Impact of Sea Lice on Wild Atlantic salmon

Ørjan Karlsen, Institute of Marine Research, Norway

Surveillance of salmon lice on outmigrating Atlantic salmon post-smolts

Three methods are used to estimate the salmon lice infestations on outmigrating Atlantic salmon in Norway; trawling using a specially designed trawl, traps adapted to catch Atlantic salmon and virtual smolt models (Kristoffersen *et al.* 2018; Johnsen *et al.* 2021) where the lice infestations are modelled. In Norway, the trawling is performed in the outer parts of fjords, usually by trawling during the day over one month each year. The start of the trawling is timed to coincide with the estimated timing of outmigration. In order to be able to determine from which river the salmon originates, salmon are assigned to home river by use of genetic tools. Consequently, lice infestation on salmon from different rivers in the fjord system being monitored may be determined. It should be noted that there are weaknesses with this method, as it assumes that there is no salmon lice related mortality (directly, or indirectly by affecting the salmon's vulnerability, e.g. to predation) before the fish reaches the trawl areas. The method also assumes that the ability to avoid the gear is unaffected by lice.

The use of specially designed traps avoids the last of the former assumptions, as this is a passive method. However, this method has shown highly variable efficiency and is at present used in only two places.

The two published models to predict salmon lice infestations on outmigrating Atlantic salmon are different. Both methods rely on the number of hatched lice released from all active salmon farms, predicted from a published formula taking into consideration the number of lice per fish, the number of fish and temperature. However, one of the models assumes a dispersion of lice decreasing in all directions from the active farms, the other uses a coupled biological-hydrodynamic model to predict the dispersion of lice. Also, the first method is calibrated (i.e. number of lice in the sea vs. infestation on fish) based on sentinel cages, while the other is calibrated against the trawl data where the fish has been assigned to a river. Finally, the assumed distribution of the timing of outmigration, migration route and migration speed are different.

The empirical trawl data and the model results do not always show the same impact. One of the reasons for this is that even though the trawling is performed in the outer parts of the fjords, the salmon still have to migrate through areas with fish farms before they reach the coast and, therefore, the empirical data will usually be underestimates. The two models shown here also give different estimates. The reasons for this are, at present, not known and are a topic of current research.

In order to predict mortality from infestations, it is assumed that if the infestation is < 0.1 lice / g fish there is no mortality, 100 % mortality if the infestation is > 0.3 lice / g fish, and 20 % and 50 % mortality if the infestation is between 0.1 – 0.2 lice / g fish or 0.2 – 0.3 lice / g fish respectively (Taranger *et al.* 2015). The smolt models assume that the fish weighs 20 g.

The consequences of salmon lice on wild Atlantic salmon post-smolts

Salmon lice have the potential to negatively affect individuals and populations. The effect of salmon lice on wild Atlantic salmon depends on several factors, although none, at present, have a direct link between known infestation on wild salmon and its effect in nature.

The effects of salmon lice on individuals have been described in a series of laboratory experiments. A salmon louse feeds on its host's mucus, skin and blood. This results in increased plasma concentrations of cortisol and osmoregulatory problems and decreases the immunological capacity of the host. The damages become more severe as the lice develops from the attached to the mobile stages. Secondary effects such as reduced growth, swimming capacity and reproduction, in addition to increased mortality, have been observed (Grimnes and Jakobsen 1996). The immune system is affected (Gallardi *et al.* 2019) and lice-infected salmon appear more susceptible to viral infections (Barker *et al.* 2019). Salmon lice may affect behaviour and swimming capacity (Bui *et al.* 2016) and increase the risk of being predated (Godwin *et al.* 2015).

Assessing the effects of salmon lice on Atlantic salmon stock levels is difficult, as the number of outmigrating fish is usually unknown. To overcome this, experiments using cultivated fish protected from salmon infestations are performed. Since the duration of the protection is limited to a few weeks or months, it is assumed that survival during their seaward migration is affected by lice infestations during the first part of the migration. It is also assumed that salmon are most vulnerable shortly after they have left the rivers due to the physiological challenges with the transfer from fresh to salt water (Thorstad *et al.* 2012) and due to predation (Handeland *et al.* 1996).

The survival of salmon during their feeding migration in the sea varies between years, probably due to natural variations in the ecosystem. Norwegian data from experiments comparing fish protected from salmon lice infestations with untreated control fish has shown that the effect of the protection varies with the general survival of the groups (Vollset *et al.* 2016). In years where the general survival was high, lice protection had no statistical effect, while in years with a general low survival, the survival in the protected groups increased. Using data from releases in Daleelva in western Norway, it was calculated that lice infestations caused about 15 % mortality in the period 1997 to 2009 (Skilbrei *et al.* 2013). In a larger meta-analysis, including more data from Norway, 18 % mortality was estimated (Vollset *et al.* 2016). In nearly all years untreated smolts were found to be slightly smaller (~0.1 kg) when returning after one year in the sea, which may indicate that lice caused a growth depression even when the mortality seemed unaffected by lice. In a 26-year long time-series from the river Erriff in western Ireland, analysis indicated that after higher lice numbers in nearby farms, there were more than 50 % lower numbers of returning 1sea-winter salmon (Shephard and Gargan 2017). In an analysis of returning salmon in Scotland and England, it was found that the condition of returning salmon was correlated to the number of lice the fish was carrying (Susdorf *et al.* 2018b) and model simulations indicated that this reduced condition could affect stock development (Susdorf *et al.* 2018a). There are obviously several differences between cultivated and wild fish, but still the results indicate that salmon lice may be an important cause of mortality for wild salmon.

Status of the impact of salmon lice on Atlantic salmon post-smolts in Norway

Salmon usually enter the sea during spring and salmon originating from rivers in the fjords swim through the fjords towards the open ocean. The distance and route they swim will affect their possibility of being infected. As the release of salmon lice from active salmonid farms usually increases during spring and summer due to temperature and farming practices, the later the fish leaves the fjords the higher the possibility of being infected. The actual distribution of the outmigration is highly variable and fish that leave the river early in the season are usually less likely to be infected than fish that migrate later. By using the 2017 – 2020 trawl data from the Hardangerfjord (western Norway), the estimated mortality of fish from rivers in the inner part of the fjord are higher than fish from outer rivers each year (Figure 1).

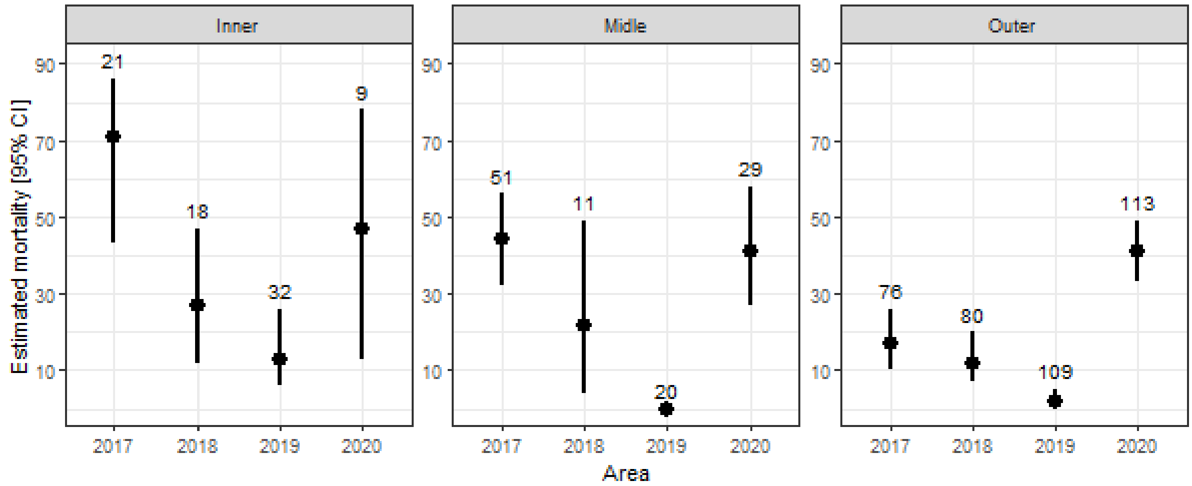

Figure 1. *Estimated mortality with confidence limits of outmigrating Atlantic salmon post-smolts caught in the outer fjord 2017 – 2020 using trawl and assigned to rivers in inner, middle or outer areas of the fjord. Numbers are shown in the figure. C.f. text for how mortality is estimated.*

Similar patterns are achieved using the virtual smolt model that the Institute of Marine Research in Norway are using (Johnsen *et al*. 2021) which combines estimated lice density with a simulated smolt migration (Figure 2). The outer rivers are less affected by lice than inner rivers.

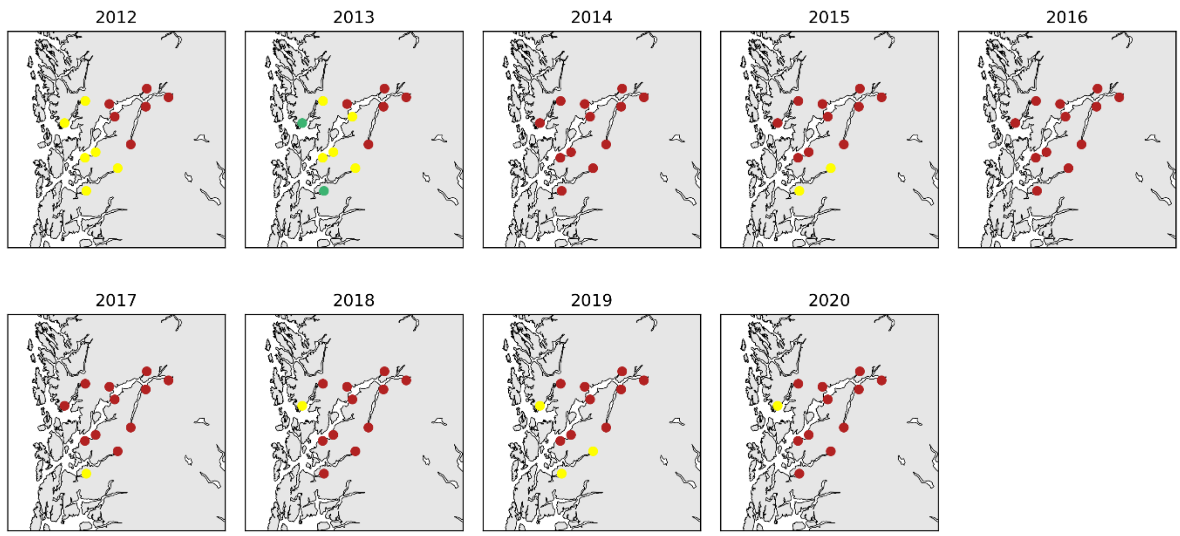

Figure 2. *Estimated mortality of outmigrating Atlantic salmon post-smolts 2012 – 2020 using a virtual smolt model. Colours indicate whether the estimates from fish from that river is <10 % (green), 10 – 30 % (yellow) or >30 % (red). C.f. Johnsen et al. (2021) for details about the model.*

Using these data and model results, together with other empirical data and model simulations, an expert group appointed by a steering group appointed by the Ministry of Trade, Industry and Fisheries is evaluating the effects of salmon lice separately for the 13 production areas in Norway in the nicknamed 'Traffic Light System'. The status is based on expected mortality of Atlantic salmon post-smolts.

At present, the expert group has evaluated the status yearly from 2016 – 2020 (Vollset *et al.* 2020). They conclude that the largest negative impact of salmon lice is observed in western Norway, particularly from the county of Rogaland to Møre and Romsdal. In several of these areas, the estimated mortality of outmigrating salmon post-smolts has, in one or more years, been determined to be > 30 %. It should be noted that the impact on the different rivers in each production area may vary considerably, as shown above.

The Norwegian Scientific Advisory Committee for Atlantic Salmon has used the smolt models to determine the effect of salmon lice on wild salmon populations in Norway (VRL, 2020). They conclude that salmon lice have reduced the number of returning salmon by 50,000 for the years 2012 – 2014, 29,000 in 2018 and 39,000 in 2019. The impact of salmon lice is most severe in western and middle Norway, and the advisory committee concluded that an increased number of populations are endangered by salmon lice and that there is a high risk that more populations will be endangered.

References

Barker, S.E., Bricknell, I.R., Covello, J., Purcell, S., Fast, M.D., Wolters, W. and Bouchard, D.A. 2019. Sea lice, *Lepeophtheirus salmonis* (Krøyer 1837), infected Atlantic salmon (*Salmo salar* L.) are more susceptible to infectious salmon anemia virus. PLOS One, 14, e0209178.

Bui, S., Dempster, T., Remen, M. and Oppedal, F. 2016. Effect of ectoparasite infestation density and life-history stages on the swimming performance of Atlantic salmon *Salmo salar*. Aquaculture Environment Interactions, 8, 387-395.

Gallardi, D., Xue, X., Hamoutene, D., Lush, L. and Rise, M.L. 2019. Impact of origin (wild vs. farmed) and sea lice (*Lepeophtheirus salmonis*) infestation on expression of immune-relevant genes in Atlantic salmon (*Salmo salar* L.) skin. *Aquaculture* 499, 306-315.

Godwin, S.C., Dill, L.M., Reynolds, J.D. and Krkošek, M. 2015. Sea lice, sockeye salmon, and foraging competition: lousy fish are lousy competitors. Canadian Journal of Fisheries and Aquatic Sciences, 72, 1113-1120.

Grimnes, A. and Jakobsen, P.J. 1996. The physiological effects of salmon lice infection on post-smolt of Atlantic salmon. Journal of Fish Biology. 48, 1179-1194.

Handeland, S.O., Järvi, T., Fernø, A. and Stefansson, S.O. 1996. Osmotic stress, antipredator behaviour, and mortality of Atlantic salmon smolts. Canadian Journal of Fisheries and Aquatic Sciences, 53, 2673-2680.

Johnsen, I.A., Harvey, A., Sævik, P.N., Sandvik, A.D., Ugedal, O., Ådlandsvik, B., Wennevik, V., *et al.* 2021. Salmon lice-induced mortality of Atlantic salmon during post-smolt migration in Norway. ICES Journal of Marine Science, 78, 142-154.

Kristoffersen, A.B., Qviller, L., Helgesen, K.O., Vollset, K.W., Viljugrein, H. and Jansen, P.A. 2018. Quantitative risk assessment of salmon louse-induced mortality of seaward-migrating post-smolt Atlantic salmon. Epidemics 23, 19-33.

Shephard, S. and Gargan, P. 2017. Quantifying the contribution of sea lice from aquaculture to declining annual returns in a wild Atlantic salmon population. Aquaculture Environment Interactions, 9, 181-192.

Skilbrei, O.T., Finstad, B., Urdal, K., Bakke, G., Kroglund, F. and Strand, R. 2013. Impact of early salmon louse, *L. salmonis*, infestation and differences in survival and marine growth of sea-ranched Atlantic salmon, *Salmo salar* L., smolts 1997–2009. Journal of Fish Diseases, 36, 249-260.

Susdorf, R., Salama, N.K.G. and Lusseau, D. 2018a. Influence of body condition on the population dynamics of Atlantic salmon with consideration of the potential impact of sea lice. Journal of Fish Diseases, 41, 941-951.

Susdorf, R., Salama, N.K.G., Todd, C.D., Hillman, R.J., Elsmere, P. and Lusseau, D. 2018b. Context-dependent reduction in somatic condition of wild Atlantic salmon infested with sea lice. Marine Ecology Progress Series, 606, 91-104.

Taranger, G.L., Karlsen, Ø., Bannister, R.J., Glover, K. A., *et al*. 2015. Risk assessment of the environmental impact of Norwegian Atlantic salmon farming. ICES Journal of Marine Science, 72, 997-1021.

Thorstad, E.B., Whoriskey, F., Uglem, I., Moore, A., Rikardsen, A.H. and Finstad, B. 2012. A critical life stage of the Atlantic salmon *Salmo salar*: behaviour and survival during the smolt and initial post-smolt migration. Journal of Fish Biology, 81, 500-542.

Vollset, K.W., Krontveit, R.I., Jansen, P.A., Finstad, B., et al. 2016. Impacts of parasites on marine survival of Atlantic salmon: a meta-analysis. Fish and Fisheries, 17, 714-730.

Vollset, K.W., Nilsen, F., Ellingsen, I.H., Finstad, B., Karlsen, Ø., Myksvoll, M.S., Stige, L.C., *et al.* 2020. Vurdering av lakselusindusert villfiskdødelighet per produksjonsområde i 2020. Rapport fra ekspertgruppe for vurdering av lusepåvirkning. 107 pp.

VRL (2020). Status for norske laksebestander i 2020. Vitenskapelig råd for lakseforvaltning, 147 pp.