A REVIEW OF RESEARCH AND FIELD DATA ON RELATIVE LOUSE INFECTION LEVELS ON WILD SALMON SMOLTS AND SEA TROUT AND THE PROXIMITY OF FISH FARMS TO RIVER ESTUARIES

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INTRODUCTION
The Strategic Framework for Scottish Aquaculture (Scottish Executive, 2003) aims to adopt
best practice in management and control of disease and pathogens. This report fulfils an
undertaking of the Strategic Framework, and reviews research and field data in Scotland and
abroad on relative louse infection levels on wild salmon smolts and sea trout and the
proximity of fish farms to river estuaries. Sea lice infestation of farmed salmonids and their
effects on wild salmonids have been the subject of a great deal of research and monitoring
in recent years (see Boxaspen, 2005). The aquaculture industry has received much criticism
regarding control of sea lice and links to falling wild salmonid numbers. However, the
science required to examine any link between fish farming and wild fish populations is
complex and difficult, and it is only through the review of work from different groups and over
long time periods that trends and links become clear. This review aims to illuminate some of
the main findings from a large amount of research carried out in the major salmon farming
countries of the Northern hemisphere.

Sea Lice Biology
The biology of sea lice was comprehensively reviewed by Pike & Wadsworth (1999). Sea
lice are caligid copepod parasites of fish. In Scotland, both *Lepeophtheirus salmonis*
(Krøyer, 1837) and *Caligus elongatus* (Nordmann, 1832) species are found on farmed
Atlantic salmon *Salmo salar* L. Of these, *L. salmonis* causes the most serious problems,
with overall abundance of *C. elongatus* lower than *L. salmonis*, and significant inverse
relationships between the two species (Revie *et al.*, 2002a). In this review, where the louse
species is not explicitly stated, the text refers to *L. salmonis*.

Sea louse eggs hatch to release free-living planktonic stages. These nauplii develop into
infective copepodids that use chemosensory mechanisms to locate their hosts
(Invarsdóttir *et al.*, 2002). Following settlement on a host, lice proceed through chalimus
larvae and pre-adult stages to adults (Johnson & Albright, 1991; Piasecki, 1996;
Schram, 1993).

*L. salmonis* has circumpolar distribution. Study of the population genetics of *L. salmonis*
found that there was a lack of genetic differentiation between populations, indicating few
barriers to gene flow and essentially random mating (see Boxaspen, in press, for review).
This might be surprising if lice were thought to complete their entire life cycle in restricted
areas such as bays, lochs or fjords. In fact, lice survive on Atlantic salmon throughout the
winter and in the feeding grounds, where random mating is possible (see below).
Host Preference

In aquarium experiments, sea trout were not found to be more susceptible to louse infection than Atlantic salmon (Bjørn & Finstad, 1998). Although Dawson et al. (1997) found that the attachment and survival of chalimus stages was lower on salmon, and salmon had lower lice abundance than sea trout, no significant differences were found in the attachment and survival of *L. salmonis* to sea trout or salmon in aquarium experiments (Bricknell, Fisheries Research Services, personal communication). The intensities of lice on sea trout and char are also similar (Bjørn et al., 2001), although it was found that large trout and char tended to have lower infestation than smaller fish (Bjørn & Finstad, 2002). In aquarium experiments analysing the susceptibility of sea run and freshwater brown trout (*Salmo trutta*), although the survival and development of lice was similar on both groups, sea trout had lower abundance and intensity of infection (Glover et al., 2001). It was not determined whether variations in the degree of louse attachment or loss caused these differences and it was postulated that natural selection for resistant fish may have influenced the lice levels in sea trout. In another study, some differences in susceptibility of sea trout populations were found (Glover et al., 2003), with a population that may historically have been exposed to more frequent and intensive lice infestation having significantly lower lice abundance, density and rate of development. In this experiment, louse density was proportional to fish length and weight.

No significant differences in lice infestation were found between different farm stocks of Atlantic salmon, but the density on one wild salmon stock was significantly lower than on another wild and a farm strain (Glover et al., 2004).

It is clear that *L. salmonis* prefers salmonids to other fish and that within a species, differences in lice levels between stocks may be found. However, no clear differences in susceptibility have been demonstrated between species and the degree of variation within a species may exceed that between species. Thus at present it appears that sea trout are not innately more susceptible to sea lice than Atlantic salmon.

Difficulties Studying Lice on Wild Fish

In the case of wild fish studies, there are many environmental variables that may influence lice infestation data (see MacKinnon, 1998). These include season, temperature, current, salinity and water quality in addition to host factors such as age, size, stock and immunocompetence and pathogen influences such as strain, viability, fecundity and pathogenicity. The number and variability of these factors creates extreme difficulty in comparing different studies. Many of these factors also impact on wild populations of fish and their stock sizes, making it extremely difficult to determine primary causes for decreases in wild fish stocks.

It can be problematical to compare studies if different variables have been measured in each case. Experimental variation also complicates the use of results from different studies. Catch methods is one obvious source of this variation (see Jacobsen & Gaard, 1997). In most studies on lice, accepted definitions of intensity, abundance and prevalence have been used (Margolis et al., 1982), so that although use of abundance data may be difficult (as stated below) and care is required when using data from separate reports, at least it is technically possible to compare data from different studies.
There may of course be many reasons for a decline in levels of natural populations such as sea trout and the ultimate cause of mortality in wild fish is very difficult to define. It is also difficult to prove a cause/effect relationship between the infection of wild fish and mortality, with extrapolation from aquarium experiments to wild populations being extremely problematical (McVicar, 2004). It can be difficult to draw conclusions from complex patterns of wild fish population decline (McVicar, 1997; 2004), but periodic consideration of available evidence may advance knowledge on the subject.

Overdispersion, or aggregation, is a situation where only a few hosts in a population have a large parasite burden and the majority of the host population have few or no parasites. In experiments, *L. salmonis* chalimus stages were overdispersed in intensity on sea trout post-smolts, but this overdispersion decreased at later stages of lice (Bjørn & Finstad, 1998). In areas where salmon farms are present, infections of sea trout and char were overdispersed (Bjørn et al., 2001). In a review of data sets, Murray (2002) concluded that sea lice were overdispersed on sea trout from a range of marine environments and that the degree of overdispersal was highest in coastal areas, near salmon farms.

The overdispersion of lice on hosts creates serious difficulties in interpreting data, particularly that from wild fish. In an over-dispersed distribution, most of the lice are on a few fish with very high loads. This makes obtaining a representative sample difficult, making estimates of mean abundance and intensity unreliable. The population effects of lice loads may be insensitive to the mean intensity; impact may instead depend on the proportions of host that have lice loads above a certain intensity. This proportion cannot be calculated from mean loads, unless the distribution of loads is also known and this is not often reported. The existence of over-dispersion may be inferred if variance in intensity of infestation exceeds the mean.

As is the case for any disease condition, lice infestation is extremely difficult to study in wild fish. To draw conclusions or reveal trends, the results of many different studies must be reviewed.

**Effects of Lice Infestation on Salmonids**

*L. salmonis* induces systemic stress responses in the skin and gills of infected salmonids (Tully & Nolan, 2002), with intensity of infection correlated with stress indicators such as plasma cortisol (Bowers et al., 2000; Bjørn et al., 2001). The susceptibility of fish to lice and the consequences of infestation are also affected by host factors of species, life cycle stage and health status, including stress, nutrition and immunocompetence (MacKinnon, 1998).

Dawson et al. (1997) found that the general pattern of skin damage caused by lice was the same on salmon and sea trout. McVicar et al. (1993) found that sea trout captured in north western Scotland in early summer had cranial lesions and fin erosion consistent with sea lice damage, but MacKenzie et al. (1998) only found dorsal fin damage, associated with chalimus infection. Other pathological changes were seen in these fish, notably in the internal organs, but could not be correlated with disease, illustrating the difficulty inherent in examining the health status or causes of mortality in wild fish.

Dawson (1998) investigated the physical and physiological impact of lice on wild sea trout in Ireland. Dorsal fin erosion was the only physical damage reported, and was found in fish with higher lice intensities, but no skin damage was found in fish bearing pre-adult or adult parasites. Fin erosion has also been associated with chalimus stage infection of sea trout in Scotland (McVicar et al., 1993) but there was no clear relation between numbers of lice and degree of damage. No correlation was found between physiological parameters and lice numbers and physiological differences between groups of fish could not be unequivocally attributed to lice infection.
A Review of Research and Field Data on Relative Louse Infection Levels

Schram et al. (1998) found a prevalence of 100% *L. salmonis* on adult sea trout off southern Norway by late autumn, with median intensity at a maximum of 8 lice per fish. There was little damage to the fish caused by the lice and no correlation between infestation and condition factor of the fish, indicating that these levels of lice did not cause serious damage to the trout.

The swimming performance of infected salmon in seawater is significantly lower than that of uninfected fish or infected fish in freshwater, suggesting that return to freshwater may relieve osmotic stress and reduce the energy requirement of infected fish (Glover et al., 2004). Although *L. salmonis* may remain on salmon up to 6 days after return to freshwater, most lice are lost in the first 48 hours (McLean et al., 1990). Therefore data on lice burdens on fish captured in freshwater or in estuarine areas where fish may have entered freshwater then returned to seawater must be treated with care.

Louse infection of sea trout and landlocked salmon was found to be correlated with changed behaviour and premature return to freshwater (Bjørn et al., 2001; Carr & Whoriskey, 2004; Finstad & Birkeland, 1997; Grimnes et al., 1998). Infested landlocked salmon that returned to freshwater had significant damage (Carr & Whoriskey, 2004). The consequences of this early return of infested sea trout was studied by Birkeland (1996). Post-smolts carried more lice than older sea trout and these lice were mainly copepodids and chalimus, in contrast to the older lice carried by older fish. 41% of the post-smolts that entered freshwater later returned to sea and had recovered from the louse infestation. A review of these and further results from Norway (see Heuch et al., 2005) indicates that premature return was not unusual during the late 1990s.

Despite the many practical considerations in using or analysing results from multiple sources, an accumulation of information from many different studies may reveal general patterns, trends or correlations. A review of information regarding sea lice damage to salmonids reveals that severe lice infestation causes physiological disturbance and physical harm to salmon and sea trout. There is currently no evidence that either species suffers more damage than the other. The levels of lice infestation that may be harmful have been studied in some detail (see below).

Harmful Levels of Lice

Harmful levels of *L. salmonis* were estimated by Bjørn & Finstad (1997) and Finstad et al. (2000) who found that development of lice to pre-adult and adult stages was accompanied by a sudden increase in the osmoregulatory imbalance of sea trout and salmon smolts and mortality of sea trout smolts. It was estimated that lice levels above 90 larvae or 50 pre-adult or adult lice could result in the death of 60g sea trout smolts (Bjørn & Finstad, 1997) and over 30 chalimus larvae may kill 40g salmon smolts when the lice develop to pre-adults (Finstad et al., 2000). No mechanical damage was found to sea trout post smolts until pre-adult stages of lice developed and this damage was more frequent and severe on moribund fish (Bjørn & Finstad, 1998). McVicar et al. (1993) found that wild post-smolt sea trout may be infected with more than 100 chalimus larvae without suffering physiological impairment, in contrast to smolts, which appear to suffer once lice levels reach 90 larvae per 60g smolt (Bjørn & Finstad, 1997). Jacobsen & Gaard (1997) found a mean abundance of 30 *L. salmonis* on salmon in feeding grounds north of the Faroe islands. This level of infestation did not appear to cause damage to the fish. The variance:mean ratio of infection on wild sea trout smolts studied by Bjørn et al. (2001) was thought to indicate mortality of the fish with the highest infections. Salmon smolts may not survive infection of more than 11 lice (see Heuch et al., 2005). This louse level caused mortality in aquarium experiments (Finstad et al., 2000) and smolts collected from the wild (Holst et al., 2003). In addition, no
wild smolts with more than 10 lice were found (Holst et al., 2003), which may indicate mortality of those that are more heavily infected.

On the east coast of Canada, wild fish examined for lice infestation had less damage than expected from the observed lice burdens, and this was taken as evidence that infection had occurred recently, potentially with larvae from nearby farms (Carr & Whoriskey, 2004).

The general conclusion is that development of lice from larvae to pre-adult and adult stages increases the harmful effects of the lice. Smolting fish appear more susceptible to damage than post-smolts. Therefore, infection of wild salmonids as they head out to sea is likely to have a greater effect than infection of mature returning fish.

**Baseline Lice Levels in Areas Without Farms**

As many authors have already pointed out, it is desirable to have baseline data on lice levels in different areas from the era prior to fish farming. As this information is not available, surveys have been undertaken in regions without farming activity.

On wild salmonids, both *L. salmonis* and *C. elongatus* have been recorded (Boxaspen, 2005 table 1). In Scotland, *C. elongatus* was rarely found on sea trout, with most lice on this species being *L. salmonis* (McVicar et al., 1993, MacKenzie et al., 1998).

In wild Atlantic salmon, Todd et al. (2000) found lice prevalence of 82-100%, with a greater abundance on older fish, indicating persistent infection in the open ocean and not just in lochs.

Studies of wild sea trout by McVicar et al. (1993) and MacKenzie et al. (1998) found up to 30% of trout infected with lice. Great variation in infection intensity was found by MacKenzie et al. (1998), and as noted above, small numbers of fish infected with many lice can skew the figures of lice abundance for an area. *L. salmonis* chalimus stages were overdispersed in intensity on experimentally infected sea trout post-smolts, but this overdispersion decreased at later stages of lice (Bjørn & Finstad, 1998). Conversely, overdispersion was found as infection progressed in wild sea trout and char (Bjørn et al., 2001).

MacKenzie et al. (1998), Bjørn et al. (2001), Bjørn & Finstad (2002) and Rikardsen (2004) all found that in areas remote from farms, the lice showed a progression of developmental stages with time, with low infestations in winter and spring, dominated by adult lice whereas higher infestations in autumn contained a high proportion of chalimus larvae.

Tingley et al. (2001) studied louse levels on sea trout caught in the North Sea off England, an area remote from salmonid farming. 96% prevalence and a mean abundance of 4 lice per fish, with 0-13 lice per fish, including chalimus stages, indicating that transmission had occurred in seawater. Seasonal effects on infestation were greater than annual, weight, condition factor, age, sex or sea time. Lice were overdispersed, but to a lesser degree than in areas where salmonids are farmed, and *Caligus elongatus* infestations were more dynamic than *L. salmonis*. Salmon returning to Ireland were also infested, with a prevalence of over 94%, including some juvenile lice (Copley et al., 2005). In a region of Norway remote from salmonid farms, Schram et al. (1998) found that the prevalence of *L. salmonis* on sea trout reached 100% in autumn, from 20-35% in March and April, but the prevalence and intensity of *C. elongatus* was lower. Similar levels of lice were found in another region by Mo & Heuch (1998). Prevalence and intensity increased in Spring but decreased from May to July. In sampling areas further north in Norway, lower prevalence levels were found on both sea trout and char and in one year the sampling area...
distant from farms had more lice than the area with farms (Bjørn & Finstad, 2002). Lower intensity in this study may be related to temperature effects or the density of fish farming in the region. Schram et al. (1998) suggested that the patterns of prevalence, infestation and aggregation indicated that lice did not cause serious damage to the trout. Mo & Heuch (1998) did not find any prematurely returning sea trout. In contrast to the findings of Butler et al. (2001), adult stages of lice dominated the Norwegian samples.

The findings of Todd et al. (2000), Tingley et al. (2001) and Copley et al. (2005) provide evidence that salmonids maintain a population of lice throughout the year. This is supported by the finding of all life stages of lice in salmon feeding grounds. Jacobsen & Gaard (1997) sampled salmon north of the Faroes. Prevalence of L. salmonis was 99.2% and C. elongatus 5.5%. The abundance and density of lice, especially chalimus and pre-adult stages, was higher on escapee 1 seawinter fish than on wild fish, but on 2 seawinter fish, infestation was similar. The presence of all stages of lice on fish in open-oceans indicates that infestation occurs here as well as in coastal locations. Although infestation in winter is low and infection success reduced, lice do survive through winter months and can reproduce (Boxaspen 2005; Boxaspen & Naess, 2000; Heuch et al., 2002).

In sea trout too, a population of lice is maintained throughout the year and in regions remote from farms. Seasonal patterns of infestation of sea trout in northern Norway were observed, similar to those found by Schram et al. (1998), with prevalence reaching over 80% in autumn (Rikardsen, 2004). These data indicated the sea trout maintain a population of sea lice through feeding in seawater even in winter.

Once the data from the studies cited above are reviewed, it can be seen that L. salmonis prevalence of over 95% is usual in areas with salmon farms. Populations of lice are maintained throughout the year and during time spent in feeding grounds remote from aquaculture. The seasonality of prevalence and intensity levels requires that care is taken when interpreting data from only a few time points or samples taken at only certain seasons. Nevertheless, the combined data from these studies provide some indication of base line lice levels in the absence of salmon farms.

Release of Lice from Farms

Lice and other parasitic copepods pose a serious problem for fish farming (see Johnson et al., 2004). These infestations, and the potential risks to wild fish, have been 'one of the most intensively reviewed topics in aquatic biology' (McVicar, 2004).

As louse infection pressure is a product of the number of fish in the system and the number of lice per fish (Heuch & Mo, 2001), it is undeniable that heavy infestation of lice in fish farms increases the infection pressure in the area, with numbers of farmed salmonids in Norway estimated to be over 10 times greater than the number of wild hosts (Heuch et al., 2005). The link between louse infection of wild fish and proximity of fish farms has received intense scrutiny and infections of wild fish are an important indicator for the success of lice control strategies (Heuch et al., 2005). Scottish farms have higher infection levels than those in Norway, possibly related to differences in temperature, environment, or treatments (Heuch et al., 2003; Revie et al., 2003b). Data from Scottish Atlantic salmon farms showed inter-annual variation in lice levels, but no association between lice levels and geographical region, stock type or coastal exposure (Revie et al., 2002b), although high current speed was associated with lower lice burdens (Revie et al., 2003a). Treatments led to pronounced cycles of infestation and were significantly correlated with numbers of chalimus, although not with numbers of mobile stages (Revie et al., 2002b; 2003a).

McKibben & Hay (2002; 2004a) sampled copepodids close to a river mouth over a period of 2 years. The greatest peak density of louse copepodids ever recorded was found close to
the river mouth. Copepodids were only found at the river mouth when the nearby salmon farm was in its second year of production and contained gravid female lice. This relationship was also found in samples from another river (McKibben & Hay, 2004a; b) and can be related to higher *L. salmonis* numbers on farms in the second year of production (Treasurer et al., 2004). This was also seen in Canada (Anon, 2005). This contrasts with *C. elongatus*, which has greater abundance in the first year (McKenzie et al., 2004). Butler (2002) estimated that 78-99% of louse eggs produced in 2000 originated from farmed fish, with escaped farm salmon contributing most of the remainder. Larval lice can be dispersed at least 4.6km from farms (McKibben & Hay, 2004a). Northcott et al. (2001) also noted high densities of lice copepodids at the tide margin.

The link between lice on farms and copepodids found in open water and near river mouths was also noted by Penston et al. (2004). Pulses of infection were found, with highest densities near the shore. Although louse copepodids do aggregate near step salinity gradients (Heuch, 1995), the high densities found near river mouths by Penston et al. (2004) were probably as a result of wind-driven transport of the larvae. Pulses of lice abundance were also seen by Marshall (2003).

Dispersal of larvae seems to be largely governed by physical processes such as wind and tide, with a net transport towards the shore on the west coast with a prevailing westerly wind, resulting in high densities at estuaries (see Tully & Nolan, 2002; McKibben & Hay, 2002; 2004a). A three-dimensional particle advection model showed extremely high variability in lice distribution in Norwegian fjords, with spreading of 0-100km in only a few days (Asplin et al., 2004), due to faster coastal currents and slower larval development in the lower temperatures found there compared to Scotland. This agrees with Murray's (2002) description of patchy distribution, albeit not accounting for patchiness in time. Bends or narrowing of the fjord resulted in convergence and/or retention of the lice. Analysis of field data from Scotland, Norway, England and Wales and Ireland confirms a degree of overdispersion, shown by variance exceeding the mean. This aggregated distribution is not explained solely by pulses of infection, but requires infection to be patchy in space as well as time, possibly in infection hot spots (Murray, 2002).

More data has been collected in Ireland. Tully & Whelan (1993) estimated that 95% of nauplius I *L. salmonis* in midwest Ireland were of farmed origin. Costelloe et al. (1996) studied planktonic larvae and their dispersion. As expected, the highest density of lice was found inside salmon cages, with the density outside the cage less than 10% of this, and decreasing with distance from the cage such that density 1km from the cage was 90% less than that 10 m from the cage, and few larvae were found more than 2 km from the farm.

A study conducted by Tully (1989) used a sentinel cage of salmon smolts among other cages and examined the prevalence and intensity of both *L. salmonis* and *C. elongatus*. The data indicated that most of the infestation originated from the farmed fish. Sentinel cages were also used by Costelloe et al. (1995), where salmon smolts were placed at varying distances from a salmon farm. The cage near the river mouth had the highest density of lice, as might be expected given the results shown by McKibben & Hay (2002; 2004a). However, lice from the farm did not appear to contribute greatly to larval density in the inner harbour, as may be expected from the hydrography of the area. Population structures of lice varied with time and between cages, with the lice settling in pulses rather than continuously.

The production of nauplii on the farms studied by Tully & Whelan (1993) was relatively constant between March and July. Seasonal variation was also seen by Costelloe et al. (1998a; b) in plankton samples from three bays in Ireland. The highest density of larvae was found during spring and then numbers decreased. Larvae were only consistently found close to a salmon farm. Peak larvae numbers in Killary harbour could be linked to peaks in the nearby farm.
Jackson et al. (1997) analysed data on lice infestations from *Salmo salar* and *Oncorhynchus mykiss* farms on the west coast of Ireland. *O. mykiss* tended to have lower infestations but differences in infestation were found between sites that were attributed to husbandry practices. Fallow periods of 14 days were long enough to break the cycle of lice infection, with minimum practical lice levels being those resulting from re-infestation from wild sources. Longer fallow periods are usually preferred, given the length of the louse life cycle, but need not be too onerous, as fallowing for over 7 weeks had no advantage over fallow periods of 5-7 weeks (Treasurer et al., 2004). Fallowing has no effect on *C. elongatus* infestation, which is less host-specific and may have many alternative hosts (Revie et al., 2002a).

*Oncorhynchus* species have also been found to carry more lice in areas associated with salmon farms (Morton et al., 2004) with a drop in lice levels when farms are fallowed (Morton et al., 2005). It has been suggested that the presence of farms increases infection pressure in this area of British Columbia by over 70 times (Krkošek et al., 2005). However, this conclusion was based on limited data and another study found similar levels of prevalence and intensity of lice (*L. salmonis* and *Caligus clemensi*) on Pacific salmon in areas with and without farms (Beamish et al., 2005). Pacific species have lower infestation levels than Atlantic salmon in the same region (British Columbia, 2004). On farms in Japan, these infestations do not create serious problems as the farm cycle is shorter than a year (Nagasawa, 2004).

Despite the problems inherent in using results and data from different studies, it is clear that farms with high numbers of sea lice increase the louse infection pressure in the vicinity. Nevertheless, the relationship between numbers of lice on the farm and numbers of infective larvae in the surrounding area is not straightforward. The release of larvae from farms is not continuous but occurs in pulses, leading to larval distribution that is patchy in time. Dispersal processes such as wind, current and freshwater input result in larval spreading that is not uniform, but is patchy in space. Although there are difficulties in interpreting some data on larval production and dispersal, it is apparent that husbandry practices on farms have a significant effect on lice infestation, with fallow periods of 6 weeks effectively breaking cycles of *L. salmonis* infection.

**Lice Levels on Wild Fish in the Vicinity of Salmon Farms**

In Scotland, wild sea trout were found infested with lice and bearing damage caused by the lice. Heaviest lice infection was found in samples in the west and northwest, areas where most salmon farming takes place, but even so, fish sampled in late summer and autumn did not have lice or lesions and fish captured on the east of Scotland also had high lice numbers but no evidence of physical damage. Thus, no clear link was found between lice intensity and proximity of salmon farms (McVicar et al., 1993; MacKenzie et al., 1998), with the latter study finding that although fish on farms could be heavily infected in April and May, wild sea trout nearby had only scarce or no infections. This might be explained by pulses of lice abundance. These pulses were also seen by Marshall (2003) although the relationship between lice on wild salmonids and on a nearby farm was only weak. Although there was evidence of progression through stages of the louse life cycle, chalimus stages dominated on the wild salmonids sampled by Marshall (2003). The farm in this study was unusual in having a three-year cycle with a one year fallow instead of the two year production cycle common in Scotland.

Data collected by Sharp et al. (1994) revealed that a high intensity of chalimus stages was associated with a greater intensity of lice. Considerable variation in louse population structure was found in this study, even from within the same loch. The degree of overdispersion was highest with highest median intensity, and the lower overdispersion found in sea trout confined in sea cages indicates that this may be a result of uneven
distribution of lice larvae in the loch and/or the trout frequently entering and leaving freshwater (Sharp et al., 1994). This pattern of distribution fits well with the model of patchy distribution described by Murray (2002).

Valuable data have been collected by the Association of West Coast Fisheries Trusts (AWCFT) in Scotland (Butler et al., 2001; Butler, 2002). Only L. salmonis were found on the trout, supporting similar findings by Sharp et al. (1994). Over the period 1994-2000, the highest lice burden and pooled abundance data showed a general increase although there was a wide variation both geographically and inter-annually. All sites sampled were less than 26 km from active salmon farms and localized lice epizootics were found, with a variation in site and year that correlated with farm cycles. A higher louse abundance on wild fish was found when nearby farms were in the second year of production. This might be expected from McKibben & Hay’s findings of more lice larvae in plankton samples when nearby farms are in the second year of the production cycle (McKibben & Hay, 2004a; b).

Where mixed year classes were found in the samples collected by the AWCFT (Butler et al., 2001; Butler, 2002), aggregate lice abundance was higher, with post smolt infections dominated by chalimus stages, whereas pre-adults dominated the infections of older fish. Heavy chalimus infections were associated with damage to the dorsal fins. The proportion of fish carrying a louse burden greater than the potentially lethal number of 30 (Grimnes & Jakobsen, 1996) varied, from 13.5% to 39.5% in different years. In the Dundonnell river, despite 48-99% of sea trout carrying more than 30 lice, only 4 moribund fish were found (Butler, 2001). This contrasts with the findings in Ireland where many infected and moribund fish were seen (Tully et al., 1993a). Since 2000, monitoring by the AWCFT has continued in Scotland, with correlation between higher lice abundance when nearby farms are in the second year of production, but an overall decrease in lice abundance in the period 2000-2004.

The effects of sea lice on wild salmonids has received a great deal of attention since heavy lice infestations were said to coincide with collapses of sea trout stocks in Ireland where mortality at sea had risen to 95% since 1989 Tully et al. (1993b). Angling catches of Scottish sea trout, particularly in the northwest, also show a decline from the 1950s to the 1990s (McVicar et al., 1993). The same situation was found in Ireland (Tully & Whelan, 1993), and also England and Wales, an area without extensive marine aquaculture (McVicar, 2004).

As discussed previously, it is notoriously difficult to determine the direct cause of any decline in wild fish stocks. McArdle et al. (1993) found Aeromonas salmonicida infection in 3 of 6 catchments where sea trout were returning prematurely. They suggest that diseases other than sea lice may have had a role in the falling sea trout numbers in Ireland. Nevertheless, the hypothesis that heavy sea lice infestation was leading to the premature return of wild sea trout and causing a drastic reduction in these stocks has received a great deal of attention and has been the subject of much research.

Tully et al. (1993b) sampled sea trout on their return to freshwater at 36 sites in northwest Ireland. The prevalence and intensity of lice ranged from 21-92% and 2-53%, respectively. The population structure of the lice varied, being over 80% copepodid and chalimus at 15 sites, but less than 20% at 7 sites. The population structure may reflect the length of time spent at sea or the length of time since infection.

Louse infestation on sea trout in 42 estuaries in Ireland over 5 years was examined by Tully et al. (1999). Sea trout post smolts showed high retention in the bay in which they migrate, but the life cycle of the louse was thought to be too long to account for horizontal transmission between sea trout in a bay. Although infestation data was highly variable, it could be shown that spatial variation was greater than temporal, with significant differences.
A Review of Research and Field Data on Relative Louse Infection Levels

in infestation between regions, bays within a region and estuaries within a bay. Infestation was significantly higher in areas where infected farms were also present, with the presence of farms being correlated with 3.5 times greater mean abundance of lice on sea trout. However, the production of larvae in one region did not influence infestation data in other regions.

Gargan et al. (1993; 2003) also found a relationship between lice on sea trout and distance from salmon aquaculture. Sea trout sampled at rivers that were varying distances from fish farms had higher maximum and median numbers of lice and a higher proportion of chalimus stages at sites close to farms. Infestations were below median level at all sites distant from farms. Highest mean lice numbers were found less than 20 km from farms and chalimus stages, indicating recent transmission, dominated infections less than 30 km from farms. Physiological and osmoregulatory problems were expected when louse levels exceeded 0.7 larvae per g fish weight, and many more sea trout in bays with salmon farms had lice above this harmful level than did sea trout in bays with no farms. Therefore it was concluded that the risk of carrying damaging lice infestations is related to the distance from farms and sea trout survival may be inversely related to lice levels.

However, some samples obtained close to farms had relatively low infestation (Gargan et al., 1993). This may be influenced by the length of time the fish had been at sea, but will also be affected by the release of infective lice larvae from farms.

It was reported that the production of nauplii from farms in April was correlated with the number of lice infesting wild sea trout 3 weeks later. However, although the production of nauplii on farms was relatively constant between March and July, the transmission to sea trout appeared to be restricted to late April and May (Tully & Whelan, 1993).

Tully et al. (1999) found that sea trout infestation with lice differs significantly in space and time and proposed that these differences were related to pulses of lice production on farms and that cross-infection with lice was possible between farms located closer than 10km to each other. As physical processes of wind and tide have significant effects on louse larval transport, these should also be carefully considered when examining the probability of cross-infection or larval transport from farms to estuaries.

In Norway too, there is a correlation between sea trout infestation and proximity to farms. Higher louse abundance was found on sea trout, salmon and char in areas of Norway where there was salmon farming (Bjørn et al., 2001; Bjørn & Finstad, 2002; Grimnes et al., 1998). Younger lice predominated in sea trout and char infections at all time points sampled at sites associated with fish farming, (Bjørn et al., 2001; Bjørn & Finstad, 2002). In northern Norway, epidemics were seen in sea trout and char in an area where there was fish farming activity (Bjørn & Finstad, 2002). However, in northern Norway, the link between high louse infestation in farms and epizootics on wild fish is not as clear as in the southwest of the country (Heuch et al., 2005).

Boxaspen (1997) found lice settlement on salmon in Norway was inversely related to distance from an infested farm. Interestingly, lice counts and temperature data from the preceding winter could be used to predict lice numbers in the following summer. This is confirmed by findings that initial spring production determines lice loads in that year (Murray, 2002; Revie et al., 2003a).

The levels of lice production from farms that constitute a threat to wild salmonids are not known and neither is it clear whether lice regulate sea trout populations. Nevertheless, it is considered highly likely that salmon farming has caused louse epizootics in southwest Norway (Heuch et al., 2005). Heuch et al. (2005) provide an expert review of the routes by which wild salmonids may be infected by sea and point out the influences of environmental
and ecological factors that influence the infection dynamics and may give rise to variable findings on the timing of infection in different regions. Data on the harmful effects of lice on sea trout indicate that the mean intensity should be restricted to less than 11 lice per fish to avoid harm. This level is unlikely to be feasible in Norway at current levels of farming and lice infestation on farms (Heuch et al., 2005). It is recommended that low levels of lice must be maintained throughout the year, and not just during spring and summer, to protect wild salmonids (Heuch et al., 2005). Although further work is required to understand the population dynamics, and the resulting infection pressure of sea lice better (Stien et al., 2005), high levels of lice on farms do pose a hazard for wild fish. The outcomes of the Hardangerfjord project in Norway (DIPnet, 2005) could provide valuable information on the interactions of lice between wild and farmed fish in a fjord system.

The lack of damage caused by lice infestation of wild salmon on the East coast of Canada did not suggest that lice were causing a decline in wild populations there (Carr & Whoriskey, 2004). The lice levels on farmed and wild fish here both increased until 2000, when new lice treatments became available for the farms.

In European waters, sea trout smolts remain close to the shore when they first enter seawater, staying in inner fjord systems whereas salmon smolts move throughout the fjord, into the open ocean (Dieperink et al., 2001; Finstad et al., 2005). If there is a high density of infective lice in this area, it will provide an optimum source of infection for smolts. Indeed, Northcott et al., (2001) and McKibben & Hay (2004b) found that sea trout are infected with lice soon after going to sea.

Smolts may return to freshwater to remove lice burdens and/or hyperosmotic stress. It is thought that the premature return of infested sea trout is probably common in areas where there is salmon farming (Heuch et al., 2005). In Scotland, more premature returns of sea trout were recorded in the second year of the farm’s production cycle (Northcott et al., 2001; McKibben & Hay, 2002). The second year of production is also the time when the highest numbers of infective lice larvae are found near the shore.

Although there is no conclusive proof that heavy lice burdens and premature return of sea trout smolts are causal factors in the decline of wild populations, where control measures are feasible, steps taken to reduce the incidence of infective lice larvae in areas where wild salmon and sea trout smolts enter seawater will reduce the potential for harmful infestation of the wild fish.
Regulatory Control of Sea Lice

All major salmon farming countries in the Northern hemisphere now have active control of sea lice, with varying types of formal regulation of lice control. Integrated sea lice management in Scotland is promoted through Area Management Agreements and the salmon farming industry association Code of Practice, whose objectives include synchronous fallowing in each management area, and aim to have zero ovigerous sea lice, especially during wild smolt migration periods (Scottish Executive, 2004). The timing of treatment is very important, and may be informed by models such as those of Revie et al. (2005) and Stien et al. (2005).

Sea lice monitoring was introduced in Irish fin-fish farms in 1994 with particular attention paid to lice levels during the smolt migration period in spring (Jackson et al., 1997). Single bay management was also introduced (Copley et al., 2001), with efficacy of treatment varying with treatment type and life cycle stages, and some bays having more successful lice control than others.

The Norwegian National Action Plan set threshold lice levels for periods when wild smolts are migrating. In Canada, action is required once infestation reaches 3 mobile lice, whatever the time of year (Anon, 2005). Since the inception of the action plan in Norway, levels of lice on wild salmon smolts in Sognefjord have dropped, but no reduction was found on sea trout smolts in middle and north Norway or south west fjords. The mean number of lice per fish in farms has reduced. However, as the total number of farmed fish may have increased in the same period, it is not clear if this reduction in average lice per fish has led to a reduction in the total number of lice or not (Heuch et al., 2005). Estimating the probability of success of this action plan is hampered by lack of knowledge on the levels of lice that will cause harm to wild populations, nevertheless it is considered that the high number of farmed fish in production is likely to result in lice levels that pose a risk to wild populations (Heuch et al., 2005).

CONCLUSIONS

Infestation of salmonids with lice is a natural phenomenon that occurs at all phases in the seawater stage of their lifecycle. Studying the infection of wild fish and their interaction with farmed populations is extremely difficult. However, a large body of knowledge has been gained from many studies on lice on salmonids, especially since the 1990s, in several countries.

Reviewing the results of many studies allows some conclusions to be reached. Heavy lice infestation is damaging and can be ultimately fatal for any salmonid. In salmon farms, heavy infestation leads to the release of extremely high numbers of infective larvae. This release seems to occur in pulses rather than continuously, and the dispersal of the larvae can be complex, influenced by wind, tide and hydrology of the area. Where these processes bring infective lice in contact with wild salmonids, higher than background levels of infestation can occur. This may prompt return to freshwater or perhaps even mortality. The levels of lice that are likely to cause detrimental effects depend on the size and species of the fish concerned.

Significant measures to reduce lice burdens in farms are in place in all salmon farming countries of the northern hemisphere. These, coupled with development of effective treatments, have been successful in reducing lice counts on farmed fish in recent years.

Lice levels on wild fish are the ultimate measure of the success or otherwise of sea lice control measures. These are difficult to determine and must be considered in the light of
knowledge of the harmful levels of lice for that species and stage of the life cycle. The most appropriate controls for farms will depend on factors such as the local environment, the ecology of wild fish in the vicinity, and the regulation of medicines, and therefore it continues to be difficult to draw conclusions based on findings from one region or country and to extrapolate these to other areas. Nevertheless, it is apparent that measures to reduce lice levels on farms to extremely low levels are required in order to prevent harm to wild fish in the surrounding area.

REFERENCES


Bjørn, P.A. and Finstad, B. 2002. Salmon lice, Lepeophtheirus salmonis (Krøyer), infestation in sympatric populations of Arctic char, Salvelinus alpinus (L.), and sea trout, Salmo trutta (L.), in areas near and distant from salmon farms. ICES Journal of Marine Science, 59, 131-139.


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