Fisheries and Oceans / Pêches et Océans

Canadian Stock Assessment Secretariat
Research Document 98/161

Secrétariat canadien pour l'évaluation des stocks
Document de recherche 98/161

Not to be cited without
permission of the authors[1]

Ne pas citer sans
autorisation des auteurs[1]

# A REVIEW OF THE POTENTIAL EFFECTS OF SALMON LICE AMONG AQUACULTURE SALMON ON WILD SALMON

Alasdair H. McVicar
Fisheries Research Services
P. O. Box 101
Victoria Road
Aberdeen, AB11 9DB
Scotland, United Kingdom

[1] This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

[1] La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Research documents are produced in the official language in which they are provided to the Secretariat.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au secrétariat.

ISSN 1480-4883
Ottawa, 1998
Canada

**ABSTRACT**

The prevention of *Lepeophteirus salmonis* infection on farmed salmon is likely to be an unachievable objective, at least in the foreseeable future. Although conclusive evidence is lacking, it is realistic to assume that lice from farmed salmon will contribute to lice in wild fish populations. The extent of this contribution and the consequences are the areas of current intense controversy. Much of this controversy can be attributed to an inadequate data-base. There is a concerning tendency for researchers to be selective in the interpretation of available data and to take highly polarised stances where any proper consideration of an alternative interpretation is avoided as being a sign of weakness of their position. It is essential that realistic dialogue between different groups involved in this topic area is fostered at every opportunity.

The general absence of historical (pre-fish farming) data on lice levels in wild salmon populations, and of an adequate more recent time-series on fish farms, prevents evaluation of temporal changes in lice levels and the factors (including farms) which may be contributing to these. Similar difficulties are found with spatial variations in lice levels. The pathogenicity of lice to salmon is well established in experimental and farm situations, but such information is difficult to obtain for wild populations. A focus of effort on achieving a reduction farm lice levels and on understanding the biology of transmission of infection to new hosts could maximise output from resources allocated to this field.

**RÉSUMÉ**

La prévention de l'infection par *Lepeophteirus salmonis* chez le saumon d'élevage apparaît comme un objectif impossible à atteindre, du moins dans un avenir prévisible. Bien que nous ne disposions pas de preuves à cet égard, il est logique de supposer que les poux des saumons d'élevage se retrouveront sur des poissons sauvages. L'envergure et les conséquences de cet apport font actuellement l'objet d'une intense controverse qui peut, en grande partie, être attribuée à l'insuffisance de notre base de données. On note une tendance inquiétante chez les chercheurs qui semblent interpréter sélectivement les données actuelles et adopter des positions bien arrêtées, et pour qui l'examen de toute autre interprétation apparaît comme un signe de faiblesse. Il est essentiel de favoriser, chaque fois que cela est possible, des échanges réalistes entre les intervenants des divers groupes s'intéressant à cette question.

L'absence généralisée de données historiques (antérieures à l'élevage) sur les niveaux d'infestation des populations sauvages de saumon par les poux, et de séries chronologiques appropriées pour les populations d'élevage, interdit d'évaluer les variations temporelles des niveaux d'infestation et les facteurs (y compris les installations piscicoles) qui les favorisent. On note des difficultés semblables pour les variations spatiales des niveaux d'infestation. Le caractère pathogène des poux pour le saumon est bien connu en conditions expérimentales et en élevage, mais des données sont difficiles à obtenir pour les populations sauvages. Le fait de mettre l'accent sur la réduction des niveaux d'infestation des poissons d'élevage par les poux et sur la connaissance de la biologie de la transmission de l'infection à de nouveaux hôtes permettrait de maximiser les résultats obtenus des ressources affectées à cette question.

## Introduction

The public perception of a scientific problem is often strongly influenced by the media coverage it receives. Unfortunately, in relation to sea lice, there have been a large number of confused statements in the popular press which have been based on inadequate information, over extrapolation of existing data or even unsubstantiated dogma. The basis of this problem partly lies in the often conflicting statements made on the topic by various scientists, particularly these associated with wild salmonid fishery interests and with the salmon farming industry. The value of even some of the more commonly used statements being made has to be treated with some caution and the frequency they have been repeated should not be taken to indicate anything about their scientific validity.

Recognising this difficulty and in an attempt to resolve it, the International Council for the Exploration of the Seas (ICES) convened a special workshop on sea lice in 1996 in Edinburgh. It was an attempt to collate existing information and to evaluate the real scientific base of knowledge available at that time on the interaction between sea lice and salmonids. Participating scientist were invited from among those actively practising research on sea lice in Scotland, England, Norway, Faroes, Ireland and Canada. Unfortunately, the conclusions of the Workshop were disappointing. Polarised stances were adopted by participants, there was a concerning lack of objectivity in discussions and data were being selectively used to support pre-conceived conclusions with contradictory data being ignored. There was little effort made to find common ground between different positions. The Report of the Workshop, published in 1997 by ICES (Anon 1997), contained many unpublished data from expert observation and of work then in progress and is still the most recent comprehensive source of information in the topic area. Other main sources of information on sea lice are contained in the reviews by Boxshall and Defaye (1993) and Lester and Roubal (1995). As indicated in Section 7.2.3 of the ICES Workshop report (Anon 1997), there is general agreement that it is safe to conclude that sea lice, *Lepeophtheirus salmonis,* from farmed salmon populations will infect wild salmonids in the same area. In a farm, any female lice which develop to maturity will produce eggs and almost irrespective of the level of release of lice eggs from farms, it would be unreasonable to come to any other view than the one that there is a probability at least some of the ensuing infective stages will find a wild host. The outstanding questions are therefore to what extent does infection of wild salmon occur from that source, and with what consequences?

The terms of reference for this paper are set out in its title and emphasises the evaluation of the "potential" effects of lice, rather than proven effects. For sea lice to have the potential to cause a problem, there firstly has to be a source of lice and secondly the salmon and parasite have to come into direct contact. In addition, for lice from farms to be implicate in a problem with wild salmon populations, it has to be shown that these have contributed a significant additional effect above that from wild sources.

The major differences in the biology and pathogenicity of *L. salmonis* and the other parasitic copepod *Caligus elongatus* which infect salmonids, preclude them from being considered together. Of particular importance is the difference in the host range, the former being mainly restricted to salmonids and the latter having a wide host range (Lester and Roubal 1995). *C. elongatus* is recognised in some circumstances to be a serious pathogen of farmed salmon (MacKinnon 1995; Stuart 1990) and in the Bay of Fundy was initially a more persistent problem than *L. salmonis* (Hogans and Trudeau 1989). However, most of the controversy surrounds the possible role of *L. salmonis* from fish farms on local wild salmonid populations and only this species is discussed in this presentation.

## Source of lice.

It is possible that infection of wild Atlantic salmon with *L. salmonis* may occur at any time when the fish are in sea water, during their migration out through coastal waters as smolts, on the oceanic feeding grounds or again in inshore waters when they return during their spawning migration. In order to evaluate the potential contribution of lice from farm sources and the consequences, it is necessary to have some understanding of the natural situation with lice in the absence of salmon farming either in a farming area prior to the development of the industry or in areas distant from farming. It is also relevant to consider the temporal and spatial patterns of lice infection within farms to determine if any changes can be associated with variations in the infection pattern in the wild population in the same areas and to consider ways in which lice from farms may transmit to wild salmon.

<u>(A) Lice on wild salmon.</u>

1. Occurrence of lice before the development of fish farming.

The presence of lice on a river-caught salmon has long been considered by anglers to be a desirable occurrence. Because the parasite will not survive in fresh water more than 25 days (Wootten, Smith and Needham, 1982) and most are lost within 2 days (McLean, Smith and Wilson 1990), their presence indicates that fish had recently entered the river from the sea. Unfortunately, although the occurrence of lice is widely reported in the angling press, the actual number of lice present on individual fish has generally not been properly recorded. Some older scientific studies include data on the prevalence and incidence of lice infection of the salmonid hosts. Huntsman (1918) reported lice on a large percentage of Atlantic salmon caught on the Miramichi River, New Brunswick, while White (1940) reported epizootics of lice on wild Atlantic salmon in the Moser River, Nova Scotia. Pemberton (1976) recorded the occurrence of sea lice on sea trout, *Salmo trutta*, in Scottish west coast sea lochs which are now used for salmon farming, but the infection level of lice on individual fish or the developmental stages found were not recorded. Marked differences were not found by Berland (1993) between the levels of lice on wild salmon in Norwegian inshore waters between 1973 when farming of salmon in Norwegian waters was in its infancy until 1992 when production had considerably increased. He stressed the need for care in the interpretation of data when different methods of capture were used. It is evident that there is a scarcity of useable historical data on the natural levels of lice in areas prior to the development of fish farming which prevents direct comparisons with the current levels in the same localities. It is only possible to state the rather obvious point that lice were present, occasionally in epizootic levels, on salmon (and sea trout) in salmon farming areas before the development of farming.

2. Current difference in lice infection between farming and non-farming areas.

Several studies have shown that salmonids in areas distant from fish farms have appreciable levels of lice infection. In the open sea, there is relatively limited information on the levels of lice present on Atlantic salmon; Pippy (1969) found less than 8 lice per fish while Jacobsen and Gaard (1997) recorded an abundance of 28 per salmon of wild origin. In the Pacific, Nagasawa *et al.* (1993) found generally similar levels on *Onchorhynchus* spp. Information by Karasev *et al.* (1995) and in later studies (Anon 1997) showed a widespread lice infection to be present on Atlantic salmon in the White Sea/Kola Peninsula area with an apparent stability in the level of infection in the area over approximately 50 years. A similar stability and low level of lice infection on sea trout in the southern North Sea was indicated by Tingley *et al.* (1997). In studies on lice levels on sea trout in southern Norway, Schram *et al* (1998) working in the Arendal area and Mo and Heuch (1998) working in the inner Oslo Fjord showed comparable levels of lice infection between the two areas, but with considerable variation occurring associated with season and host factors. Johnson *et al.* (1996) reported a high level of mortality of sockeye salmon (*Onchorhynchus nerka*) in 1990 attributed to heavy *L. salmonis* infection (100% prevalence with a mean intensity of 300 lice per fish) in Alberni Inlet on west Vancouver Island. Both this and a disease occurrence in Nova Scotia reported by White (1940) were specific incidents associated with low river conditions and the crowding together of pre-spawning fish at high water temperatures. These observations demonstrate the potential for lice to be highly pathogenic, even in non-farming situations, particularly when other compounding factors are present.

Most studies on lice levels on wild salmonids have concentrated on areas where fish farming occurs, particularly in Norway, Scotland and Ireland. Extensive data now exist from these (Anon 1997), particularly from sea trout in Ireland (Anon 1995). In Scotland (MacKenzie *et al.* 1998) and in Ireland (Tully and Whelan 1993) the highest levels of lice infection occur in the main areas of salmon farming activity. In the smaller geographic scale within the farming areas no relationship could be detected between the level of infection and the distance to the nearest farm up to 14 and 25km.

As a general observation, most of the data available on levels of lice infection show a considerable variation between different areas, and even within the same area in different samples taken at different times, both in different years and even seasonally within the same year (Lester and Roubal 1995). This is not surprising as similar area, host, time and sampling specific differences have also been shown with a wide range of other fish diseases in the marine environment. These variations occur to the extent that it is not possible to directly use comparisons of spatial differences in levels of fish diseases in environmental quality related studies (McVicar 1997). Instead, comparisons of trends in disease levels are more appropriate. Modelling studies on flatfish diseases, including a parasitic copepod, have shown that many biological and physical determinant factors may contribute, either individually or in combination, to the levels of disease found (Begg 1994). These results indicate the dangers of comparing data on lice levels in relation to a single factor, such as the presence of fish farming, when there are many other variables present in the different sets of data. Although it may be possible to establish good correlations between different sets of data, this does not necessarily indicate a cause-effect relationship. Many factors could simultaneously affect different data sets. For example, in the context of differences in the levels of lice infection found between farming and non farming areas, the biological aspects of lice challenge may lead to naturally higher levels of infection in enclosed, sheltered sea loch/fjord systems. As these are areas also favoured by fish farms, this alone could be a major contributory factor to the differences being found.

Despite all the work which has been conducted on sea trout, results on the contribution of farm lice to wild populations are not conclusive in either direction, and it is still an open question whether or not lice levels have shown any significant change in this host species. Much less work has been done to date on lice levels on Atlantic salmon.

3. Possible contribution from escaped farmed salmon.

When farmed fish escape, they will carry any lice burden they have with them into the wild environment. Many escaped fish survive and later appear in the oceanic feeding grounds mixing with salmon of wild origin. For example, in the feeding grounds to the north of Faroes, it has been shown by Hansen *et al.* (1993) that escaped salmon make up approximately 20-40% of catches. As adult female sea lice may survive for up to half a year (Schram *et al.* 1998), it is possible that sea lice from these may transfer to wild salmon (Jacobsen and Gaard 1997), or their progeny contribute to the abundance of the infective stages in the area. It has also been shown by Jacobsen and Gaard (1997) that farmed salmon caught north of Faroes have a significantly higher level of lice infection compared to fish of wild origin in the same area. It is possible that some of these additional lice were from infections obtained prior to their escape from farms, but other factors such as fish behaviour may also contribute. This higher level of lice on escaped fish compared to wild fish indicates a real risk of additional infection in the natural environment, specifically linked to these escaped farmed fish, a risk which increases with increasing numbers of escaped fish. However, balanced against this is the lower levels of wild salmon present as available hosts due to the decline in the wild stocks in recent years

4. Other evidence for lice transfer from farmed to wild salmonids.

In the absence of direct evidence of lice transfer from farmed to wild salmon and of time-sequence data of trends in lice levels which could be used to indicate if lice infection patterns in an area have changed, it may be asked if other evidence can be obtained to indicate the extent to which lice from farms affect wild fish. Recognisable features of lice on farmed salmon which could be recorded when these infect wild salmonids would provide an accurate quantification of any level of transfer of infection between the two groups of fish. To this end, genetic markers in the different populations of lice are being investigated by researchers in the Universities of St Andrews and Stirling in Scotland. Preliminary results by Todd *et al.* (1997) have been encouraging as they have indicated some differences in the frequency of occurrence of some genetic markers, although it was stressed that this research was still at an early stage. Morphological differences have also been found between different lice populations (Sharp *et al.* 1994) although none have been found specifically associated with farm populations of lice. Other markers such as the occurrence of carotenoid pigment in lice which has derived from the feed of farmed salmon have also been considered (Noack *et al.* 1997). All of these approaches have their difficulties and none has yet provided an indication of the extent that lice from farm origins infect wild salmonids.

(B) Lice on farmed salmon.

Most salmon farms are, at least some of the time, infected with *L. salmonis* and so provide a major new focus of lice to an area which is an infection risk to wild salmon in the vicinity. Anything which prevents this infection in farms, or decreases the level, can be considered to be beneficial in reducing this threat. As it is in the interest of all fish farmers to control lice levels in their stocks, this objective is a common interest to both wild fishery interests and to fish farmers. Research efforts have been concentrating on providing improved lice control methods in mariculture and although steady progress is being made, there is still considerable scope for further development.

1. Avoidance or prevention of lice infection.

The original source of all *L. salmonis* infections in salmon farms is from wild salmonids and although much of the subsequent infection is derived from within the farm it is likely that some re-infection continues from these external sources. Because of the widespread natural reservoir of lice on wild salmonids in all farming area, avoidance of infection on farmed salmon is likely to be an unachievable objective for sea cage salmon farming. Scottish experience has shown that pump-ashore farms do not become infected with lice, but this is unlikely to be a realistic solution for the salmon farming industry to resolve the problem with infection, as the additional operational costs associated with such facilities has raised major doubts about their commercial viability. The possibility of preventing infection through enhancing resistance, either by vaccination or salmon strain selection, is still largely at the conceptual stage although research is in progress in this area in several countries.

2. Levels of lice on farmed salmon.

In sea cages in all Atlantic salmon farming areas, it is recognised that the level of infection is known to differ considerably both spatially and temporally (Jackson *et al.* 1997). Some farm sites are more prone to lice infection than others and some years are known as "bad lice years". In particular, major seasonal differences in both the prevalence and intensity of infection have been found (Schram *et al. 1998)*. No specific reasons have been identified for such variations, highlighting the general lack of information available on the biology of these parasites. In Scotland, there is no obvious direct relationship between the initial accumulation of lice within a farm and the proximity of a salmon farm to recognised salmonid rivers, and hence to probable aggregations of wild salmon (MacKenzie *et al.* 1998). This lack of correlation is probably not surprising as the factors influencing the distribution of the infective agent, the process of infection of a host and the occurrence of disease are multifactorial and complex and unlikely to be controlled by a single independently operating variable.

The limited published information available to the ICES lice workshop on precise levels of *L. salmonis* infection in farm populations of salmon did not reveal any clear trends in the levels of lice infections, although it was noted that individual farm management practices and use of chemotherapy masked any background "natural" patterns (Anon 1997). Because of the reservoir of infection in the natural environment, it is likely that there will always be a need for the regular use of lice control methods in farms.

Self re-infection of farms, particularly associated with multi year-class sites, has been identified as a major contributory factor to lice levels on salmon farms. The effectiveness of temporarily removing all salmon from individual farms for a period in order to break the life cycle of lice and the subsequent reduction of infection levels (Grant and Treasurer 1993) has led to an increased use of fallowing in most salmon farming areas. The need to use several farm sites in order to grow one year group of fish on a site from smolt input to harvest, and at the same time maintain continuity of production, places considerable additional costs on smaller companies. Conflict with planning authorities and other marine resource users may also occur, as a proliferation of sites is required to maintain the same overall level of production in an area. Despite this, there has been an increase in area or single bay management strategies (Jackson *et al.* 1997). The need for a robust and reactive management strategy with general acceptance of the principles and good dialogue between interested parties is stressed.

Strategies to control lice levels assume a high priority in all European and North America countries farming salmon and most have either an official or a voluntary management system already in place. In Ireland, a statutory lice monitoring policy was implemented in 1991 and several years of good quantified data on the consequences on lice levels on farms have now been collected (Jackson *et al.* 1997). This demonstrated that the implementation of improved and co-ordinated husbandry practices such as annual site fallowing, separation of generations, the virtual elimination of two-sea-winter fish and improved treatment regimes has led to a progressive reduction in farm lice levels, both nationally and on individual farms. Practical minima of lice levels has been reached on some farms where re-infestation from wild sources is a constant reality. A similar structured monitoring programme of farm lice levels is also in place in Canada and a comprehensive document on the integrated pest management of sea lice in salmon aquaculture is currently in the final stages of production by the National Working Group on Integrated Management of Sea Lice. In Scotland, a voluntary Code of Practice has been established by the Scottish Salmon Growers Association involving regular monitoring and the synchronised treatment within defined management areas, particularly early in the year when parasite numbers and reproductive success are low. Experience by the salmon farming industry is showing a significant reduction in lice levels where the Code has been adopted. However, quantified information on the consequences of improvements in farm lice controls in terms of lice numbers on individual farms may not always be generally available as commercial sensitivities can restrict outside access to disease data in fish farms.

Although improvements in lice management strategies have contributed significantly to reducing problems from *L. salmonis*, there is no room for complacency as lice are still considered to be the greatest disease threat to farmed salmon in all parts of the North Atlantic area. Where reduction in the level of lice in salmon farms have been demonstrated, any consequences to lice infection on wild salmonids has not yet been clarified.

(C). Other sources of lice.

It has been shown that *L. salmonis* copepodid larvae do not infect non-salmonids (Bron *et al.* 1993) but adults may temporarily infect gadoid fish (Bruno and Stone 1990). As a consequence, there may be particular risks of such fish becoming significant short-term reservoirs of lice available to infect wild salmonids when farm treatments, such as hydrogen peroxide, detach large numbers of living lice from the farmed fish. However, the extent, or even the reality of this risk is unknown.

**Potential for contact between salmon and lice.**

The natural relationship between salmon and sea lice is likely to be the result of a long period of close association between the two organisms. As infection levels and pathogenicity are the result of dynamic processes, any alterations to aspects of the biology of the salmon or parasite may upset any natural balanced position which has been reached between the two organisms and have major consequences on either or both members of the relationship. When considering the potential for change associated with lice from farms on wild salmon, it is therefore important to consider these aspects of the biology of fish and parasite most likely to affect the most critical phase in the life of any parasite, namely the location and infection of a new host.

In comparison to many other parasites, such as the helminths, the number of eggs and therefore of transmissible stages produced by one *L. salmonis* is remarkably small (Wootten *et al.* 1982, Ritchie *et al.* 1993). This would indicate that this parasite has developed a highly successful and economic way of locating and infecting a new host. The main infective stage, the copepodid, is non-feeding and experimental studies have shown that this has a limited survival time in the water dependant on temperature and salinity (up to 10 days)( Lester and Roubal 1995). Infectivity rapidly decreases with the age of the copepodid so that the period of effective transmission potential is probably quite short, likely to be a matter of only a few days. This has major implications in establishing contact with the host. Various laboratory studies have shown that the copepodid positions itself in the water column through responding in a non-random way to several types of stimuli (light, current and probably chemical) to ensure greater chance of contact with the host (Bron *et al.* 1993).

Some field information is becoming available on the occurrence in the wild of the free living larval stages of lice and the patterns of infection of salmonids. In studies using plankton tows in Ireland (Costelloe *et al.* 1995; 1996; 1998) larvae were consistently recovered from immediately around a salmon farm, but also periodically at high levels in a river estuary some distance from the farm where no direct correlation with the peak in larval production in the farm could be established. Costelloe *et al.* (1996) showed a reduction in larval densities of 90% within 1 km of a fish farm due to dilution, vertical mixing, natural mortality and to local hydrographic conditions causing retention of larvae within the farm. Pulses in the occurrence of lice larvae have been noted by several authors (Tully 1989; Costelloe *et al.* 1998) and depend on many factors including environmental hatching cues, tide, photoperiod and time of year. Probably largely as a consequence, the lice infection patterns of farmed salmon in many areas also show a periodicity or pulses in the pattern of infection. In field trials in Ireland with caged sentinel salmon smolts, Costelloe *et al.* (1996) found infection rates with lice high both close to a fish farm and also in a river estuary distant from the farm. Similar trials in Scotland showed sentinel smolts nearest to a fish farm becoming most heavily infected with evidence for episodes of infection of limited duration occurring (McVicar *et al.* 1993). The pattern of infection of sea trout in inshore waters in Scotland could not be directly linked to the presence of infection on nearby salmon farms (MacKenzie *et al.* 1998). It is concluded that no direct evidence has been obtained of the role and significance of salmon farms in the transmission of sea lice to wild sea trout and salmon.

Evolutionary pressures will tend towards mechanisms to enhance infection with lice where there are aggregations of susceptible new hosts. With sea trout, there is a tendency for an inshore distribution in the immediate post smolt period, although differences in the nature of the estuary could considerably affect the extent of migration away from the near vicinity of the estuary (Johnstone *et al.* 1995). Sea trout therefore mainly accumulate their lice infection in these inshore waters. With salmon, in contrast, there is evidence that they may move rapidly offshore on entering the sea (Jonsson *et al.* 1993; Lacroix and McCurdy 1996) and in recent years substantial numbers of salmon post-smolts have been caught from the open ocean in the Norwegian Sea and off the north west of Scotland (Shelton *et al.* 1997). As has been pointed out by Costelloe *et al.* (1995) and MacKenzie *et al.* (1998) such differences could substantially affect the exposure of the different salmonids to inshore challenges with lice. It is therefore not possible to directly extrapolate data from one salmonid species to the other. However, escaped salmon may behave differently from their wild counterparts and spend more time in inshore waters being exposed to infection before migrating to the oceanic feeding grounds. Jacobsen and Gaard (1997) considered a significantly higher level of lice infection found in escaped fish caught in the open ocean was a consequence of these fish carrying lice from coastal areas in higher abundance than wild smolts. An increased susceptibility of these fish to infection could also be a factor.

At sea, Atlantic salmon characteristically accumulate on the rich feeding grounds at the boundary ("front") where the warm, high saline Atlantic water meets the cooler, less saline Arctic water. Jacobsen and Gaard (1997) presented evidence from the area north of the Faroes that new infestation with lice occurs in these open oceanic waters, with the level of infection progressively increasing over time. The consequence is that most Atlantic salmon returning to the coast carry significant levels of lice infection, although the actual numbers found in samples are strongly influenced by size of fish, the area sampled and the fishing method used (Berland 1993). The complexity of the dynamics of infection prevents assessment of the possible consequences of any alteration in the numbers of lice in these open sea areas due to a contribution from lice of farm origin.

When salmon return to inshore waters prior to ascending spawning rivers, a further opportunity for lice to infect them may be presented. The level of risk will depend on the residence time of salmon in the area and in particular if this is sufficiently long for lice to have completed their full generation life cycle. The precise distribution in inshore waters may be critical as it has been shown in one area in Ireland that high infection intensity can be found in an estuary compared with other local waters (Costelloe *et al.* 1995). The risk of a direct contribution of lice infection from fish farms will considerably increase if these returning salmon spend time in the immediate vicinity of farms, as it has been shown by Costelloe *et al.* (1996; 1998) that infective stages of lice commonly occur near to farms. The paucity of information on the distribution of wild salmon in inshore waters, and in particular around fish farms, prevents any conclusions in this area.

## Consequences of lice infection on wild salmon.

Mucus and epidermis are considered to be the main dietary component of *L. salmonis* although adult females extensively feed on blood (Wootten *et al.* 1982). Major epizootics occur in farmed salmon due to the associated extensive damage particularly to the dorsal fins and skin of the head, osmoregulatory failure and secondary infections of lesions. Most damage is associated with the pre-adult and adult stages and particularly with the development of the former (Dawson *et al.* 1997) although in experimental situations, lesions on the head were observed to recover as lice matured. In wild Atlantic salmon, severe lesions are rarely observed associated with sea lice. Exceptions are reports by Huntsman (1918) of lice on a large percentage of Atlantic salmon caught on the Miramichi River, New Brunswick with associated skin lesions and secondary infections and by White (1940) of epizootics of lice on wild Atlantic salmon in the Moser River, Nova Scotia with similar lesions and mortalities. Similarly, Johnson *et al.* (1996) reported a high level of mortality of sockeye salmon (*Onchorhynchus nerka*) in 1990 attributed to heavy *L. salmonis* infection (100% prevalence with a mean intensity of 300 lice per fish) in Alberni Inlet on west Vancouver Island. Both this and the report by White (1940) were specific incidents associated with low river conditions and the crowding together of pre-spawning fish at high water temperatures. These observations demonstrate the potential for lice to be highly pathogenic, even in non-farming situations, particularly when other compounding factors are present.

The scarcity of lice-associated disease incidents in wild salmon may be due to the generally lower numbers of lice per fish but the possibility that it is only the lightly infected fish which survive and can be sampled should not be ignored. As indicated by McVicar (1999) there are major difficulties in assessing the impact of highly pathogenic disease conditions in wild fish populations and indirect methods may have to be used. The apparent rarity of signs of disease associated with infections such as lice should not be taken as indicating they do not have a significant impact on the fish population. The highly skewed (overdispersed) pattern of infection typical of sea lice infections (MacKenzie *et al.* 1998) results in some fish having a considerably higher than average intensity of infection and the fate of such fish in the wild would be of considerable interest. Jacobsen and Gaard (1997) found one escaped farmed fish caught on the oceanic feeding grounds with an infection of 299 lice but did not indicate the condition of the fish.

## Other infections transmitted by lice

Nylund *et al.* (1993) reviewed the potential for lice to carry and transmit various other infectious agents (bacteria and viruses) from fish to fish. Several infections can be transferred and it was shown experimentally that ISA virus could be transferred from infected salmon to challenged salmon. There are major implications from such observations to lice control methods in farms, particularly where significant numbers of live lice are detached from farmed salmon (for example with hydrogen peroxide treatments) and where these then seek new hosts. Because of the dangers of a parasite leaving a host to seek a new host, under normal circumstances it is unlikely that large numbers of lice will move between fish in the wild, particularly when the host populations are relatively dispersed. McVicar *et al.* (1993) found an adult *L. salmonis* within 11 days of transfer of sea trout to an isolated sea cage, indicating that such transfers of lice do sometimes occur.

## Conclusions.

Any addition to the numbers of lice in an inshore or offshore area has the potential of altering the balance away from natural levels of infection. Although there is some evidence for relatively stable population structures of lice occurring on wild salmon, in the absence of usable historic data on lice levels prior to the development of farming in an area, it is not possible to determine if there have been any subsequent changes occurring. In addition, the probable complex and multifactorial nature of the factors leading to a particular level of lice infection precludes the direct comparison of lice levels between different areas. It is reasonable to assume that lice from farms contribute to lice populations in wild salmon, but the extent and consequences of this is still a matter of conjecture.

## Research recommendations

The ICES Workshop on the Interactions Between Salmon Lice and Salmonids (Anon 1997) identified many areas where there was inadequate data on interactions between sea lice and salmonids and suggested a comprehensive series of research topics which could fill these gaps. Many of these suggestions had the characteristics of a "wish list" and it is unlikely that adequate resources will be made available to meet their full requirements. Realistically, research topics should be identified which are firmly based on good scientific principles, are likely to provide good returns from budgets and where there is a high probability of a scientifically definitive result (either positive or negative) being realised on clearly defined questions. Many of the studies which have been previously undertaken on possible inter-relationships between lice from farms on wild fish have been seriously under-resourced, a fact which has significantly contributed to the restricted nature of the research and the subsequent inability to make conclusions on cause-effect relationships from the data obtained. It is essential that projects are designed to consider single variables if possible. In particular, information is required on trends of infection levels in both farmed and wild salmon in the same area to evaluate correlations between the different data sets, to have more information on the dispersion of the infective stages of lice from farms and to have more knowledge of the behaviour of salmon smolts and returning adults in inshore waters in the vicinity of farms. Although studies are in progress to attempt to identify features of lice specific to farms, direct evidence for the transfer of lice from farmed fish to wild fish is still lacking, and more research is required in this area.

## References


Anon. 1995. Report of the Sea Trout Working Group. 1994. Department of the Marine, Dublin.

Anon. 1997. Report of the Workshop on the Interactions Between Salmon Lice and Salmonids. ICES CM 1997/M:4, 204pp.

Begg, G.S. 1994. The population ecology of disease in the common dab (*Limanda limanda* L.). PhD Thesis University of Aberdeen, 392pp.

Berland, B. 1993. Salmon lice on wild salmon (*Salmo salar*) in western Norway. In: Pathogens of wild and farmed fish: sea lice. G.A.Boxshall and D. Defaye (Eds). Ellis Horwood, Chichester, 179-187.

Boxshall, G.A. and Defaye, D., (Eds) 1993. Pathogens of wild and farmed fish: sea lice. Ellis Horwood, Chichester. 378 pp.

Bron, J.E., Sommerville, C. and Rae, G.H. 1993. Aspects of the behaviour of copepodid larvae of the salmon louse *Lepeophtheirus salmonis* (Kroyer, 1837). In: Pathogens of wild and farmed fish: sea lice. G.A.Boxshall and D. Defaye (Eds). Ellis Horwood, Chichester, 125-142.

Bruno, D.W. and Stone, J. 1990. The role of saithe, *Pollachius virens* L., as a host for the sea lice, *Lepeophtheirus salmonis* Kroyer and *Caligus elongatus* Nordmann. Aquaculture 89: 201-207.

Costelloe, J., Costelloe, M. and Roche, N. 1995. Variation in the sea lice infestation on Atlantic salmon smolts in Killary Harbour, West Coast of Ireland. Aquaculture International 3: 379-393.

Costelloe, M., Costelloe, J. and Roche, N. 1996. Planktonic dispersion of larval salmon-lice, *Lepeophtheirus salmonis*, associated with cultured salmon, *Salmo salar*, in western Ireland. Journal of the Marine Biological Association of the United Kingdom 76: 141-149.

Costelloe, M., Costelloe, J., O'Donohoe, G.O., Coghlan, N.J., Oonk, M. and van der Heijden, Y. 1998. Planktonic distribution of sea lice larvae, *Lepeophtheirus salmonis*, in Killary Harbour, west coast of Ireland. Journal of the Marine Biological Association of the United Kingdom 78: 853-874.

Dawson, L.H.J., Pike, A.W., Houlihan, D.F. and McVicar, A.H. 1997. Comparison of the susceptibility of sea trout (*Salmo trutta* L.) and Atlantic salmon (*Salmo salar* L.) to sea lice *Lepeophtheirus salmonis* (Kroyer, 1837) infections. ICES Journal of Marine Science 54: 1129-1139.

Grant, A.N. and Treasurer, J.W. 1993. The effects of fallowing on caligid infestations on farmed Atlantic salmon (*Salmo salar* L.) In Scotland. In: Pathogens of wild and farmed fish:

sea lice. G.A.Boxshall and D. Defaye (Eds). Ellis Horwood, Chichester, 255-260.

Hansen, L.P., Jacobsen, J.A. and Lund, R.A. 1993. High numbers of farmed Atlantic salmon, *Salmo salar* L., observed in oceanic waters north of the Faroe Islands. Aquaculture and Fisheries Management 24: 777-781.

Hansen, L.P., Hastein, T., Naevdal, G., Saunders, R.L. and Thorpe, J.E. (Eds). (1991). Interactions between cultured and wild Atlantic salmon. Aquaculture (Special Issue) 98, 324pp.

Hogans, W.E. and Trudeau, D.J. 1989. *Caligus elongatus* (Copepoda: Caligoida) from Atlantic salmon (*Salmo salar*) cultured in marine waters of the lower Bay of Fundy. Canadian Journal of
Zoology 67: 1080-1082.

Huntsman, A.G. 1918. Report on affected salmon in the Miramichi River, New Brunswick. Contributions to Canadian Biology 1917-1918: 169-173.

Jackson, D., Deady, S., Leahy, Y. and Hassett, D. 1997. Variations in parasitic caligid infestations on farmed salmonids and implications for their management. ICES Journal of Marine Science, 54: 1104-1119.

Jacobsen, J.A. and Gaard, E. 1997. Open-ocean infestation by salmon lice (*Lepeophtheirus salmonis*): comparison of wild and escaped farmed Atlantic salmon (*Salmo salar* L.) ICES Journal of Marine Science, 54: 1113-1112.

Johnson, S.C., Blaylock R.B., Elphick, J. and Hyatt, K.D. 1996. Disease caused by the salmon louse *Lepeophtheirus salmonis* (Copepoda: Caligidae) in wild sockeye salmon (*Onchorhynchus nerka*)stocks of Alberni Inlet, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 53: 2888-2897.

Johnstone , A.D.F., Walker, A.F., Urquhart, C.G. and Thorne, A.E. 1995. The movements of sea trout smolts, *Salmo trutta* L., in a Scottish west coast sea loch determined by acoustic tracking. Scottish Fisheries Research Report 56: 1- 21.

Jonsson,N., Hansen, L.P. and Jonsson, B. 1993. Migratory behaviour and growth of hatchery-reared post-smolt Atlantic salmon *Salmo salar*. Journal of Fish Biology 42: 435-443.

Karasev, A.B., Kuzmin, O.G., Finstad, B. and Nilsen, S.T. 1995. Salmon rivers of the Kola Peninsula. Salmon lice (*Lepeophtheirus salmonis* Kroyer) on Atlantic salmon (*Salmo salar* L.) from the Varzuga River. ICES CM 1995/R:3, 14pp.

Lacroix, G.L. and McCurdy, P. 1996. Migratory behaviour of post-smolt Atlantic salmon during initial stages of seaward migration. Journal of Fish Biology 49: 1086-1101.

Lester, R.J.G. and Roubal, F.R. 1995. Phylum Arthropoda. In: Fish Diseases and Disorders. Volume 1 Protozoan and Metazoan Infections. P.K. Woo (Ed). CAB International, Cambridge, 475-598.

MacKenzie, K., Longshaw, M, Begg, G.S. and McVicar, A.H. 1998. Sea lice (Copepoda: Caligidae) on wild sea trout (*Salmo trutta* L.) In Scotland. ICES Journal of Marine Science, 55: 151-162.

MacKinnon, B.M. 1995. The potential of cunner, *Tautogolabrus adspersus*, to act as cleaner fish in removing sea lice (*Caligus elongatus*) from farmed salmon in eastern Canada. Canadian Journal of Fisheries and Aquatic Science 52: 175-177.

McLean, P.H., Smith, G.W. and Wilson, M.J. 1990. Residence time of the sea louse, *Lepeophtheirus salmonis* K., on Atlantic salmon, *Salmo salar* L., after immersion in fresh water. Journal of Fish Biology 37: 311-314.

McVicar, A.H. 1997. The development of marine environmental monitoring using fish diseases. Parassitologia 39: 177-181.

McVicar, A.H. 1999. Options for controlling disease and improving health in farmed salmon, as a means of reducing risks posed by escapes. Canadian Stock Assessment Secretariat, Working Paper xxxx.

McVicar, A.H., Sharp, L.A. and Pike, A.W. 1993. Infectious diseases of Scottish sea trout and salmon. In: Problems with Sea Trout and Salmon in the Western Highlands. Atlantic Salmon Trust, Pitlochry: 48-60.

Mo, T.A. and Heuch, P.A. 1998. Occurrence of *Lepeophtheirus salmonis* (Copepoda: Caligidae) on sea trout (*Salmo trutta*), in the inner Oslo Fjord, south-eastern Norway. ICES Journal of Marine Science 55: 176-180.

Nagasawa, K., Ishida, Y., Ogura, M., Tadokoro, K. and Hiramatsu, K. 1993. The abundance and distribution of *Lepeophtheirus salmonis* (Copepoda: Caligidae) on six species of Pacific salmon in offshore waters of the North Pacific Ocean and Bering Sea. In: Pathogens of wild and farmed fish: sea lice. G.A. Boxshall and D. Defaye (Eds). Ellis Horwood, Chichester, 166-178.

Noack, P.T., Laird, L.M. and Priede, I.G., 1997. Carotenoids of sea lice (*Lepeophtheirus salmonis*) as potential indicators of host Atlantic salmon (*Salmo salar* L.) origin. ICES Journal of Marine Science, 54: 1140-1143.

Nylund, A., Wallace, C, and Hovland, T. 1993. The possible role of *Lepeophtheirus salmonis* (Kroyer) in the transmission of infectious salmon anaemia. In: Pathogens of wild and farmed fish: sea lice. G.A. Boxshall and D. Defaye (Eds). Ellis Horwood, Chichester, 367-373.

Pemberton, R. 1976. Sea trout in North Argyll sea lochs, population, distribution and movements. Journal of Fish Biology 9: 157-190.

Pippy, J.H.C. 1969. Preliminary report on parasites as biological tags in Atlantic salmon (*Salmo salar*). I. Investigations 1966 to 1968. Fisheries Research Board of Canada, Technical Report, 134: 44pp.

Ritchie, G., Mordue (Luntz), A.J., Pike, A.W. and Rae, G.H. 1993. The reproductive output of *Lepeophtheirus salmonis* adult females in relation to seasonal variability of temperature and photoperiod. In: Pathogens of wild and farmed fish: Sea lice. G.A. Boxshall and D. Defaye (Eds) 153 - 165.

Schram, T.A,, Knutsen, J.A., Heuch, P.A. and Mo, T.A. 1998. Seasonal occurrence of *Lepeophtheirus salmonis* and *Caligus elongatus* (Copepoda: Caligidae) on sea trout (*Salmo trutta*), off southern Norway. ICES Journal of Marine Science 55: 163-175.

Sharp,L., Pike, A.W. and McVicar, A.H. 1994. Parameters of infection and morphometric analysis of sea lice from sea trout (*Salmo trutta*, L.) in Scottish waters. In: Parasitic Diseases of Fish. A.W. Pike and J.W Lewis (Eds) Samara Publishing Ltd, Great Britain, 151-170.

Stuart, R. 1990. Sea lice, a maritime perspective. Bulletin of the Aquaculture Association of Canada 90: 18-24.

Shelton, R.G.J., Turrell, W.R., MacDonald, A., McLaren, I.S. and Nicoll, N.T. 1997. Records of post-smolt Atlantic salmon, *Salmo salar* L., in the Faroe-Shetland Channel in June 1996. Fisheries Research 31: 159-162.

Tingley, G.A., Ives, M.J. and Russell, I.C. (1997). The occurrence of lice on sea trout (*Salmo trutta*, L.) captured in the sea off the East Anglian coast of England. ICES Journal of Marine Science 54: 1120-1128.

Todd, C.D., Walker, A.M., Wolff, K., Northcott, S.J., Walker, A.F. Ritchie, M.G., Hoskins, R., Abbott. R.J. and Hazon, N. 1998. Genetic differentiation of populations of the copepod sea louse *Lepeophtheirus salmonis* (Kroyer) ectoparasitic on wild and farmed salmonids around the coasts of Scotland: Evidence from RAPD markers. Journal of Experimental Marine Biology 210: 251-274.

Tully, O. 1989.The succession of generation and growth of the caligid copepods *Caligus elongatus* and *Lepeophtheirus salmonis* parasitising farm Atlantic salmon smolts (*Salmo salar* L.). Journal of the Marine Biological Association of the United Kingdom 69: 279-287.

Tully, O. and Whelan, K.F. 1993. Production of nauplii of (Kroyer) (Copepoda: Caligidae) from farmed and wild salmon and its relation to infection of wild sea trout (*Salmo trutta* L.) off the west coast of Ireland in 1991. Fisheries Research 17: 187-200.

White, H.C.1940. Life history of *Lepeophtheirus salmonis*. Journal of the Fisheries Research Board of Canada 6: 172-175.

Wootten, R., Smith, J.W. and Needham, E.A. 1982. Aspects of the biology of the parasitic copepods *Lepeophtheirus salmonis* and *Caligus elongatus* on farmed salmonids, and their treatment. Proceedings of the Royal Society of Edinburgh 81B: 185-197.