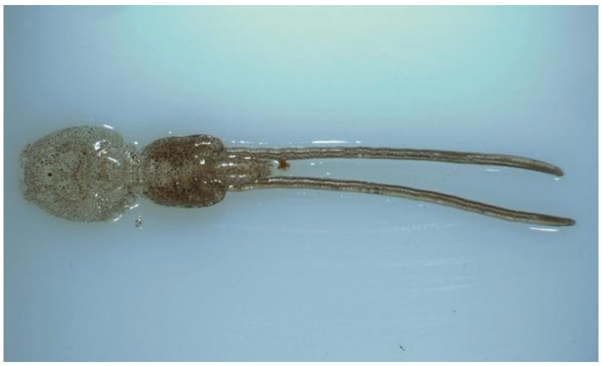
SEA LICE MONITORING AND NON-CHEMICAL MEASURES



Gravid female sea louse.
Photo by: Dr. Shawn Robinson (DFO)

Figure 1. Map of Fisheries and Oceans Canada's (DFO) six administrative regions.

Context

The management of sea lice has been a challenge for the salmon aquaculture industry, both nationally and internationally. Two management objectives are of particular importance at present:

(1) ensuring that transmission of sea lice from farms to wild populations does not negatively impact the latter and

(2) ensuring the health of fish on farms.

Fisheries and Oceans Canada's (DFO) Aquaculture Management Directorate requested peer-reviewed science advice to support the optimization of sea lice management, including the development of integrated pest management, mitigation strategies and science-based conditions of license.

Considerable information is available on the various aspects of sea lice biology, monitoring, and control and management strategies, although less information is available on non-chemical control measures. To improve the accessibility of the information to management, and to provide clear and robust peer-reviewed advice on monitoring and managing sea lice, it is necessary to review and consolidate this large body of work.

In Canada, there are distinct biophysical differences between salmon farming regions on the Atlantic and Pacific coasts that must be considered when providing advice on management measures. These differences include such factors as species of sea lice, the presence of alternate hosts and oceanographic conditions.

This Science Advisory Report is from the national peer review on Sea Lice Monitoring and Non-Chemical Measures, held in Ottawa, September 25-27, 2012. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule *as they become available.*

SUMMARY

- Sea lice and fishes co-evolved, so infestations in wild salmonid and non-salmonid fishes are a natural phenomenon. Transmission of sea lice between and within wild fish populations and salmon farms is known to occur, however, the dynamics of transmission will depend on a multitude of environmental and biological factors, and will be site and time-dependent.
- Sea lice dynamics (i.e., development and survival) are influenced by salinity and water temperature (which affect survival, growth, development rate, and reproductive success of sea lice), water movement (tides and currents), behaviour of infective larval stages and motile pre-adult and adult stages, and the abundance and proximity of suitable fish hosts.
- Hydrodynamic water circulation models, which may be useful in examining sea lice dispersal, are available for all salmon farming areas in Canada, and preliminary biophysical models of sea lice dynamics, have been developed for some regions. These tools could then be used to model sea lice dispersion and survival, help define broader management areas for sea lice control, study the dynamics of sea lice infestations and predict where and when sea lice outbreaks might be prevalent.
- Management and regulatory thresholds defining the level of on-farm sea lice per fish, that trigger the application of control measures for managing sea lice infestations, have been shown to be a useful management tool for reducing risk of transfer of sea lice from farmed to wild salmonids in some areas of British Columbia.
- A more flexible, dynamic and risk-based approach to setting thresholds than has been used in the past is recommended. In establishing management thresholds, consideration should be given to biological (e.g., proximity to and timing of wild fish migrations), environmental (e.g., temperature and salinity) and farm management (e.g., stocking levels and treatment options) factors.
- Sea lice monitoring programs currently in use in Canada for both farmed and wild fish are providing useful information, but could be improved. Monitoring programs should be designed to address the specific objective(s) of the monitoring program, and should include defined methods and protocols and a process to evaluate whether the monitoring program is effective in meeting objectives.
- In designing surveys and monitoring programs for sea lice on wild fish populations, ensuring representative sampling of all potential host species and stages, limiting loss of sea lice during capture and handling, and ensuring accurate identification of sea lice to species and life-history stage should be considered.
- Within a defined area, the abundance of sea lice on a farm is positively correlated with the number of neighbouring farms with sea lice, suggesting that the density of farms affects sea lice numbers. Therefore, if sea lice management on adjacent farms or within a management area is not coordinated, the management action may be less effective. Determining the appropriate size and location of a management area (farm, bay, fisheries area, etc.) is key to developing an effective sea lice management strategy, and this is influenced by a number of environmental and management factors (i.e., management objectives, number and location of farms, number and age of fish stocked on farms, distance between farms, local hydrodynamics, water temperature and salinity, farm management practices and logistics).

- Fallowing can be an effective tool to help reduce sea lice levels if it can be conducted at the appropriate management area level rather than by individual farms (i.e., coordinated fallowing of farmed sites), and if there are few wild hosts in the area which could act as a reservoir of sea lice. The effectiveness of fallowing as a sea lice control tool depends on factors such as abundance of wild host species in the area, proximity of farms, and environmental factors that influence sea lice development and dispersal of infective stages. The size of the zone to fallow should consider historical patterns of infestation, hydrodynamic conditions of the area, and when available, information from dispersal modelling.
- Non-chemical approaches to sea lice control, including the use of cleaner fish, sea lice traps, increased bivalve filtering through use of Integrated Multi-trophic Aquaculture (IMTA) approaches, utilization of sea lice-resistant strains of Atlantic salmon, and the use of immunostimulatory feeds have shown promise for helping to control sea lice under experimental conditions, but have generally not been applied commercially in Canada. None of these, individually, is likely to resolve serious infestations, but all may ultimately be part of an integrated sea lice management strategy. Some of these approaches may ultimately become components of an integrated pest control management strategy for sea lice management but more research is required to improve the efficacy of these strategies before they can be used economically on a large scale.
- An integrated, multi-facetted approach to managing sea lice in net-pen sites that is specific to the local area is recommended. Such an adaptive approach can permit customized management strategies to address area-specific issues. Such approaches do not rely on a single tool to control sea lice, but rather encompass several management strategies to improve the likelihood of success. A similar adaptive multilevel approach to pathogen control has been successfully used for bacterial and viral diseases.

BACKGROUND

Net pen salmon farming in Canada occurs in the coastal bays and inlets of British Columbia, New Brunswick, Nova Scotia, and Newfoundland and Labrador. Salmon farming yields a substantial proportion of Canada's total fish production and contributes to the national economy, with the highest production currently on the Pacific coast. Production is stable in British Columbia and New Brunswick, and is currently expanding in Newfoundland and Labrador and Nova Scotia.

Salmon stocked into marine cages are initially free of sea lice, but may acquire sea lice infestations from wild marine fish or from other farmed fish in the area. The result is that many salmon farming areas experience some level of sea lice infestations. There is concern that the salmon farms may amplify the number of sea lice in an area that can then be transferred back to wild fish, potentially impacting wild salmon populations. Heavily sea lice infested fish also reduce the value of the crop for the farmer. Globally, annual revenue losses attributable to sea lice outbreaks can be in the tens of millions of dollars (CDN). These concerns raise the need for effective sea lice control strategies.

Sea lice are parasitic copepods. Sea lice life history is broadly divisible into free-living (including the planktonic naupliar and copepodid stages) and parasitic (chalimus, pre-adult and adult stages attached to host fish) phases. Water temperature and salinity regulate development and survival in both life phases. The free living stages are known to have numerous adaptations which allow them to recognise physical and chemical environmental gradients which elicit behavioural responses that optimise host finding and settlement.

In Canada, there are three sea lice species of primary concern: *Lepeophtheirus salmonis* found on both the Atlantic and Pacific coasts, *Caligus elongatus* found on the Atlantic coast and *Caligus clemensi* on the Pacific coast. Genetically distinct varieties of *L. salmonis* occur on the Pacific and Atlantic coasts. The primary fish hosts for *L. salmonis* are anadromous salmonids, both wild and farmed, and uniquely the threespine stickleback in the Pacific. Both *Caligus* species are parasitic on a range of non-salmonid and salmonid marine species including farmed and wild salmon. *Caligus* spp. are known to parasitize a wider range of fish species than *L. salmonis.*

The copepodid stage is the most common stage that infects salmon, although some transfer of pre-adult and adult stages can occur between fish. Generally, Atlantic salmon are more susceptible to sea lice infestation than Pacific salmon species. There is a wide range of susceptibilities to infestation with *L. salmonis* among Pacific salmon species. Infestations tend to be of reduced duration and of lower intensity on the less susceptible species. In addition to the species of salmon, the abundance of sea lice on salmon is influenced by a number of factors, including: the age of the salmon or time in seawater; by location and season; by numerous other environmental factors affecting both the sea lice and the host; the proximity to sources of sea lice; and the application of sea lice treatments.

Serious fish health issues can occur when salmon are heavily infected by sea lice. This is especially true for farmed Atlantic salmon in the Atlantic Provinces. Sea lice feed on the skin and associated mucus, and when present in high numbers their feeding activities can lead to the development of open wounds. Damage caused by sea lice feeding may increase the opportunity for infection with pathogens, cause osmotic and other stress, and can ultimately lead to the death of the host. Disease impacts resulting from sea lice infestations are mainly known to occur on salmon farms when infestation rates are extremely high. There have been few studies of disease associated with sea lice infestation in wild fish in both the Atlantic and Pacific coasts.

The level of sea lice infestation is regularly monitored on farmed salmon on the Atlantic and Pacific coasts. In addition, surveys to monitor sea lice infestations on wild fish hosts have been conducted on both coasts, although the number of surveys conducted is much higher on the Pacific coast.

Sea lice can be a threat to the health and welfare of farmed salmon and farms are considered to be a potential reservoir for transmission to wild fish. Such transmission has the potential to negatively impact juvenile salmon during their outmigration. For these reasons, control of sea lice on salmon farms is important.

ANALYSIS

Population ecology and epidemiology of sea lice in Canadian waters

1. Role of sea lice hosts (wild salmonid and non-salmonid) as reservoirs, and other factors influencing sea lice dynamics near or on farms.

Hosts

Salmon in the marine environment are potential hosts for sea lice. Wild salmon returning to local rivers to spawn are important sources of *L. salmonis* that may infect farmed salmon. The risk of this transmission is highest during the spawning migration which varies with location (Pacific or Atlantic), species of salmon and in some cases, stock of salmon. A small number of Pacific salmon stocks reside in the near shore environment year-round and depending on the number, these fish may serve as a reservoir of *L. salmonis* infestation. Prevalence (proportion of individuals with sea lice) and intensity (number of sea lice per fish) of infestation vary by salmon species (and by stock within species), by location, and among years. The magnitude of the exposure of farmed salmon to sea lice is unknown, since migration timing, migration routes, total abundance of wild hosts and infestation loads on these fish are not fully known.

Escaped farmed salmon may also be a source of dispersal, infestation and re-infestation of sea lice to farmed and wild salmon. The magnitude of this risk will also depend on the number and distribution of escaped salmon. Studies have reported on the broad scale and generally non-directed movements of escaped salmon. Movements of accidental and experimental releases of farmed Atlantic salmon in eastern Canada and in the North Atlantic have been documented within a bay, along the coast and across open ocean channels.

All species of juvenile salmon may host *L. salmonis* and *Caligus* spp.. The population size of out-migrating juvenile salmon is considerably higher than that of returning adults, but infestation levels on out-migrating juveniles tend to be much lower, since infestation only begins when the juveniles enter the marine environment. Prevalence and intensity of infestation of juveniles vary by salmon species and stock, location, time spent in seawater, among years and with distance from sources of sea lice. Information is generally available on the timing of saltwater entry of juveniles, but detailed knowledge of migration routes and behaviour of wild juvenile salmon is limited or nonexistent for most species and stocks. The risk of sea lice transmission from farms to wild juvenile salmonids is likely highest during the out-migration period. Wild adult salmon are probably an important source of sea lice infestation to farmed salmon, but juvenile salmon are unlikely to contribute significantly as they seldom have a high prevalence or abundance of sea lice.

Non-salmonid species also host sea lice and are thus potential reservoirs for the transfer of sea lice to both wild and farmed salmon. Although primarily a parasite of salmonids, *L. salmonis* has been found on threespine sticklebacks in British Columbia. The ecological significance of this finding remains uncertain since *L. salmonis* have not been observed to complete their lifecycle on sticklebacks. Non-salmonid hosts for *L. salmonis* in Atlantic Canada have not been found.

Many species of marine fish are known to host *Caligus* spp. and may serve as reservoirs for infestation on salmonids. The prevalence and intensity of infestation varies by species, location and among years. For some commercially significant host species (e.g., Pacific herring) there is information available on population size, migration patterns, ecology, and biology of the adults, but information is less complete for the juvenile stages. For non-economically important species (e.g., threespine stickleback) little is known of population size, migration patterns, ecology, and biology. There is no information available on the health impacts of sea lice on non-salmonid species or on the magnitude of their role in transmitting sea lice to farmed and wild salmon.

Other Factors

Water temperature, salinity and water movement (from tides and currents) are the major physical and environmental factors influencing sea lice dynamics. Temperature and salinity influence sea lice development, growth, survival and reproductive rate. Currents and water column mixing processes influence the transport and dispersal of the free-living stages of the sea lice (naupliar and copepodid stages).

Salinity near salmon farms is influenced by freshwater inflow, exchanges of water between inlets and coastal shelf waters, water column mixing processes (especially wind and tides) and inlet bathymetry. Water temperature is influenced by these factors and by atmospheric and oceanic heat exchanges (for example, solar heating). Ocean currents are influenced by the horizontal density gradients generated by the three-dimensional temperature and salinity fields as well as by tides, winds, surface waves, large scale atmospheric pressure and turbulent mixing processes.

All of the characteristics listed above may vary on time scales of minutes to seasons, and on spatial scales of metres to hundreds or thousands of kilometres. The degree and pattern of variation differs between salmon growing areas, such that each aquaculture growing region has a unique combination of physical characteristics.

Annual minima in water temperatures tend to be higher (> 4 - 6^{o}C) on the Pacific coast than on the Atlantic coast (< 2^{o} C), while annual maxima are higher in parts of the Atlantic coast (e.g., eastern Nova Scotia) than on the Pacific coast. These are general characteristics and much depends on local conditions. Winter water temperatures on the west coast do not significantly hinder *L. salmonis* development, but east coast winter water temperatures can significantly slow or stop development.

Full-salinity seawater is optimal for *L. salmonis* development. Different life stages of this parasite have different salinity tolerances so it is difficult to generalise on the impact of salinity on development and mortality. Adult *L. salmonis* can survive at salinities less than full-strength seawater, but there is evidence of negative effects, including mortality, after extended exposure to low salinities.

There are insufficient data to understand the effects of temperature and salinity on *Caligus* spp.

Vertical stratification of the water column associated with two-layer flows can affect sea lice dispersion. Stratification tends to be greater in areas with strong freshwater outflow, for example along much of the Pacific coast and in parts of Newfoundland. However, local conditions may be highly variable.

Water currents in the Bay of Fundy on the Atlantic coast are predictable and periodic due to the strong tidal dynamics of the area, while currents in other areas are less predictable due to relatively weak tidal currents and the relative prominence of wind and freshwater driven currents. Strong fall-winter winds and storms, which strongly influence oceanographic conditions, are characteristic of most coastal areas of Canada.

Dynamics of sea lice on and near farms are also influenced by biology and behaviour of free-living stages. Larval stages of sea lice are phototactic and they respond to chemical and mechanical stimuli which allow them to position themselves in the water column to optimise host location. This behaviour also influences the speed and direction of transport and ultimately the extent and direction of dispersion. The free-living sea lice stages do not feed, relying on lipid reserves during this period. The duration of the lipid reserves depends on the amount of lipid initially deposited in the eggs and on temperature.

Based on current science information, the free-living stages of sea lice can disperse distances of tens of kilometres. Dispersion depends strongly on currents and the other environmental and biological factors described above.

2. Scientific basis for setting management and regulatory thresholds to treat farm salmon and minimize the risk of harm to wild juvenile salmon from exposure to farm-source sea lice.

Thresholds (stated levels of sea lice per fish used to trigger a management action at a farm) for applying control measures are a commonly-employed management tool that will likely continue to have utility for sea lice control in future.

The science informing the establishment of thresholds for sea lice management actions to protect wild salmon has evolved over time, and based on the current state of knowledge a more risk-based approach to setting thresholds may be appropriate.

Factors that should be considered in setting thresholds include (but are not limited to) the following:

- The size of a management area.
- The number of farms in a management area.
- The total number of farmed salmon on the farm, or in the management area.
- The proportion of farmed salmon on the farm or in the management area infested with sea lice (prevalence).
- The number of sea lice on the farm or in the management area, divided by the number of farmed salmon (abundance).
- The relative contribution of wild and farmed populations to the total abundance (load) of sea lice in a management area; this gives an indication of the relative risk from each source and affects the management strategy.
- The timing and duration of the “window” of risk, which varies by species, area, season, environmental conditions, and between years.
- The presence of a particularly susceptible size or life history stage of the species of concern.
- The relationship between the level of risk presented to the size of the population of concern.
- The availability of treatment options.
- In future, a transition to a more dynamic approach which takes into account the factors noted above may be a preferred approach to the limited management guidance that is provided by static thresholds. However, for dynamic thresholds to be feasible there are a few gaps in scientific understanding that need to be filled. These gaps include the following:
- More precise knowledge on the migration routes of wild hosts.
- The probability of re-attachment of copepods released into the water column, on to a host, under various contexts.
- Improved models of sea lice dynamics on farms (especially success of reproduction in low prevalence settings, self-infestation on farms, etc.).

Depending on the management objective behind the threshold, the health of wild fish populations may also be a relevant consideration for determining thresholds. This may require the following considerations:

- Improved knowledge around the impact of sea lice on wild fish populations.
- Understanding of the relevance and importance of indirect effects of sea lice infestation on wild hosts, such as increased predation due to changes in behaviour.

Monitoring for sea lice on farmed and wild salmon in western and eastern Canada and advice on sound methodologies

3. Sampling design protocols for on-farm sea lice monitoring, including: number of fish to be sampled, identification of sea lice, number of samples, handling of fish, etc.

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4. Program design for on-farm sea lice monitoring, including: frequency of sampling, timing, environmental factors to be considered, sea lice dynamics, etc.

Nationally, two objectives are being addressed through on-farm sea lice monitoring, depending on location. On the Pacific coast, the objective is to maintain a farm level sea lice load below a threshold of 3 motile (pre-adult and adult) *L. salmonis* per fish during the general period of wild pink and chum salmon smolt seaward migration (March - end of June). This threshold was originally established while research was undertaken to evaluate the effects of sea lice on wild juvenile salmon. On the Atlantic coast, the objective of on-farm sea lice monitoring is early detection of sea lice infestation and treatment of the farmed salmon. Assessment informs veterinarians of the potential requirement for immediate treatment of the cage, farm and/or management area.

In the Atlantic Provinces, sampling typically consists of evaluating a small number of fish (usually five) from each of 4 to 6 cages within a farm. Cage selection can be random or based on the position of the cages at the farm, for example with those on the flood side being selected preferentially. These selected cages are sampled at each sampling event. Fish are sampled by attracting them using feed and netting them out of the cage such that fish captured using this technique are representative of the actively feeding population in the cage. Generally, this sampling approach is scientifically accepted as being sufficient to describe the sea lice abundance at a cage/farm level.

In British Columbia, at least three cages per farm are assessed, 1-2 times per month (twice per month during the spring period), with 20 fish per cage sampled. One “reference”[1] cage (the first cage stocked) plus at least two randomly selected cages are sampled at each sampling event. A subsample of the population in the cage is captured using a seine net and a further subsample of 20 fish is selected from this group.

A cluster sampling approach that involves sampling smaller numbers of fish from a larger number of cages would allow a more accurate estimation of mean sea lice abundance at the farm level and is a particularly valuable method when sea lice management will be conducted on a cage by cage basis (i.e., with bath treatment). The sampling method used in British Columbia (fewer cages, more fish) was found to provide similar estimates of farm-level sea lice abundance when evaluated against the cluster sampling approach. This may be attributable to the low abundance of sea lice levels found on farmed Atlantic salmon in British Columbia.

Regardless of how fish are sampled, or on which coast sampling is being conducted, sea lice infestation assessments are conducted in a similar manner. Captured fish are anesthetized and examined for the presence of attached sea lice. Following assessment of attached sea lice, any sea lice that became detached from the fish and remain in the anesthetic tote are also counted and used in calculating the average sea lice loads. Identification of the various sea lice stages, conducted as part of on-farm monitoring, provides additional information for decision making about management measures. Motile stages of sea lice are assessed to species and sex (adult stages); attached stages are enumerated but not identified to species or life stage. There may be times when the “standard” process will need to be modified to meet specific monitoring

[1] The term “reference” cage is specified in legislation.

objectives, for example, if wild and farm fish need to be assessed simultaneously within the confines of a scientific project.

In order to capture changes in the mean sea lice abundance at the farm level, routine sampling is important. The frequency of sampling should be based on the following:

- monitoring program objectives, including the level of discrimination required;
- environmental factors (e.g., water temperature, salinity, oxygen, plankton or harmful algal blooms, etc.);
- biology, including the sea lice species; and
- current sea lice counts.

Pre- and post-treatment sea lice assessments are and should be conducted to effectively evaluate treatment efficacy. The timing of these evaluations should be decided based on knowledge of treatment mode action and with the expected time of effect.

The collection of farm level environmental information is necessary to inform sea lice monitoring programs. At a minimum this should include salinity, temperature and dissolved oxygen, at least daily and preferably hourly.

5. Sampling design protocol for wild fish sea lice surveys and monitoring2, including: number of fish to be sampled, identification of sea lice, number of samples, handling of fish, background sea lice levels, etc.

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6. Program design for wild fish sea lice surveys and monitoring, including: frequency of sampling, out-migrations, in-migrations, sampling location, timing, environmental factors to be considered, sea lice dynamics, and other considerations (e.g., species differences, at-risk status of wild stocks of interest), etc.

An optimal wild fish sea lice survey/monitoring program is one that uses methods and protocols that:

1) enable the collection of robust data on salmonid and non-salmonid host distribution and abundance,
2) ensure representative sampling of all potential host species and life-history stages,
3) limits sea lice loss during capture and handling,
4) ensures accurate identification of sea lice to species and life-history stage,
5) ensures samples are preserved for appropriate analysis and archived, and
6) samples the minimum number of fish required to obtain results that are scientifically sound.

There has been more effort to survey and monitor sea lice on wild fishes in British Columbia than in eastern Canada. Surveys have addressed the following broad objectives:

1) potential risks posed by sea lice to wild salmon,
2) the extent of bi-directional movements of sea lice between the wild and farmed salmon,

[2] “Survey” implies a one-off study for a given objective; “monitoring” implies a series of surveys to understand temporal changes. Both are relevant for sea lice.

3) the effectiveness of on-farm sea lice management strategies for reducing burdens on wild fish, and
4) temporal monitoring of abundance.

The specific design of survey programs will be highly dependent on the scientific or management questions being asked.

Surveys have used a variety of sampling methods and protocols. In general the strengths and weaknesses of these various methods and protocols are known, but are not always communicated or discussed, especially during the interpretation of data. A comprehensive, peer-reviewed description of best practice for methods and protocols for sampling wild salmon for sea lice was developed by the British Columbia Pacific Salmon Forum[3].

Sampling programs should address the following considerations:

1) ecological and behavioural differences between species of sea lice,
2) ecological and behavioural differences between host species and/or hosts of different ages,
3) the inherent natural variability of large ecosystems,
4) the complex interactions between hosts, sea lice, and environmental factors, and
5) logistic and available resources.

Limitations in all programs should be recognized, clearly communicated and considered when reporting results.

Ideally, surveys on salmon farms will be conducted at the same time and to a level that will support the interpretation of data from wild fish surveys, if the goal is to relate prevalence on farms to that in the wild.

Control or reference sites (to compare prevalence in areas with no salmon farms to sites near farms) are difficult to establish, given background differences in oceanographic conditions and in wild fish stock composition and behaviours. However, there is value in obtaining relative indices among locations with and without salmon farms and between years, as these can provide information to assess natural variation between locations and temporal changes associated with management intervention.

“Sentinel” fish (contained, sea lice free, susceptible fish species placed into the environment) may provide information on the rate of increase of sea lice on wild species and on other aspects of sea lice dynamics in the wild. Fish counting fences have provided information on infestations on returning Atlantic salmon on the east coast, and are a valid sampling approach for future surveys.

Oceanographic modelling in several coastal ecosystems in Canada is relatively well advanced and offers the potential to aid in the planning and interpretation of survey data. The value of these models to generate general patterns of water circulation to be used in the planning and interpretation of surveillance programs will be improved by running the models with environmental data from multiple years.

Monitoring programs for sea lice on wild fish should be conducted with regard to the whole range of fish health issues, and include measurement of environmental factors known to influence fish health or the occurrence of disease.

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[3] This document is now out of print but is reproduced in the Research Document on wild fish monitoring produced for this CSAS meeting.

Key unknowns in planning wild fish monitoring and survey programs include lack of information on lesser-known sea lice species, loss rates of sea lice during capture, influence of development stage of salmon and sea lice on their interactions, and effects of the environment more broadly on wild salmon health.

7. ***Protocols for the management and dissemination of data resulting from monitoring programs.***

The form of any data sharing system would depend on the objective(s) to be attained, for example: transparency in public reporting; use of information by scientists for analyses; early detection; and/or monitoring effects of treatment.

There are several existing data management systems for on-farm monitoring programs, including the ongoing reporting of sea lice information from farms in British Columbia (originally established by the government of British Columbia and continued by DFO), and the new Decision Support System (DSS) program operated by the Atlantic Veterinary College which compiles reports on sea lice from farms in Atlantic Canada (the site-specific information is not made public). Data from farms are collected by and belong to industry, so there are privacy and confidentiality issues to be addressed in any dissemination of this information to third parties.

For information from monitoring and survey programs on wild fish, data management is the responsibility of those conducting the surveys, and dissemination has typically been through normal publishing and reporting processes.

Standards and policies for data sharing would have to be established as part of any formal data management and dissemination process, and some mechanism would be needed to ensure that these were respected. A formal data management and dissemination mechanism would require a long-term commitment by an appropriate organisation, to manage this process.

Non-chemical measures of control and prevention

8. ***Scientific advice on factors that influence the effectiveness of fallowing as a means of sea lice control, including fallowing time required, scale of fallow (e.g., farm-scale versus bay-scale), other factors required to interrupt sea lice population dynamics on farms to decrease next year's load, etc.***

Fallowing (removing farmed fish from the site, in some cases along with parts of the cage gear, for a period of time) has been used as a tool for disease and environmental management in farming. It can be applied to the management of sea lice, although as currently practiced, it is generally applied to manage other fish health issues.

Fallowing farm sites removes the farmed salmon hosts from the immediate area in order to control the level of sea lice around farms. However, for fallowing to be effective, all susceptible fish would need to be removed from the site and the site should remain fallow for a period of time longer than the time required for development of sea lice from the egg to copepodid stage plus the lifespan of the copepodid. These periods are strongly influenced by water temperature. Fallowing should also consider the presence or absence of wild host species in the area, since the presence of wild fish infected with sea lice near the farm site will make fallowing less effective. This may be an issue more for *Caligus* spp., which parasitize a broader range of host species than *L. salmonis*.

Individual farms may not act in isolation; therefore, fallowing should be synchronized with all farms in a particular area (for example in bay management areas) to increase the effectiveness of fallowing. This area would be considered the fallowing zone. The effective size of the fallowing zone should be based on the area that shares infective stages of sea lice. The configuration of the appropriate management area should be determined using hydrodynamic information, and statistical models that evaluate neighbour effects and dispersion models.

9. The effect of farm density (number of farms in an area) and stocking density on sea lice population dynamics at different scales (i.e., individual pens, individual farms, within a bay or area).

Sea lice can experience exponential population growth under optimal environmental conditions, given a sufficient density of hosts.

The risk of sea lice infestation will increase with farm density (number of farms in an area). Studies have shown that within a defined area, abundance of sea lice on a farm is positively correlated with the number of neighbouring farms with sea lice, suggesting that the density of farms affects sea lice numbers (Kristophersen et al. 2013, Jansen et al. 2012).

Sea lice numbers on farms may not be strongly associated with cage level density of fish (kg/m^3) (i.e., in Chile, Kirstophersen et al. 2013), but studies have not been conducted in Canada. In Norway, local biomass density is positively correlated with sea lice abundance on farms (Jansen et al. 2012). Therefore, the total number of fish on individual farms may be less important in determining sea lice numbers than the total number of fish on all farms in an area. The number of fish on a farm is more important than density in cages in determining sea lice abundance.

The critical number of farms in an area to maintain sea lice below a desired level will depend on the following:

- The management objectives and the abundance/prevalence of sea lice necessary to meet these objectives.
- The number of fish on the farms.
- The number and location of farms.
- The distance between farms.
- The water currents and flushing of the area and farms.
- The age of stocked fish (since abundance of sea lice generally increases with age).
- The environmental conditions (water temperature and salinity).
- Farm management practices.
- Logistical considerations.

Understanding wild fish migration patterns and the dynamics of resident wild fish populations can provide valuable information on appropriate placement of farms to reduce the external sea lice infestation pressure on the site. Siting farms where sea lice are less likely to be successful could significantly reduce exposure to viable infective copepodids. Farms in close proximity to one another, such that they share water during the period of the free swimming sea lice life stage, can act as a reservoir of infestation for one another. Farm siting and selection of the appropriate management area can reduce exposure and the likelihood of re-infestation within a farm.

10. Scientific evidence on the effectiveness of other means of sea lice control such as, but not limited to, sea lice traps, cleaner fish, IMTA (biological filtering), etc.

Although non-chemical methods to help control sea lice densities have been studied for many years, interest has been increasing due to the threat of declining effectiveness of chemical treatments, the desire to limit reliance on chemotherapeutants, and the desire of industry to move towards an integrated pest management approach. The non-chemical methods are still mostly in the trial stages in Canada and no definitive conclusions on their effectiveness have been made.

Some fish groups, known as cleaner fish, have been shown to be effective at grazing sea lice off salmon. The use of cleaner wrasse (Labridae) in salmon farms has been actively developed since 1989 in Norway and Scotland, where five fish species are currently in use. In eastern Canada, there is at least one species with potential as a cleaner fish, the cunner (*Tautogolabrus adspersus*), which has had mixed results in initial trials. The lumpfish (*Cyclopterus lumpus)* has shown some potential as a cleaner fish in Norway and also occurs in eastern Canada. Cleaner fish species are not known to occur on the west coast.

Traps for sea lice have been developed by various groups over the last thirteen years. They have used principles developed by agricultural sciences for trapping insect pests including light, physical trapping and chemical attractants known as semiochemicals. The current generation of traps under development catches a broad range of marine invertebrates and a greater sophistication and selectivity is required for them to be effective for sea lice. The development of semiochemical-based traps in Europe is a potentially useful innovation.

Integrated Multi-Trophic Aquaculture (IMTA) is a concept in which nutrients from excess feed and waste originating from a fed aquaculture site, such as a salmon farm are recycled by other nearby farmed species such as seaweeds and filter-feeding molluscs. Its main purpose has been to develop a more ecologically sustainable approach to farming, but one of the features of this approach is the incorporation on the site of filter feeding shellfish which have the ability capture and consume larval zooplankton, including sea lice. Lab trials have demonstrated that the blue mussel (*Mytilus edulis*) and several other bivalve species are capable of consuming naupliar and copepodids stages of sea lice. No definitive field trials have been completed, although some are underway. One limiting factor is the low density of sea lice larvae in comparison to natural zooplankton, which may affect the number of sea lice larvae shellfish are capable of capturing due to the dilution factor. Techniques may have to be employed to selectively concentrate the sea lice near the shellfish.

Some strains of Atlantic salmon have been found to carry lower sea lice levels than others, which had led to an interest in selective breeding for the development of strains with increased resistance to sea lice. Research has been conducted in several laboratories, including in Canada. Eggs from salmon with increased resistance to sea lice are commercially available in Norway. In general, selective breeding for sea lice resistance is in its early stages.

Research is underway to determine whether feed additives which stimulate the immune system may increase the resistance of farmed salmon to sea lice infestations. The manufacturer of one proprietary feed which contains immunostimulants claims that this feed increases resistance to sea lice infestation.

Sources of Uncertainty

An important general source of uncertainty identified by this process is the relative importance of local factors influencing survival, development and dispersal of infective stages of sea lice. These include the following:

- Biological factors, such as the behaviour of larvae, which may influence transport, and the duration of larval life, based on the extent of lipid reserves.
- The functional relationships between local environmental factors (particularly temperature and salinity) and larval survival and development.

- Local characteristics of water currents, which can have significant spatial and temporal variability.
- The role of wild hosts.

A good understanding of local conditions is essential to assess the appropriate size of areas or zones to be managed for sea lice, as is the direction and importance of transmission of sea lice between farmed and wild populations. However, knowledge of these local conditions and factors is uneven, and in some areas lack of such knowledge may be a key uncertainty facing management. The hydrodynamic water circulation modelling work ongoing on both Pacific and Atlantic coasts represents a sound approach to predicting sea lice dispersal without complete knowledge of local conditions, in order to inform management decisions and to identify questions that warrant further research.

There is uncertainty about the magnitude of bi-directional transmission of sea lice between wild hosts and farmed salmonids, although such transmission is known to occur. There is also uncertainty about the relative importance of farmed salmon and other reservoirs (wild populations) in the transmission of sea lice to wild salmonids.

Another important source of uncertainty relates to the impact of sea lice infestations on the health of wild fish populations. Parasitism by sea lice on wild fishes is a natural phenomenon, but it is assumed that this can have negative effects on fish health depending on environmental and other conditions. A more holistic assessment of the overall health of wild juvenile salmon would help to better interpret the consequences of sea lice infestations to wild salmon populations and help to better define the risks posed to wild populations by sea lice infestations on salmon farms.

A number of other sources of uncertainty and research recommendations identified in relation to the various topics covered in this Science Advisory Report are described in the Proceedings of the peer review meeting and in the various research documents.

CONCLUSIONS AND ADVICE

Population ecology and epidemiology of sea lice in Canadian waters

1. ***Role of other sea lice hosts (wild salmonid and non-salmonid) as reservoirs and other factors influencing sea lice dynamics near or on farms.***

Other Hosts

Sea lice and fishes co-evolved, so infestations in wild fishes are a natural phenomenon. Wild salmonids (adult and juvenile) and non-salmonids host sea lice but the levels vary with fish species, age of fish, environmental conditions, location and temporally (seasonally/annually/ daily) as well as with sea lice species.

Farmed salmon become infected with sea lice originating from other farms or wild hosts since they are sea lice free when stocked into cages. The period of outmigration of juvenile wild salmon represents the period of highest risk of sea lice infestation to wild salmon. The extent of transmission will depend on other environmental and biological factors (see below) and will be site and time-dependent.

Other Factors

Environmental factors and oceanographic processes are important to sea lice survival and transport, as are factors related to larval competency such as behaviour and lipid reserves. These factors vary considerably between farms, farming regions, seasons and years.

Observations on primary physical characteristics (temperature, salinity, ocean currents) are available from all areas, but some areas have more data than others.

Based on current information, free-living stages of sea lice can disperse tens of kilometres. Hydrodynamic water circulation models, which may be useful in examining sea lice dispersal, are available in all farming regions (British Columbia, New Brunswick, Nova Scotia and Newfoundland), and preliminary biophysical models of sea lice dynamics have been developed in some regions (mainly for British Columbia). These can be used, or will soon be available, to model dispersion and survival and improve predictive capabilities. Continued work to improve models and parameterize relationships of sea lice biology with environmental conditions would improve our ability to forecast, understand and treat infestations.

2. ***Scientific basis for setting management and regulatory thresholds to treat farm salmon and minimize the risk of harm to wild juvenile salmon from exposure to farm-source sea lice.***

Thresholds currently in place were developed based on information available at the time, and in some areas of British Columbia have been shown to be useful in reducing the risk of transfer of sea lice from farmed to wild salmon. However, the science has continued to evolve and recent research suggests that a more flexible, risk-based approach to establishing management thresholds may be appropriate.

Such a transition to a more flexible, dynamic approach to setting management thresholds should be considered. Considerations to be addressed in making this transition include total abundance of sea lice in a given area, the relative contribution of wild and farmed fish to total abundance (which may be challenging to assess), time of year, presence of susceptible species and stages, proximity to sources of sea lice larvae, and environmental conditions.

Monitoring for sea lice on farmed and wild salmon in western and eastern Canada and advice on sound methodologies

3. ***Sampling design protocols for on-farm sea lice monitoring, including: number of fish to be sampled, identification of sea lice, number of samples, handling of fish, etc.***

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4. ***Program design for on-farm sea lice monitoring, including: frequency of sampling, timing, environmental factors to be considered, sea lice dynamics, etc.***

Monitoring programs should be designed to address clearly defined objectives, and should include defined methods and protocols and a process to evaluate whether the monitoring program is effective in meeting objectives.

Current on-farm sea lice monitoring programs are providing useful information but could be improved by taking into consideration the following: the objectives of the monitoring program; environmental factors; biological factors, including sea lice species; and a process to evaluate whether the on-farm monitoring program is meeting the objectives of the program.

The monitoring objectives will help determine the frequency, spatial and temporal coverage with which environmental factors are measured. Local considerations will be useful in evaluating the relative effectiveness of environmental monitoring at the site level versus the area level.

5. ***Sampling design protocol for wild fish sea lice surveys and monitoring, including: number of fish to be sampled, identification of sea lice, number of samples, handling of fish, background sea lice levels, etc.***

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6. ***Program design for wild fish sea lice surveys and monitoring, including: frequency of sampling, out-migrations, in-migrations, sampling location, timing, environmental factors to be considered, sea lice dynamics, and other considerations (e.g., species differences, at-risk status of wild stocks of interest), etc.***

Monitoring of sea lice in wild populations can be a valuable tool to help understand the dynamics of transmission of sea lice between farms and wild populations, and to help evaluate the effectiveness of management actions.

Surveys and monitoring programs for sea lice on wild fish populations should be designed to address specific objectives. There is a substantial literature on survey design for wild fish populations which can be referred to. Monitoring may be particularly challenging where wild stocks are small or at risk (for example inner Bay of Fundy Atlantic salmon).

In designing surveys and monitoring programs for sea lice in wild fish populations, the following should be considered: survey or monitoring program objectives; collection of robust data on wild host distribution and abundance; ensuring representative sampling of all potential host species and stages, limiting loss of sea lice during capture and handling, ensuring accurate identification of sea lice to species and life-history stage; minimum number of fish required to obtain scientifically sound results; ecological and behavioural differences between species of sea lice and between species of hosts; inherent natural variability of large ecosystems; complex interactions between hosts, sea lice, and environmental factors; and logistical and resources parameters.

Limitations of survey design, which will contribute to uncertainties in the results, and should be clearly stated as part of the communication of the results.

The set of best practices for surveys of sea lice on wild populations developed by the British Columbia Pacific Salmon Forum should be consulted in designing such surveys.

7. ***Protocols for the management, dissemination and analysis of data resulting from monitoring programs.***

No specific advice was provided on this issue. The approach to managing and disseminating monitoring program data will depend on the objectives of the monitoring program, and will need to take into account issues of privacy and confidentiality of the data.

Non-chemical measures of control, and prevention

8. ***Scientific advice on factors that influence the effectiveness of fallowing as a means of sea lice control, including fallowing time required, scale of fallow (e.g., farm-scale versus bay-scale), other factors required to interrupt sea lice population dynamics on farms to decrease next year's load, etc.***

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9. ***The effect of farm density and stocking density on sea lice population dynamics at different scales (i.e., individual pens, individual farms, within a bay or area).***

Sea lice on a farm originate from two sources:

1) within the farm (self-infestation) and
2) outside the farm (wild fish and other farm fish).

In controlling sea lice levels on farms consideration needs to be given to both of these sources.

If sea lice management on adjacent farms or within the management area is not coordinated, the presence of sea lice larvae and copepodids in the surrounding water may be constant, leading to re-infestation and effectively preventing the reduction of sea lice burden on farms. Synchronization of sea lice control strategies between adjacent farms or within a management area is critical to preventing the cycle of treatment and re-infestation. A key element to be considered in developing a coordinated sea lice control strategy is the determination of the appropriate size and location of the management area (farm, bay, fisheries area, etc.). Factors involved in determining a management area include the following:

- The management objectives and the limit on sea lice abundance or prevalence necessary to meet those objectives.
- The number and location (including siting considerations) of farms.
- The number of fish stocked on the farms.
- The distance between farms.
- The local and regional hydrodynamics.
- Logistic considerations.

In addition, historical data on fish stocking and sea lice abundance should be considered to support coordinated programs.

Fallowing may be effective in the management of sea lice, although as currently practiced, it is generally applied to manage other fish health issues.

Coordinated fallowing of farmed sites will help reduce levels of sea lice in the fallowing area, if there are few wild hosts in the area which could act as a reservoir of sea lice. The effectiveness of fallowing as a sea lice control tool depends on factors such as abundance of wild fish and sea lice in the area, proximity of farms, and environmental factors affecting dispersal of infective stages.

To be most effective in reducing sea lice abundance, the area to be fallowed should be determined in advance, based on historical patterns of sea lice infestations, or (when available) on hydrological information and sea lice dispersion models. Fallowing duration should exceed the developmental time and longevity of infective sea lice stages.

10. Scientific evidence on the effectiveness of other means of sea lice control such as, but not limited to, sea lice traps, cleaner fish, IMTA (biological filtering), etc.

A number of non-chemical approaches to sea lice control are currently experimental in Canada. These include cleaner fish, larval traps, Integrated Multi-Trophic Aquaculture (IMTA), sea lice resistant salmon strains, and immuno-stimulatory feeds. None of these, individually, is likely to resolve serious infestations but all may ultimately be part of an integrated sea lice management strategy.

Most of the approaches being investigated have shown promise in lab-based trials, but research is still underway and will require evaluation in commercial-type situations in the field. Some of these (e.g., sea lice resistant salmon strains, immunostimulatory feeds) are closer to commercial application in Europe, and cleaner fish are currently being used in commercial aquaculture operations in Europe.

If justified by the ongoing research, additional infrastructure development would be required to implement some of these alternate approaches, such as large-scale Atlantic salmon selective breeding programs, hatcheries for development of new species of cleaner fish, and new engineered structures on the site.

At this time, the best approach to assessing alternative control measures would be to continue ongoing research programs in Canada and to monitor developments in other countries.

Additional Conclusions and Advice

An integrated, multi-facetted approach to managing sea lice in net-pen sites that is specific to the local area is required. This adaptive approach can permit customized management strategies to address area-specific issues. Further, these types of plans do not rely on a single tool to control sea lice, but rather encompass several management strategies to improve the likelihood of success. Such an adaptive multilevel approach to pathogen control has been successfully used for bacterial and viral diseases. Where sea lice are problematic, the management approach will most likely have to take into consideration the number of fish in an area, as well as the synchronization of management actions (including fallowing and treatments) on farms in close proximity to one another.

National and international collaborations among different organizations (e.g., industries, provinces, universities, DFO, etc.) involved in sea lice control is extremely important and should continue, with the general objective of ensuring a quick response to developing problems.

Given that knowledge of sea lice epidemiology, and of the impact of sea lice control measures on farmed and wild populations is rapidly evolving, it is important for practitioners in Canada to follow developments in other countries. However, it is also important to recognize that the situations in various regions of Canada may be significantly different than those of other countries.

SOURCES OF INFORMATION

This Science Advisory Report is from the September 25-27, 2012 assessment of Sea Lice Monitoring and Non-Chemical Measures. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Kristoffersen, A.B., E.E. Rees, H. Stryhn, R. Ibarra, J.-L. Campisto, C.W. Revie, and S. St-Hilaire. 2013. Understanding sources of sea lice for salmon farms in Chile. Preventive Veterinary Medicine 111(1-2): 165-175.

Jansen, P.A., A.B. Kristoffersen, H. Viljugrein, D. Jimenez, M. Aldrin, and A. Stien. 2012. Sea lice as a density-dependent constraint to salmonid farming. Proc. R. Soc. B. 279(1737): 2330-2338.

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