Sea lice and Salmon Aquaculture: Lecture notes

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1 Title slide

2 Contents

This lecture will cover some key points relating to sea lice, in the context of salmon aquaculture. Various parasites affect different species of fish, but the species we discuss here are often specialist parasites of salmonid fish (salmon and trout species).

The lecture will cover the life cycle and dispersal of sea lice in the water column, how they infect and affect wild and farmed fish. We will talk about approaches to reducing their abundance, including efforts to model their spread.

3 Global distribution of wild and farmed salmon

Sea lice are found wherever salmonid fish species are found. Salmon are generally found naturally in northern latitudes. The most commonly farmed species is the Atlantic salmon, which is farmed in Chile as well as the natural northerly range.

The country with the highest commercial production of salmon is Norway, followed by Chile and Scotland.

4 Sea lice – general points

Sea lice infect fish by attaching to their skin, often close to gills, fins, and other areas of soft tissue.

They pose a persistent challenge for aquaculture, reducing fish welfare, and causing frequent bad publicity with respect to the potential impact of the lice on wild fish, and the effect of the chemicals used to treat them on non-target species sharing the water body with the aquaculture sites.

The economic costs associated with treating sea lice are estimated to be around £24m in the UK alone, and over £221m globally (annually).

5 Main species found in Scotland

In Scotland, the most common species is Lepeophtheirus salmonis. Caligus species are also found, but in rather lower abundances at present. Lepeophtheirus are well within their geographic range in Scotland, being tolerant to much colder waters in Norway.

6 Sea lice life cycle

The sea louse life cycle has two key components: a pelagic larval phase, and an attached phase in which mating and reproduction occurs.

The larval phase has two stages. When larvae hatch as nauplii, they have very little swimming capability and more passively with the flow of currents. After a few days, they develop into copepodids, which have some limited swimming capability, and can attach to a host fish if one is encountered. Swimming is primarily used to attach to a host. During the larval phase, sea lice survive on the reserves they are born with (they are “lecithotrophic”).

Once attached to a host fish, lice can feed on mucus and soft tissue of the fish, and grow rapidly in size. Once they reach later life stages they are able to move around on the fish to locate mates. Adult females produce long strings of eggs, each containing up to around 200 eggs (several sets of strings can be produced).

7 Larval dispersal of sea lice

Sea lice spread from fish to fish by means of a pelagic larval stage. This lasts up to 14 days (depending on water temperature and mortality). Eggs hatch as “nauplii”, which develop into infective copepodids after around 4 days at Scottish water temperatures. At warmer temperatures, development is faster, and slower at colder temperatures.

Nauplii are passive, while the copepodids have some limited swimming ability, which may enable them to make daily vertical migrations over the top few metres of the water column in response to light (phototaxis), and to swim directionally towards potential salmonid hosts. Copepodids have been show to be capable of detecting hosts via chemical cues in the water column.

8 Factors affecting larval lice

Sea lice larvae are transported by water currents. They are predominantly found in surface waters, which are more affected by meteorology such as wind and rain.

Sea lice are thought to attempt to avoid fresh water pockets and layers. These may be found at the surface in sea loch environments, and force the sea lice to migrate vertically to deeper, more saline layers.

Salinity is a key factor driving mortality of sea lice – fresh water causes mortality for all stages (including attached adults). Mortality also probably occurs due to predation, though this is a little known part of the life cycle.

As noted previously, development time to infective stage is related to temperature.

At the abundances normally seen, sea lice larvae are very difficult to find during sampling efforts of the water column.

9 Lice on wild fish

10 Atlantic salmon life cycle

Atlantic salmon have a life cycle that lasts several years. They hatch in a freshwater environment, remaining in their home river for a period of between 1-7 years, before migrating to the sea as “smolts”. They spend at least one year in the ocean (often longer), feeding and developing reproductive capability. Finally they migrate back to their home river (most probably using smell or geomagnetic perception) in order to spawn.

The freshwater component of the life cycle means that juvenile salmon are safe from being infected by sea lice at this point.

11 Lice on wild fish: key points

Sea lice occur naturally on wild fish, and existed long before the presence of salmon farms.

The most common places for sea lice infections are likely to be close to the coastline. Trout, for example, tend to spend a longer time in saline coastal environments, and consequently are infected more frequently and at a higher intensity than salmon.

12 Mortality of smolts (juvenile fish)

Lice can directly cause mortality of young smolt fish, especially when found in high numbers (greater than around 10-13 lice per fish).

13 Effects on adult fish

There are also a range of impacts for adult fish due to the presence of lice, including bleeding, changes in mucus biochemistry, tissue damage, loss of microbial and physical protective function (increased risk from other pathogens), loss of appetite and metabolic rate, and osmoregulatory imbalance.

All of these issues become worse at higher abundances, though it is rare for lice to directly cause death of adult fish.

Lice attach mainly to areas of sorter tissue, such as near fins and gills.

14 Scottish Sea trout post-smolt monitoring

A study by the Rivers and Fisheries Trusts of Scotland (RAFTS) in 2013 looked at the incidence of sea lice on sea trout around the west coast of Scotland. Most sites were close to key rivers in the region.

Locations and sample sizes are shown in the map and table.

15 Post-smolt monitoring results

There was a high level of variation between rivers.

Three numbers are reported here for each sample.

- Abundance: The mean number of sea lice per fish in the whole sample.
- Intensity: The mean number of sea lice per infected fish
- Abundance Median: When ranked numerically, the middle value of sea lice abundance within the population of fish.

Where abundance and intensity are similar, most fish were infected with lice (West Riddon or Goil, for example), while samples where a small number of fish had higher numbers of lice are reflected in a large difference (Laxford, Borrodalen and Kannaird, for example).

The overall mean abundance and intensity were 2.5 and 4.5 respectively. This may be compared with the industry treatment threshold of 1 louse per fish, or reporting threshold of 3 lice per fish.

16 Smolt return rates and the impact of lice

The impact of sea lice on wild fish is thought mainly to occur on smolts when they migrate out to sea. At this stage they are small enough to be susceptible to mortality if affected by large numbers of lice.

A study in 2013 considered mortality of many thousands of tagged smolts released into the sea in Irish waters over the previous 12 years. Some smolts were vaccinated against sea lice, while others were not. Efforts to recapture the smolts were made upon their return to their home rivers over the following years.

Marine survival decreased over time (those released later were less likely to return).

It was also found that treating the smolts against lice improved return rates by around 1% (in comparison with the number released). However, an article published in response to this work noted that, given a return rate of around 4-5%, a reduction in return rate of 1% equates to a reduction in breeding population of around 25%.

17 Lice on farmed fish

18 Media controversy

There has been a large amount of media controversy over the impact that sea lice on fish farms have on wild fish populations, and the impact of chemical treatments used to control them. This has been one of the industry's key challenges over recent years.

19 Lice on farmed fish: general points

Farmers generally try to keep lice numbers low.

In Scotland, treatments to remove lice must be carried out when there is more than 1 lice per fish (on average) over all fish sampled in one week

Lice numbers must be reported to the government when more than 3 lice per fish are found

20 Lice reporting

In Norway, lice numbers are reported weekly via an online mapped database, with counts at each farm being shown. This makes tracking outbreaks straightforward and has allowed researchers to gain valuable insights into the dispersal and dynamics of sea lice populations.

In Scotland, lice counts are reported monthly, aggregated over all farms within "Fish Health Management Reporting Areas". The counts are published once every three months by the Scottish Salmon Producers' Organisation. The areas used are designed to match the areas used in historic records for wild fish catches, and could hypothetically be used to track influences on wild fish in this way. However, the aggregated nature of the counts and the fact that areas are not necessarily hydrodynamically distinct areas means that analysis of the counts is difficult.

One producer (Marine Harvest) has recently started producing sea lice counts for each of its sites operating in Scotland, on a monthly basis (since January 2017).

21 Area-aggregated counts in Scotland

Sea lice abundances vary with region in Scotland. In particular, the north west mainland and western ilse have tended to have higher counts over the recording period. Counts in the Northern Isles have generally remained low; this area may have relatively weak connections with the rest of the country, in terms of larval lice.

There is often a peak in abundances in late summer, due to the faster growth rates that sea lice achieve during the warmer months. In 2013 and 2014, a peak in abundance in the NW mainland was immediately followed by a peak in the Western isles.

22 Managing sea lice

23 Lice control: site management

On salmon aquaculture sites, lice are managed via a number of means.

The "Code of good Practice for Finfish Aquaculture" recommends the management of farms within coordinated areas. "Farm Management Areas" are set up for this purpose. Within each area:

- lice control treatments are practiced synchronously
- sites are stocked with a single generation of fish (there are no overlapping year classes in the two-year production cycle)
- fallowing of all sites within a management area to break lice life cycles is carried out.

24 Lice control: cage treatments

There are tow main types of chemical treatments applied to control sea lice

Bath treatments (e.g. Gautam et al. 2017) may use chemicals, or more recently, warm fresh water. Chemicals used include azamethiphos ("Salmosan"), hydrogen peroxide ("Paramove") and deltamethrin ("AlphaMax" - discontinued). Attached lice fall off fish and die, and treatments are effective immediately.

In-feed treatments may be given via a supplement or additional ingredient in fish feed products. The main chemical currently used is emmamectin benzoate ("SLICE"). Following consumption of this chemical, lice find it more difficult to attach to fish, as the chemical is passed out via the fish's skin. Attached lice fall off fish and die. Effects are gradual, and take place over around 30-40 days.

There are several issues associated with chemical treatments. Firstly, stress on the fish being treated affects their health. Secondly, chemicals are discharged into the environment, either directly or via fish faeces. This has impacts on the benthic environment and can harm non-target crustacean species. Such discharges are strictly regulated in Scotland by the Scottish Environmental Protection Agency. Finally, development of resistance is a challenge. Chemicals which may have a near 100% efficacy when they are first introduced have always declined in efficacy over a number of years, as lice evolve over a number of generations to be resistant to their use.

25 Development of resistance to chemicals

The maps here show how resistance to available chemicals has developed in Norway over the last 15 years.

26 Lice management: cleaner fish

A promising technology for lice control is the use of cleaner fish. These fish are stocked with salmon in their cages, and can graze lice from the skin of the salmon. The two main species used are Wrasse species and Lumpfish.

In order for this to work, the ratio between salmon and cleaner fish must be correct, as must the amount of feed provided. If this is not the case, cleaner fish may either ignore the salmon and lice, or may cause injury to the salmon themselves.

Issues relating to cleaner fish include the risk posed by transmission of other diseases (carried by the cleaner fish), and also sources the actual cleaner fish. At present, most wrasse for this purpose are obtained by wild fisheries, and the sustainability of this source is not known. Culture of cleaner fish is a current key line of investigation.

27 Lice management: barrier technologies

A final method of reducing lice infestation is the use of so called barrier technologies. These involve placing a physical barrier in the portion of the water column most frequently occupied by sea lice larvae (the top 5 m). Designs include skirst which encompass an entire cage, or "snorkels", which provide a relatively narrow route for salmon to reach the surface (to prevent damage to their swim bladder. Studies have found that deeper snorkels generally have improved results.

Issues associated with this include changes to the oxygenation of the water within the protected portion of the water column, and the risk of damage to cages and barriers during storm conditions.

Closed containment systems are also being researched, though no system has yet been made suitably operational.

28 Modelling sea lice

In all salmon producing areas, groups of researchers have investigated the use of mathematical and computational models for understanding the dynamics of sea lice populations.

29 Biophysical modelling overview

One type of modelling that has come into common use is "biophysical modelling", which incorporates the effects of physical processes such as wind and tidally driven current patterns with biological aspects affecting individual sea lice.

Such models incorporate a physical model (meteorology and currents). The output from this is used to drive a particle tracking model, which predicts the movements of individual sea lice from a range of source sites (aquaculture sites, for example), and includes factors such as mortality, development, and behaviour. The output from this model may be analysed directly to understand "connectivity", or is may be used as input to a spatial population model to describe how outbreaks occur over space and time.

The different mode outputs can be validated in different ways, using a range of data sources.

30 West coast of Scotland lice dispersal

An example is given here from the Scottish west coast. On the left, a snapshot of currents output from a hydrodynamic model are shown.

These are used to drive the movement of particles, released from aquaculture sites (middle). The tracks of particles are followed, and any particles that move within a certain radius of another site (after they have reached a particular age of competency, here 3.6 days), are counted as successfully dispersing.

Considering all such successful dispersal events, we can build and plot a connectivity matrix, which identifies strong and weak connections between sites. This varies depending on particle release date, as different wind patterns change the overall dispersal between sites (animation on right).

31 Connectivity analysis

Marking non-zero connections between sites, and shading arrows according to connection strength, allows identification of key groupings of sites within the network. This may inform the arrangement of management areas within the domain.

32 West coast connectivity

As noted in an earlier slide, farms are managed within local spatial units: "Farm Management Areas" (FMAs). It is hoped that coordinated chemical treatments and fallow periods within these units will be successful in controlling sea lice abundances.

An analysis of the connections between FMAs indicates the extent to which these units are likely to be successful in controlling the spread of sea lice.

Here, we note that there are connections between FMAs, particularly in a general northward pattern. Some clusters of FMAs are noted, particularly in the Clyde, Linnhe, and Skye/Alsh regions.

33 Benefits of spatial management

Nonetheless, managing sites within these units does offer a significant reduction in the level of "external" connectivity, in comparison with managing sites in isolation (the easiest sand least coordinated approach). An approximate 75% reduction is noted in this region.

34 Optimal spatial management units

Removing low valued connections from the connectivity matrix, the matrix of sites can be split up into "optimal" units. After deciding a threshold, and setting values below that to zero, a natural compartmentalisation arises.

The units shown in the figure reflect those that would be expected to best contain sea lice larvae, based on a particular level of "tolerated" connectivity flux between areas.

35 Life cycle models

The output from connectivity models can be used to drive population models, which predict how abundances would change over time. Here, a connectivity matrix is used as input to a model which defines development of lice on each farm site.

Theoretically, this may help to inform treatment and management strategies, or assist in identifying sites posing particular issues. These models may also help identify outbreaks of lice prior to their detection, if they are suitable parameterised.

36 Space for new sites

Based on the locations of sites, their stocked biomass/fish counts, and lice counts, areas of high and low lice abundances in the wild may be identified. These assist both in identifying where developments could take place, or assessing areas where densities are likely to be very high, and unacceptable risks to wild fish may occur, for instance.

37 Other modelling efforts

There are similar modelling efforts in all salmon producing countries. To date, work in Norway is the most well developed.

38 Final comments

At present, lice levels are maintained at a level where there unlikely to be significant harm to the farmed fish.

There is still significant debate about the effect that sea lice from farms have on wild salmon, but less debate about the effect on sea trout.

There is room for improvement in sea lice management techniques.

Sea lice remain the number one priority in Salmonid aquaculture.