Impact of sea lice on wild Atlantic salmon

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Surveillance of salmon lice on out-migrating Atlantic salmon postsmolt

Three methods are used to estimate the Salmon lice infestations on out-migrating Atlantic salmon; trawling by use of 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 is modelled. The trawling is performed in outer parts of fjord usually by trawling during the day one month each year. The start of the trawling is adapted to estimated timing of out-migration. In order to be able to determine from which river the salmon originates, the salmon are assigned to home river by use of genetic tools. Consequently, infestation on salmon from different rivers in the fjord system surveilled 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 to e.g. 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 only two places.

The two published models to predict salmon lice infestations on out-migrating Atlantic salmon are different. Both methods rely on that the number of hatched lice released from all active salmon farms, predicted from a published formula taking into consideration number of lice per fish, number of fish, and temperature. However, one of the models assumes a dispersion of lice decreasing at 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 fish has been assigned to river. Last, the assumed distribution of the timing of outmigration, migration route and migration speed are different.

The empirical trawl data and the model results are not always showing 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 has to migrate through areas with fish farms before they reach the coast, and the empirical data will therefore usually be underestimates. The two models shown here also gives different estimates. The reasons for this are at present not known and is 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 assumes that the fish weights 20 g.

The consequences of Salmon lice on wild Atlantic postsmolts

Salmon lice has the potential to negatively affect individuals and populations. The effect of salmon lice on wild Atlantic salmon relies on several approaches, though none of them at present has a direct link between known infestation on wild salmon and the effect in nature.

The effect of salmon lice on individuals has been described in a series of laboratory experiments. Salmon lice feeds on its hosts mucus, skin, muscle and blood. This results in increased plasma concentrations of cortisol, osmoregulatory problems, end 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 as reduced growth, swimming capacity and reproduction in addition to increased mortality has been observed (Grimnes and Jakobsen 1996). The immune system are affected (Gallardi *et al.* 2019), and lice-infected salmon appears more susceptible for 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 effect on the stock level of Atlantic salmon is difficult, as the number of out-migrating fish is usually unknown. To overcome this, experiment 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 the survival during their seaward migration is affected by lice infestations during the first part of the migration. It is also assumed that the salmon is 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 metanalysis including more data from Norway it was estimated a mortality of 18 % (Vollset *et al.* 2016). It was nearly all years also found that untreated smolts was 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 seems 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 more than 50% lower number of returning 1-seawinter 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 postsmolts of Atlantic salmon in Norway

Salmon usually enters the sea during spring, and for salmon originating from rivers in the fjords they swim through the fjords towards open ocean. The distance and route they swim will affect their possibility to be 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 to be infected. The actual distribution of the out-migration is highly variable, and fish that leaves the river early in season usually are less likely to be infected than fish that migrate later. By using the trawl data 2017-2020 from 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).

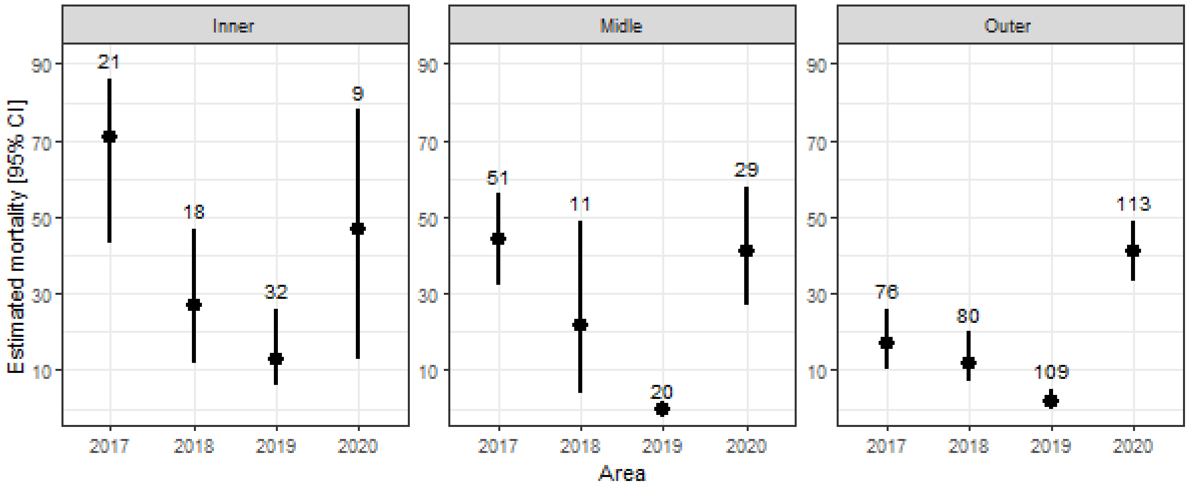

Figure 1. Estimated mortality with confidence limits of out-migrating Atlantic salmon postsmolts caught in the outer fjord 2017-2020 using trawl and assigned to rivers in inner, middle or outer areas of the fjord. Numbers are shown in the figure. C.f. text for how mortality is estimated.

Similar patterns are achieved using smolt models that combines estimated lice density with a simulated smolt migration (Figure 2). The outer rivers are less affected by lice that inner rivers.

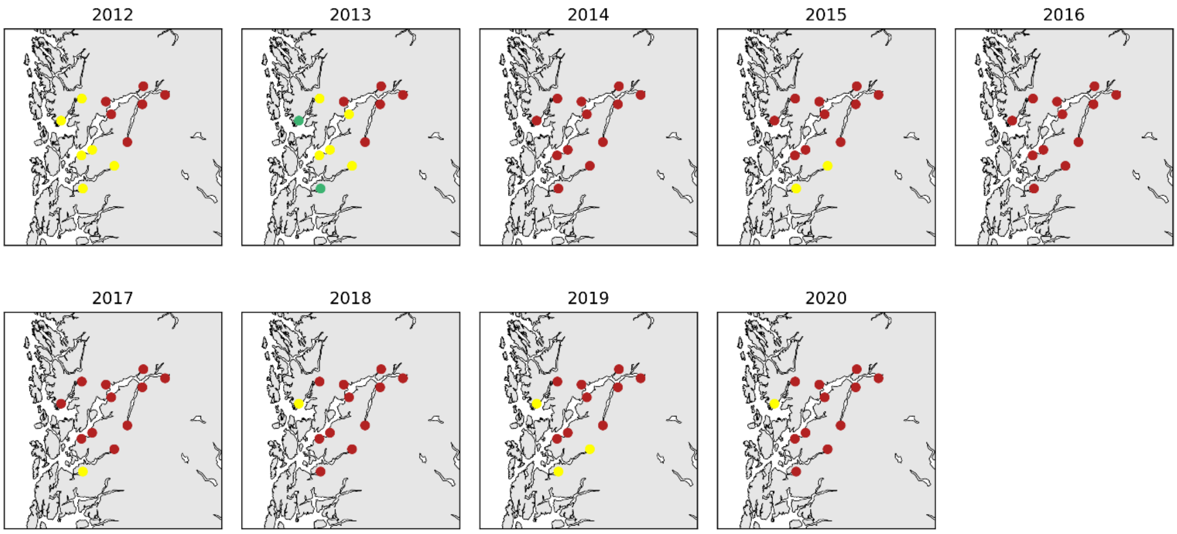

Figure 2. Estimated mortality of out-migrating Atlantic salmon postsmolts 2012-2020 using the smoltmodell. Colours indicate whether the estimates from fish from that river is >10% (green), 10-30% (yellow) or > 30% (red). C.f. Johnsen *et al.* (2021) for details about calculations.

Using these data and model results, together with other empirical data and model simulations, an expert group appointed by a steering group that is appointed by the Ministry of Trade, Industry and Fisheries is evaluating the effect of salmon lice separately for the 13 production areas in Norway in the nicknamed Traffic light system. The status is based on expected mortality on postsmolts of Atlantic salmon.

At present, the expert group has evaluated the status yearly 2016-2020 (Vollset *et al.* 2020). They conclude that 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, the estimated mortality of out-migrating salmon postsmolts has 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 in order 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 2012-14, 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.

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