Agenda item 6.2
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Development of lice dispersal models and their utility in predicting impacts on wild Atlantic salmon

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Lice dispersion

Salmon lice (*Lepeophtheirus salmonis*) drifts passively with the water currents in the fjords and along the coast for days to weeks before they are no longer able to infect fish. These currents may transport lice considerable distances both prior to and during the period they are infectious (Asplin *et al.* 2014), and the vertical behavior of the louse has implications for how it is transported horizontally (Johnsen *et al.* 2014, 2016). Detailed information on water currents, temperature and salinity is therefore important to provide a precise description of how the infectious copepodids distributed in space and time.

The Institute of Marine Research in Norway use hydrodynamic models based on the Regional Ocean Model System (ROMS, www.myroms.org) to predict the dispersal of salmon lice. NorKyst800 is a model for Norwegian near-shore waters and has an 800 m horizontal grid resolution and 35 terrain-following vertical layers (Albretsen *et al.* 2011). Results from NorKyst800 provides a reasonably good description of conditions along the coast and in most fjords, but it is necessary with higher grid resolution in narrower fjords. The NorFjords fjord model has a horizontal grid resolution of 50-200 m and receives open boundary values from NorKyst800. Realistic forcing of the ocean model from atmosphere, tides and rivers are included (Asplin *et al.* 2014; Johnsen *et al.* 2014). Fresh water input from a hydrological model developed by the Norwegian Water Resources and Energy Directorate (NVE) and atmospheric wind fields from the mesoscale WRF wind model (www.wrf-model.org) with a 1 km horizontal grid are fed into the model. The hydrodynamic model verified by comparing with observed physical data as temperature, salinity and measured water currents.

There are some differences in the output, as that the 800 m model underestimated the peak velocities (Figure 1). However, the authors concluded that the comparison of the models with observed currents showed a good correlation and concluded that the models were able to realistically recapture the actual currents (Johnsen *et al.* 2014).

NorKyst800 with ca. 2600 times 900 times 35 volumetric units in the computational grid is close to the practical size of a model simulation to cover the entire Norwegian coast may have. The main constraint in NorKyst800 model system in the current setup is the model resolution. This represent a limitation of what is practically feasible nationwide with current availability of computing resources. This challenge is partly met by that the finer NorFjord model can be nested into the Norkyst800 model for selected production areas as needed. Performance computing, access to supercomputers, is sufficient to run the current model systems. High-performance computing is however a bottleneck for further development towards higher resolution.

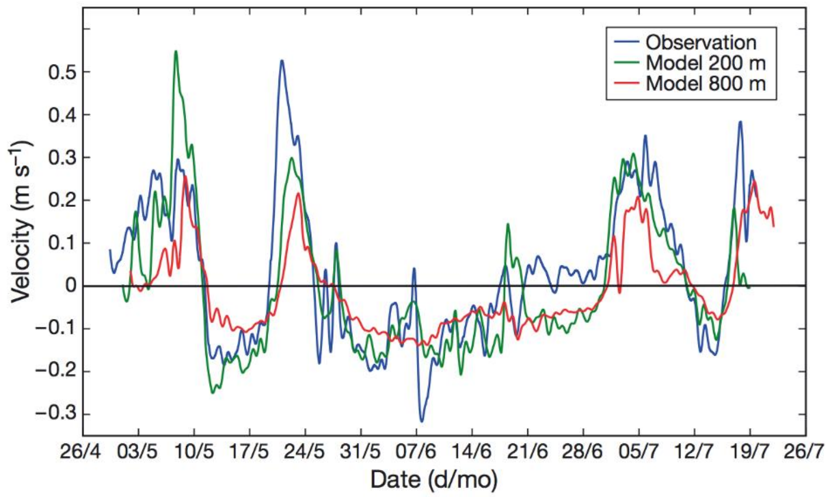

Figure 1. Along-fjord current at 11 m depth from an observational buoy in the Hardangerfjord (blue line) and from the corresponding position in the 200 m (green line) and 800 m (red line) resolution numerical models. Positive values are currents directed towards the head of the fjord (Johnsen et al. 2014).

The hydrodynamic model results consist of hourly values of three-dimensional currents, salinity and temperature and serve as input to the salmon lice dispersion model. The salmon lice advection and growth model is based on the Lagrangian Advection and Diffusion Model (Ådlandsvik and Sundby, 1994). The salmon lice model simulates the vertical behavior of salmon lice by simulating swimming up during day and down during night. The first three pelagic stages are simulated, the duration of the two non-infective nauplii stages are set to 50 daydegrees (days x temperature), while the copepodids is assumed infective between 50 and 150 daydegrees (Asplin *et al.* 2011). The salmon lice that is put into the model is based on weekly reported mean number of female salmon lice, temperature on 3 m depth and monthly data on number of fish in the farms along the coast. From this number of hatched nauplii is calculated (Stien *et al.* 2005). Output from the salmon lice model are hourly information on the particle position, age, temperature and salinity. Combined, these models estimate the density of salmon lice along the Norwegian coast.

Validation of the lice dispersion model

Salmon lice copepodids are found mainly in the upper meters of the water column during the day and tends to aggregate in shallow estuarine areas. The highest density of lice is often found along the shores. In the Faroe Islands, the density was highly variable from shore and 200 m outwards, indicating a patchy distribution. Hydrodynamic models often predict that the distribution of sea lice tend to be patchy distributed. This is also the general picture from field studies.

At present there is no data available to validate the simulated density of nauplii and copepodids in the water column. Therefore, in order to validate the infectious dose, we are at present limited to use indirect measures based on infestations on either wild fish caught using traps, nets or trawled, farmed postsmolt salmon stocked in sentinel cages or farmed salmonids.

While both fish farms and sentinel cages are positioned in fixed positions for a known period of time, wild fish moves freely. A major difference between fish in sentinel cages and farmed fish is that in sentinel cages the fish has been left for a restricted period of time, and the lice is thoroughly counted in the lab. The counting of salmon lice on farms is divided into sessile, preadult and adult male lice, or adult female lice. We consider counting of the sessile lice on farmed fish less reliable due to difficulties in counting these small stages. Therefore, the preadult and adult male lice are used, and the infestation is calculated either as an increase in lice population or back-calculated to time of infestation. Both methods rely on known temperature dependent development, and assume a mortality during the free-swimming nauplii and copepodid stages, and mortality on the fish after attachment. Even though the number of farms that may be used is limited in particular during periods of the year due to use of anti-lice measures as anti-parasitic chemicals prior to stocking in the sea, lice nets or cleanerfishes, the number of farms and their distribution along the coast makes this an interesting approach. Statistical models seems able to at least to some degree predict the increase in lice abundance based on infection pressure calculated among other variables from sea distance (Kristoffersen *et al.* 2014). An attempt to predict infestation using the NorFjords 160 m model on farms during winter in western Norway indicated that predicted infestation was correlated to back calculated estimated infestation (R = 0.48). This does indicate that present farm data to some extent may predict the lice infestation in an area, but the variability does not allow for precise estimates. However, we do assume that reliable counting of sessile lice on the farms may improve the estimates.

Sentinel cages are small cages (about 1 m^3) where farmed postsmolt salmon is stocked for 2-3 weeks before the infestation on the fish is counted. These cages are hung 0.5 m below surface and used to estimate infection pressure in fixed positions and time periods. The exact position and the period they have been exposed is known. However, as the period between attachment and molting to chalimus 1 takes some time, there will be uncertainties in when the lice attached to the fish. Generally, the correlation between predicted copepodid density using the hydrodynamic model and observed infestation was relatively high ($R^2 = 0.56$ for linear regression), and these analyses also indicated that the model should include temperature and salinity (Karlsen *et al.* 2016). In cases where the model predicted very high lice density the infestation was relatively high in all cases. However, in situations where the model predicted low copepodid density, there were occasions with also high infestations. The data used in this analysis was mainly from the Hardangerfjord in 2014. A larger dataset is presently covering four fjords (see below) and the years 2012-2015 are being analyzed, and in this analysis other factors as region and season are included. We suspect that this may influence in particular the mortality during the planktonic stages. Assuming that the infestation is directly related to lice density in the water (i.e. infestation pressure), these initial analysis indicates that the model is able to predict infestation in these areas. However, there are some limitations with these analyses. The sentinel cages are only positioned in a few fjords (Hardangerfjorden, Romsdalsfjorden, Namsen/Vikna and Altafjorden) subjected to fallowing regimes resulting in synchronous development of biomass and lice within the fallowing zones, and fjords protected from salmon farming where infestation is low. Whether they are valid under other conditions as along the open coast is not known. However, by comparing qualitatively the predicted infestation pressure with observed infestation on sea trout caught using traps or nets, the observations indicate that this should be possible. We do conclude that the models should be able to predict the infestation pressure in regions, though validation should be extended to more positions and into coastal areas.

Utility of the models in predicting impacts on wild Atlantic salmon

The models predict density of infectious salmon lice in time and space. However, in order to predict effect on wild fish this infection pressure needs being translated into either abundance on wild fish or a measure of the increased risk of mortality of a population due to salmon lice density. In the "Risk assessment of Norwegian Aquaculture" a salmon lice risk index, attempting to estimate the increased mortality due to salmon lice infections, are used. This is based on the assumption that small salmonid post-smolts (<150 g body weight) will suffer 100% lice-related marine mortality, or return prematurely to freshwater for sea trout, if they are infected with > 0.3 lice/g fish weight, and 50% mortality if the infection is between 0.2 and 0.3 lice/g, 20% mortality if the infection is between 0.1 and 0.2 lice/g and 0% mortality if the infection is < 0.1 lice/g fish weight (Taranger *et al.* 2015). By using this method, and assuming a mean salmon postsmolt weight, the number of lice or infestation pressure may be translated into probability of lice-related marine mortality.

The only direct measurement presently made on infestation on outmigrating salmon postsmolt is by trawling in the outer parts of the fjords during the migration period using a special designed fish–lift trawl. This method gives an estimate of the infection these fish has accumulated from they left the rivers. Since it is not known which river the fish originates from, when it left the river, for how long time it has spent in the fjords or which route it has taken, it is not straightforward to use trawl data as a validation of the infection pressure.

However, it should be possible to assess the risk of infection the population experiences by sending fishes through the modelled infection pressure during their migration from the river to the sea and register the infestation pressure they experiences. Though there are uncertainties, the timing and duration of the migration from the rivers may be estimated. By simulating the migration period, travel distance, path, and speed and the estimated infestation pressure they experience, the risk of lice-related marine mortality may be estimated. The infection pressure may be estimated as the probability of encounter a salmon louse, or the probability of encounter a patch with high density of salmon lice as the latter is more likely to inflict high mortality than the first. Preliminary analysis has shown that such a procedure with relatively little effort may be done for all known Norwegian salmon rivers, and including the model predictions of lice density the risk of lice-induced marine mortality may be estimated, and also quantify the uncertainties in these estimates.

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