming allows pathogen transmission between wild and farmed stocks.
- Disease threats of farmed salmon to wild fish are related to the number of salmon per salmon farm and the number of salmon farms in a region.
- The point at which the number of salmon per farm and the number of farms in a region becomes ecologically damaging is unpredictable and difficult to identify.
- It is not possible to construct general guidelines that protect wild fish from disease threats of open net pen salmon farms.
- It is very difficult if not impossible to monitor for disease impacts of open net pen salmon farms on wild fish even if they are severe.
- Proposed organic standards do not address the number of organic and non-organic salmon farms that can be situated in a region and so cannot control the disease threat to wild fish.
- The only way to ensure salmon farms do not pose disease threats to wild fish is to use closed containment technology that removes viruses, bacteria, and parasites from farmed salmon effluent before being released into the environment.

Rationale

There are many salmonid pathogens that can threaten both wild and farmed stocks (Table 1).

Pathogen	Type	Disease
IHN Virus	Virus	Infectious haematopoietic necrosis
IPN Virus	Virus	Infectious pancreatic necrosis
Renibacterium salmoninarum	Bacteria	Bacterial kidney disease
Vibrio salmonicida	Bacteria	Vibriosis
Yersinia ruckeri	Bacteria	Enteric redmouth disease
Aeromonas salmonicida	Bacteria	Furunculosis
Piscirickettsia salmonis	Bacteria	Salmon rickettsial disease
Lepeophtheirus salmonis	Salmon lice	Morbidity and mortality
Caligus elongates	Sea lice	Morbidity and mortality
Caligus clemensi	Sea lice	Morbidity and mortality

Table 1. Some pathogens of wild and farmed salmon.

Open net pen salmon aquaculture may or may not be ecologically responsible, from the perspective of disease threats to wild fish, depending on the scale of production (i.e. number of salmon per farm and the number of farms in an area). The point at which the scale of production becomes ecologically damaging is inherently unpredictable, nearly impossible to identify, and cannot be generalized. The scale of production includes the summation of all farmed salmon – organic and non-organic – in a given region. Because the proposed organic standards do not address the number of organic and non-organic open net pen farms that can be situated in a region it is not possible for organic standards to keep the density of farmed salmon in an area below a density (if it were possible to know this threshold) that protects wild salmon.

The disease threats of salmon farms to wild fish increase as the number of salmon farms in a region increases. When the number of farms in an area is low and the number of salmon per farm is low then the chances of disease outbreaks is reduced and the magnitude of pathogen transmission from farmed to wild salmon is reduced. However, when there are high abundances of salmon per farm and/or many farms in a region the chance of disease outbreaks is high and the magnitude of pathogen transmission from farm salmon to wild fish is increased. This is a fundamental epidemiological law – the chance of disease outbreaks increases as host density increases (*1*-*5*).

For viral and bacterial pathogens the probability of outbreaks increases as host density increases and at sufficiently high abundance epidemics can emerge and persist (*1, 2, 5*). Therefore at high abundances of salmon per farm and/or when there are many farms in an area the chance of bacterial or viral disease outbreaks is high and wild salmon are correspondingly at risk. In Canada outbreaks of at least IHN, furnculosis, bacterial kidney disease, and vibriosis are known to have occurred in open net pen farmed salmon stocks. The transition from host abundances where disease outbreaks are rare to when they are common may be gradual or abrupt and is inherently unpredictable (*5*). This makes it nearly impossible to identify target host densities at which viral or bacterial outbreaks in farmed salmon are prevented and the risk of pathogen exposure of wild fish is reduced.

Similarly for parasites, the abundance of parasites per host increases with host abundance (*1, 2, 6*). Even at low parasite abundances (parasites per host) the risk to wild fish may be large if the number of farmed salmon in a region is high because the transmission of parasites from farmed salmon to wild fish is determined by multiplying the number of parasites per farmed salmon by the number of farmed salmon per farm times the number of salmon farms (*7, 8*). Therefore, reducing the number of parasites per farmed salmon is not enough to prevent disease problems in wild fish; the total number of farmed fish in a region must also be kept low. This has been a primary problem for sea lice threats of farmed salmon to wild salmonids in Norway (*7*), Ireland (*8*), and Canada (*9*) where the presence of many salmon farms in a region combines to produce a major parasite threat to wild salmon.

In general, it is not possible to determine the scale at which the intensity of farmed salmon production in a region will transition from ecologically benign to ecologically damaging. The details of the scale at which the production of farmed salmon will cause disease and parasite threats to wild salmon populations will depend on the epidemiological details of the pathogen, on the ecological details of the exposed wild salmon populations, and on the physical oceanographic processes in the areas where wild and farmed salmon coexist. The precise point at which the scale of aquaculture production becomes ecologically damaging is therefore inherently unpredictable and will vary on a case by case basis. While certain management practices such as fallowing, rotational locations, selecting sites with high flushing may reduce the risk of disease, it is not possible to construct general guidelines that will ensure protection of wild fish from disease threats from open net pen farmed salmon.

The situation is exacerbated by the fact that it is not possible to monitor the efficacy of management practices at protecting wild fish from disease exposure from farmed salmon. Monitoring disease dynamics in the ocean is notoriously difficult because infected wild fish may not live to be sampled. While considerable progress has been made at tracking sea lice transmission from farmed salmon to wild salmon (*10*), most salmonid pathogens are viral or bacterial and disease symptoms caused by these pathogens are generally not detectable until just before death. Disease in wild fish populations is commonly not detectable even if disease is having severe impact on wild fish populations. Thus, disease can be an invisible cause of wild fish declines and salmon farms can be an invisible driver.

There is a multitude of pathogens that infect both wild and farmed salmon. Open net pen salmon farming can allow transmission of these pathogens between wild and farmed stocks. Disease outbreaks become more prevalent and salmon farming becomes more ecologically damaging when there are many open net pen salmon per farm and/or many open net pen salmon farms in a region. It is not possible for organic standards to protect wild salmon from pathogens from farmed salmon because organic standards cannot control the number of organic and non-organic salmon farms situated in a region. The only way to ensure salmon farming is not ecologically damaging, from the perspective of disease threats to wild fish, is to move to closed containment technology that removes viruses, bacteria, and parasites from salmon farm effluent before it is released into the surrounding environment.

Specific NOSB Question 2:

What is the prevalence or rate of sea lice infestations in wild fish populations where there are no net pens? What are the regional variations? Are sea lice infestations inherent with open net pen systems? How can they be controlled without prohibited substances in an organic system?

Summary

I answered these questions from the perspective of salmon lice (*Lepeophtheirus salmonis*) and Pacific salmon in British Columbia. Among Pacific salmon, pink and chum are the best studied.

- In areas without salmon farms sea lice prevalence on juvenile pink and chum salmon during their first three months of marine life ranges 0-5%.
- Infestations of wild juvenile Pacific salmon with salmon lice have only occurred in areas with salmon farming.
- Open net pen farmed salmon are susceptible to salmon lice infection because lice occur naturally and can be transmitted from wild salmon and among salmon farms.
- Salmon lice can breed on farmed salmon and be transmitted to wild juvenile salmon raising infections from natural levels (<5%) up to 100% and cause up to 95% mortality.
- The magnitude of sea lice transmission from farmed salmon to wild salmon depends on the number of sea lice per farmed salmon, the number of salmon per farm, and the number of salmon farms in a region.
- Proposed organic standards cannot ensure the protection of wild salmon from exposure to sea lice from open net pen salmon farms because they do not address the number of organic and non-organic salmon farms that can be situated in a region nor their coordinated management.
- There are no strategies that do not involve chemical therapeutants that have been shown to eliminate sea lice from open net pen farmed salmon.
- The only way to ensure sea lice are not transmitted to wild salmon is to move to closed containment technology that removes sea lice from farmed salmon effluent before being released into the surrounding environment.

Rationale

Salmon lice (*Lepeophtheirus salmonis*) have been studied on wild juvenile Pacific salmon in British Columbia in areas with and without salmon farms since 2001. Recurrent salmon lice infestations have been reported from all salmon farming areas studied in British Columbia, but this is limited to two regions (*10-12*). Other salmon farming regions in British Columbia have been studied but these data have not yet been published. The areas without salmon farms include three distinct regions of British Columbia and all show salmon lice prevalence is <5% on juvenile pink and chum salmon during their first three months of marine life (*11, 13, 14*).

The best-studied salmon farming region of British Columbia is known as the Broughton Archipelago and is located east of northern Vancouver Island. Since 2001 there have been recurrent infestations of salmon lice on wild juvenile pink and chum salmon that are strongly associated with salmon farms (*10, 11, 15-17*). The infestations have been variable in intensity, with salmon lice abundance decreasing with management action such as fallowing (*16*) and increasing when there is more than one salmon farm along the wild juvenile salmon migration routes (*10*). Individual salmon farms can increase the abundance of infectious salmon lice larvae for over 30 km of wild salmon migration route (*17*). When there are several active farms along the migration route the abundance of infectious larvae can be elevated for over 80 km of wild salmon migration route which amounts to the first 2-3 months of marine life of juvenile pink and chum salmon (*10*).

In all years the mean abundance of salmon lice on juvenile pink and chum salmon in the Broughton Archipelago have greatly exceeded the natural abundances of sea lice observed in regions with no salmon farms. Similar patterns have been observed in the only other salmon farming region of British Columbia where data are published: the Discovery Islands (*12*). There, salmon lice abundance on juvenile pink and chum salmon is related to the number of salmon farms to which the wild juvenile salmon have been exposed (*12*). In addition to pink and chum, similar trends were observed for juvenile sockeye salmon as well as a different species of louse – *Caligus clemensi* – on juvenile herring. Canada's most valuable wild salmon stock, Fraser River Sockeye, migrate through these waters and it is possible that increased salmon lice exposure caused by salmon farms is responsible for recent recruitment failures and severe fishery restriction of this stock.

There are other factors that affect sea lice population dynamics in addition to salmon farms, such as temperature and salinity. Relatively warmer temperatures increase salmon lice developmental rates (*18*) and survival is poor in laboratory conditions when salinity declines below 30 ppt (*19*). It is difficult to gauge the effects of salinity on sea lice in nature, however, because sea lice are known to respond to salinity and light and can situate themselves in favorable positions of the water column (*20, 21*). Because the water column has vertical structure in current, salinity, and temperature it is possible to observe a diverse range of dispersal patterns of sea lice from salmon farms (*22*), including those observed repeatedly in the Broughton Archipelago (*10, 17*). Clearly, the risk of salmon lice spread from farmed to wild salmon is decreased in areas with cold water and low salinity.

The abundance and distribution of other natural hosts of salmon lice will also affect the population dynamics of sea lice. Sea lice occur naturally on adults of all species of wild Pacific salmon (*23, 24*) and adult salmon carry these lice into coastal waters during their return migration (*25*). Adult Pacific salmon return to coastal waters about 3 months after juvenile salmon enter the sea (*26, 27*). The period when both adult and juvenile salmon both occupy coastal habitats enables salmon lice to be transmitted from adult to juvenile salmon (*14*). Once the adult salmon migrate into freshwater their salmon lice rapidly die because of the low salinity. Salmon lice may persist in coastal ecosystems over the winter by infecting small populations of cutthroat trout, Dolly Varden, and Chinook salmon, and other salmonids. In spring, wild juvenile salmon migrate to sea and experience low sea lice exposure from these overwintering hosts (prevalence is less than 5%) until the return migration of adult salmon when salmon lice prevalence rises abruptly to 10-20% (*14*).

It is important to understand that the salmon migration schedule described above gives rise to a three month period immediately following marine entry of wild juvenile salmon in which the exposure of wild juvenile salmon to salmon lice is very low (*14*). Salmon farms provide an overwintering host population for salmon lice that is several orders of magnitude larger than the naturally occurring overwintering hosts. Farmed salmon in open net pens can become infected by wild adult salmon when they return to coastal waters (*25*) and sea lice can subsequently breed on the farmed salmon during the winter and pose a major threat to wild juvenile salmon the following spring (*9, 10, 14, 24*). Because it takes more than one year for farmed salmon to grow from smolt to harvestable size it is not possible to construct a stock and harvest schedule or a stock and fallow rotation that avoids providing salmon lice an abundant overwintering host.

Salmon are most vulnerable to salmon lice during their first three months of marine life because they are small (0.3-2 grams), they have poorly developed scales, and are physiologically stressed by the transition from freshwater to marine habitat. Salmon lice are lethal to juvenile pink and chum salmon when they are small (0.3-2 grams) and lack scales (*28*) but are relatively benign when salmon reach ~10-20 grams and have scales (*29*) which is their developmental state after 2-3 months of marine life when they would naturally encounter salmon lice from returning wild adult Pacific salmon (*14*). As such, salmon lice from farmed salmon pose a parasite threat to wild salmon that occurs when the wild salmon are smallest and most vulnerable to salmon lice infection.

Salmon farms can expose wild juvenile salmon to an abundance of salmon lice during their first 2-3 months of marine life (*9, 10, 24*) and this has resulted in epizootic mortality of wild juvenile salmon that ranges 9-95% (*10*). The mortality estimates increase with the number of salmon farms the wild juvenile salmon must migrate past as well as with time in the migration season because lice accumulate as time passes (*10*). A simple mathematical model that synthesizes this information predicts an initial rapid decline in pink salmon population abundance and pink salmon population collapse ultimately occurs when louse abundance is in the range of 1-5 motile *L. salmonis* per juvenile pink salmon (*14*). This is consistent with observed population declines of pink salmon in the Broughton Archipelago. It is clear that open net pen salmon farms pose a major threat to wild salmon populations by increasing the exposure of wild juvenile salmon to salmon lice.

One obvious management action consistent with organic standards that is available to control salmon lice on farmed salmon and minimize the threat of salmon lice to wild juvenile salmon is fallowing. Fallowing reduces salmon lice abundance on salmon farms because it removes the farmed salmon entirely from the net pens. In one experiment, fallowing salmon farms along a wild salmon migration route during the juvenile pink and chum salmon out-migration reduced salmon lice abundance on wild juvenile salmon (*16*) and the survival of this cohort of pink salmon was very high (*30*). However, because it takes more than one year for farmed salmon to grow from smolts to harvestable size it is not possible to fallow salmon farms every year during the wild juvenile salmon out-migration. Thus, it is necessary to have another louse control strategy that can be applied to farmed salmon during the wild salmon outmigration.

There are no known louse control methods, besides fallowing, that can eliminate salmon lice from open net pen farmed salmon in a way that is consistent with organic standards. Chemical therapeutants such as emamectin benzoate and ivermectin are routinely used to reduce lice on European salmon farms (*24*) and probably reduce lice on farmed salmon in British Columbia, though this has not yet been shown. However, salmon lice can evolve resistance to these chemicals and the chemicals themselves are not allowed under organic standards. Cleaner wrasse are fish species that eat salmon lice from the sides of farmed salmon and so may help reduce sea lice abundances on farmed salmon (*31*). In order for the use of wrasse to meet organic standards the wrasse would have to be native Pacific species caught locally otherwise the escape of wrasse through the net pens would constitute the introduction of non-native species. In the Atlantic, escaped wrasse from open net salmon farms may also be against organic standards. I am unaware of any research on or use of cleaner fish sourced from local Pacific populations for application on salmon farms in British Columbia.

The most effective management programs for controlling salmon lice on farmed salmon in open net pens come from integrated pest management strategies that are coordinated at the scale of salmon farming region rather than at the scale of the individual farm (*32*). Such strategies involve selecting sites with high flushing and poor conditions for salmon lice, coordinated fallowing to break the life-cycle of salmon lice and reduce farm to farm transmission, and the application of wrasse and chemical therapeutants. Coordinated area management is necessary for at least two reasons. The first is that the susceptibility of salmon farms to salmon lice is dependent on the management of nearby farms (farm to farm transmission). Because salmon lice can disperse for over 30 km, the area management strategy may have to span regions of coastline over 100 km. The second reason is that the threat of salmon lice to wild salmon from farmed salmon is determined by the exposure caused by all salmon farms to which the wild salmon are exposed; salmon farm sites that in isolation may be benign can become highly exposed to salmon lice and damaging to wild salmon by the introduction of new open net pen salmon farms in the same region.

Organic standards for prospective open net pen farms apply at the level of individual farms but not at the regional level that spans several farms. Thus, the standards do not apply at the level of farm operation and management where the processes occur that determine the threat of salmon lice to wild juvenile salmon. Proposed organic standards do not control the siting of organic or non-organic farms in proximity to each other or their coordinated management. Thus, even if there were organic methods that could eliminate salmon lice from open net pen farmed salmon – and there are none – it would nevertheless be impossible for the standards to ensure the protection of wild juvenile salmon from increased salmon lice exposure caused by salmon farms. For this reason the organic standards as applied to open net pen salmon farming are fundamentally flawed and cannot achieve organic principles. Only once coordinated area management of open net pen salmon farming is demonstrated to meet organic principles and only once organic standards are expanded to apply at the regional scale can organic certification for open net pen salmon farms be considered. As currently written, organic standards for salmon farming can only be met by using closed containment technology that removes sea lice (and all other waste, pathogens, and contaminants) from farmed salmon effluent before being released into the environment.

References

1. B. T. Grenfell, A. P. Dobson, *Ecology of Infectious Diseases in Natural Populations* (Cambridge University Press, Cambridge, 1995).
2. P. J. Hudson, A. Rizzoli, B. T. Grenfell, H. Heesterbeek, A. P. Dobson, *The Ecology of Wildlife Diseases* (Oxford University Press, Oxford, 2001).
3. R. M. May, R. M. Anderson, *Infectious Diseases of Humans* (Oxford University Press, Oxford, 1991).
4. R. M. Anderson, R. M. May, Regulation and stability of host-parasite population interactions. I Regulatory processes *Journal of Animal Ecology* **47**, 219 (1978).
5. J. O. Lloyd-Smith *et al.*, Should we expect population thresholds for wildlife disease? *Trends in Ecology and Evolution* **20**, 511 (2005).
6. P. Arneberg, A. Skorping, B. Grenfell, A. F. Read, Host densities as determinants of abundance in parasite communities *Proceedings of the Royal Society of London Series B* **265**, 1283 (1998).
7. P. A. Heuch, T. A. Mo, A model of salmon louse production in Norway: effects of increasing salmon production and public management measures *Diseases of Aquatic Organisms* **45**, 145 (2001).
8. J. R. A. Butler, Wild salmonids and sea louse infestations on the west coast of Scotland: sources of infection and implications for the management of marine salmon farms *Pest Management Science* **58**, 595 (2002).
9. C. Orr, Estimated sea louse egg production from Marine Harvest Canada farmed Atlantic salmon in the Broughton Archipelago, British Columbia, 2003-2004 *North American Journal of Fisheries Management* **27**, 187 (2007).
10. M. Krkošek, M. A. Lewis, A. Morton, L. N. Frazer, J. P. Volpe, Epizootics of wild fish induced by farm fish *Proceedings of the National Academy of Sciences of the USA* **103**, 15506 (2006).
11. A. Morton, R. Routledge, C. Peet, A. Ladwig, Sea lice (*Lepeophtheirus salmonis*) infection rates on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon in the nearshore marine environment of British Columbia, Canada *Canadian Journal of Fisheries and Aquatic Sciences* **61**, 147 (2004).
12. A. M. Morton, R. Routledge, M. Krkošek, Sea lice infestation of wild juvenile salmon and herring associated with fish farms off the east central coast of Vancouver Island, BC *North American Journal of Fisheries Management* **in press** (2007).
13. C. R. Peet, M.Sc. Thesis, University of Victoria (2007).
14. M. Krkošek *et al.*, Effects of host migration, diversity, and aquaculture on sea lice threats to Pacific salmon populations *Proceedings of the Royal Society of London Series B* **in press** (2007).
15. A. B. Morton, R. Williams, First report of a sea louse, *Lepeophtheirus salmonis*, infestation on juvenile pink salmon, *Oncorhynchus gorbuscha*, in nearshore habitat *Canadian Field Naturalist* **117**, 634 (2003).
16. A. Morton, R. D. Routledge, R. Williams, Temporal patterns of sea louse infestation on wild Pacific salmon in relation to the fallowing of Atlantic salmon farms *North American Journal of Fisheries Management* **25**, 811 (2005).

17. M. Krkošek, M. A. Lewis, J. P. Volpe, Transmission dynamics of parasitic sea lice from farm to wild salmon *Proceedings of the Royal Society of London Series B* **272**, 689 (2005).
18. A. Stien, P. A. Bjorn, P. A. Heuch, D. A. Elston, Population dynamics of salmon lice Lepeophtheirus salmonis on Atlantic salmon and sea trout *Marine Ecology-Progress Series* **290**, 263 (2005).
19. I. R. Bricknell, S. J. Dalesman, B. O'Shea, C. C. Pert, A. J. M. Luntz, Effect of environmental salinity on sea lice Lepeophtheirus salmonis settlement success *Diseases of Aquatic Organisms* **71**, 201 (2006).
20. P. A. Heuch, A. Parsons, K. Boxaspen, Diel Vertical Migration - a Possible Host-Finding Mechanism in Salmon Louse (Lepeophtheirus-Salmonis) Copepodids *Canadian Journal of Fisheries and Aquatic Sciences* **52**, 681 (1995).
21. P. A. Heuch, Experimental-Evidence for Aggregation of Salmon Louse Copepodids (Lepeophtheirus-Salmonis) in Step Salinity Gradients *Journal of the Marine Biological Association of the United Kingdom* **75**, 927 (1995).
22. P. A. Gillibrand, J. W. Kate, Dispersal of sea lice larvae from salmon farms: A model study of the influence of environmental conditions and larval behaviour *Aquatic Biology* **in press** (2007).
23. K. Nagasawa, Annual changes in the population size of the salmon louse *Lepeophtheirus salmonis* (Copepoda : Caligidae) on high-seas Pacific Salmon (*Oncorhynchus* spp.), and relationship to host abundance *Hydrobiologia* **453**, 411 (2001).
24. M. J. Costello, Ecology of sea lice parasitic on farmed and wild fish *Trends in Parasitology* **22**, 475 (2006).
25. R. J. Beamish, C. M. Neville, R. M. Sweeting, N. Ambers, Sea lice on adult Pacific salmon in the coastal waters of central British Columbia, Canada *Fisheries Research* **76**, 198 (2005).
26. C. Groot, L. Margolis, *Pacific salmon life histories* (UBC Press, Vancouver, 1991).
27. T. P. Quinn, *The Behavior and Ecology of Pacific Salmon and Trout* (University of Washington Press, Seattle, 2005).
28. A. Morton, R. Routledge, Mortality rates for juvenile pink *Oncorhynchus gorbuscha* and chum *O. keta* salmon infested with sea lice *Lepeophtheirus salmonis* in the Broughton Archipelago *Alaska Fisheries Research Bulletin* **11**, 146 (2005).
29. S. Jones, E. Kim, S. Dawe, Experimental infections with Lepeophtheirus salmonis (Kroyer) on threespine sticklebacks, Gasterosteus aculeatus L., and juvenile Pacific salmon, Oncorhynchus spp *Journal of Fish Diseases* **29**, 489 (2006).
30. R. J. Beamish *et al.*, Exceptional marine survival of pink salmon that entered the marine environment in 2003 suggests that farmed Atlantic salmon and Pacific salmon can coexist successfully in a marine ecosystem on the Pacific coast of Canada *ICES Journal of Marine Science* **63**, 1326 (2006).
31. J. W. Treasurer, A review of potential pathogens of sea lice and the application of cleaner fish in biological control *Pest Management Science* **58**, 546 (2002).
32. A. J. Mordue, A. W. Pike, Salmon farming: towards an integrated pest management strategy for sea lice *Pest Management Science* **58**, 513 (2002).