Study Guide for
Sea lice and Salmon Aquaculture by T.P. Adams

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Abstract

This document provides the study guide for unit 8 in a Masters-level course in 'Planning and Managing the Use of Space for Aquaculture' made by the AquasSpace project. It accompanies a set of slides and a separate commentary on the slides. The unit describes the problem of sea-lice infestation in salmon aquaculture and how modelling can help spatial planning and site management to ameliorate the problem.

The unit to which this refers may be cited as: Adams, T.P. (2018) Sea lice and Salmon Aquaculture. AquaSpace project (H2020 no 633476), SAMS, Oban, Scotland.

Contents

1 Study Guide

This text was written during the H2020 Aquaspace project (2015-2018, contract no. 633476) for a Masters-level course in 'Planning and Managing the Use of Space for Aquaculture'. The course consists of a number of units; this unit describes the problems caused by sea-lice to salmonid farming and the use of a modelling tool in spatial planning and lice management.

The material for this unit comprises a set of slides and an accompanying document that provides a slide by slide commentary. It is suggested that the student print the commentary and refer to, and annotate, it whilst viewing the slides. Alternatively, the commentary provides information for a lecturer to use when presenting the slides as a 1-hour lecture.

There is also some suggested reading, and a computational exercise that assumes familiarity with the 'R' programming language.

The learning outcomes for this unit are to be able to:

1. describe the lifecycle of sea-lice parasites of salmonids;
2. explain the several ways in which this is a problem for farmers;
3. describe control measures;
4. describe and critically evaluate the part that MSP can play in dealing with this issue;
5. describe the use of biological-hydrodynamic modelling as a tool to help in MSP and in lice management at sites or groups of sites.

2 Exercises

Materials are provided for a simple modelling exercise which requires familiarity with the 'R' programming language. A zipped package `AquaspaceMM-8-SeaLice-exercise` contains slides, a script in 'R', and a csv data file.

3 Further reading

- section 2.1 in Tett et al. (2018) (obtainable from Scottish Parliament website), provides more details of the sea-lice problem in and its management; for convenience an edited text of this section is reproduced in Appendix A;
- Adams et al. (2016) (open access paper) gives more details of the connectivity modelling described in the slides.

4 Self-Assessment Questions

The SAQs that follow test your achievement of the learning outcomes and help you think actively about the points raised in this lecture. No answers are given.

1. What is the significance of the pelagic stage in the life of sea-lice?
2. What is the evidence that sea-lice harm wild populations of salmonids?
3. What are the several problems with chemical treatments for lice?

4. How can lice management areas help control lice infestations?
5. How are lice represented in the bio-physical model?
6. How might the model help in spatial planning of aquaculture?
7. What additional data would increase the effectiveness of the model as a tool for helping to manage sea-lice infestations of farmed salmon?

References

Adams, T. P., Aleynik, D., and Black, K. D. (2016). Temporal variability in sea lice population connectivity and implications for regional management protocols. *Aquaculture Environment Interactions*, 8:585–596. DOI: 10.3354/aei00203.

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Appendix

The following appendix has been edited from section 2.1 in a report about the environmental impact of salmon farming in Scotland. The authors were E. Vorspoor, D-C. Hunter and M. Coulson (UHI). For tables, diagrams and references, see the full report by Tett et al. (2018).

A Sea Lice impacts in Scotland

Sea lice, *Lepeophtheirus salmonis* and *Caligus elongatus* (amongst others), are ectoparasites and a key impediment to the expansion of the Scottish salmon farming industry in the sea.

A.1 Lice and salmon

Sea lice occur naturally in the marine environment and are commonly found on wild adult salmon (Costello, 2006). Their life cycle lasts about 2 months, and has a free-living stage followed by a parasitic phase (Frazer, 2009). Wild salmon can potentially infect farmed stocks when the former return from the ocean. Larval lice from untreated farmed salmon can increase the infestation levels on other farmed salmon, as well as on wild salmonids as they migrate past the cages to the sea (Bjørn et al., 2011; Middlemas et al., 2013; Serra-Llinares et al., 2014; Helland et al., 2015; Gargan et al., 2017).

Damage to salmon from sea lice

The parasitic phase can cause both morbidity and mortality of salmon as the parasite feeds on its host's mucous, blood, and skin (Costello, 2006). The first parasitic stage (chalimus) in the sea lice life cycle commonly only inflicts minor damage unless the infestation is excessively high and within the dorsal fin area (Bjørn & Finstad, 1998). The chalimus stage is succeeded the pre-adult and fixed adult stages, which can inflict severe damage as they feed on the salmonid tissues; high infestation rates can lead to mortality of the host fish (Bjørn & Finstad, 1998; Dawson et al., 1998; Wells et al., 2006; 2007).

In addition to the mechanical tissue damage caused by lice feeding, the host fish also experience increased stress, diminished swimming capability, and imbalances in water and salt levels (Finstad & Bjørn, 2011; Thorstad et al., 2015). Between 0.04 and 0.15 lice per gram of fish weight can elicit these responses in salmonids (Nolan et al., 1999; Wagner et al., 2003; Wagner et al., 2004). For smolts and post-smolts, both laboratory and natural infestations studies indicate that eleven or more pre-adult and adult stages lice per fish will cause mortality (Finstad et al., 2000; Wells et al, 2006).

Lice and farming

Salmon farming provides favourable conditions for the growth of sea lice populations due to the high density of hosts (Torrissen et al., 2013). There is evidence that high sea lice abundance has direct negative effects on farmed fish (Jones & Beamish, 2011).

Sea lice and wild salmonids

A clear relationship between the increased abundance of sea lice due to salmon farming and presence on wild hosts in the sea has been demonstrated outwith Scotland (Marshall, 2003; Morton et al., 2004; Serra-Llinares et al., 2016). The only reported scientific study in Scotland relates to wild sea trout monitored over five successive farm cycles (Middlemas et al., 2010, 2013), which found that lice burdens above critical levels (based on laboratory studies of sea trout) were significantly higher in the second year of the production cycle. Preliminary analysis of data from fallowing zones indicated that lice levels in farming areas are also correlated with farmed biomass (ICES, 2016).

The consequences of increased sea lice levels for wild salmonid populations is unclear. It is reasonable to expect that if levels on wild fish increase, there is potential for a negative impact. However, quantifying wild salmonid population mortality due to sea lice infections is complex, and the magnitude of lice effects depend on environmental, biological and ecological variables that have not been studied in depth (Helland et al., 2015; Vollset et al., 2015). Mortality levels due to sea lice have been predicted to cause a fall of 1% to 20% in adult salmon abundance (Jackson et al., 2013; Krkošek et al., 2013). However, salmon lice may only threaten population viability if high infections persist over a number of years and if populations are already depressed. Average parasite induced mortality in smolts has been estimated as in the range of 0.6% to 39% (across various locations and years) in experiments based on protecting groups of smolts chemically against salmon lice (Gargan et al., 2012; Jackson et al., 2013; Krkošek et al., 2013; Skilbrei et al., 2013; Torrissen et al., 2013; Vollset et al., 2016). However, even a small percentage loss of smolts or adults may be significant if it combines with losses due to other causes so that salmon become critically endangered or lost (e.g. Finstad et al., 2007; 2012).

A.2 Sea lice management

In Scotland, actions to control sea lice levels on fish farms are managed through legislation and a voluntary code of good practice. The three legislative frameworks are:

- The Aquaculture and Fisheries (Scotland) Act 2007;
- The Aquaculture and Fisheries (Scotland) Act 2013;
- The Fish Farming Businesses (Record Keeping) (Scotland) Order 2008.

Salmon farms currently work to control lice using several approaches (Aean et al., 2015). These include: chemical in-feed treatments such as emamectin benzoate (EMB; active ingredient in SLICE$^{(R)}$); chemical bath treatments such as hydrogen peroxide; biological controls such as cleaner fish (e.g. wrasse or lumpfish); and new techniques such as thermal bath treatments.

The legislation is enforced by Fish Health Inspectors (FHI) appointed by Scottish Ministers.

Evolution in sea lice of resistance to pesticides and other treatments

Medicinal treatment of farmed fish has, so far, been the most reliable method of sea-lice control, and this has led to extensive use of the available compounds (Grant, 2002;

Aaen et al., 2015). This has resulted in resistant parasites occurring on farmed, and possibly wild, salmonids: resistance has recently been found to be widespread, albeit variable, in all farming areas (Aaen et al., 2015).

This includes resistance to EMB, known commercially as SLICE$^{(R)}$ (McEwan et al., 2015; Grøntvedt et al., 2014; Helgesen et al., 2015) and to hydrogen peroxide bath treatments (Treasurer et al., 2000). An epidemiological study found a gradual decline in efficacy of this compound since 2004 (Lees et al., 2008), with further reductions in efficacy of EMB reported during the last decade. For example, in Scotland, a sevenfold reduced sensitivity towards EMB has been reported in an isolated salmon lice population on the West Coast (Heumann et al., 2012). A study in Scotland (Treasurer et al., 2000) found that sea lice were also able to develop resistance to hydrogen peroxide treatment, reducing the effectiveness of this form of treatment.

Data availability and public trust issues

Currently data on certain aspects of Scottish Aquaculture production are published on the Scotland's Aquaculture website. However, this website does not present any details for sea lice on the farms. The only publicly available data for sea lice on farms at presented for Scotland are those which are published in an aggregated format in the SSPO Health reports. Thus, it is difficult to report with any certainty, and in any detail, on the general or location specific nature and extent of the problem of sea lice on salmon farms in Scotland.

A.3 Diagnosis

The proliferation of sea lice on farms in Scotland is an issue in terms of fish welfare and economic cost as well as potential impacts on wild salmon. Sea lice impacts have been well researched in regards to physical host damage, but significant knowledge gaps remain. These include:

- The extent to which salmon farming practices are increasing the abundance of sea lice in the marine environment, and on wild salmonids, in Scotland;
- What, if any, additional mortality this causes to wild Scottish salmonid populations.

However, there is a gradually emerging body of evidence, from studies elsewhere, that sea lice not only have the potential to have a negative effect on wild salmon, but that in many situations this is likely to be the case (Gargan 2000; Finstad et al., 2000; Bjørn et al., 2001; Butler 2002; Ford & Myers 2008; Otero et al., 2011; Skaala et al., 2014; Vollset et al., 2014; Taranger et al., 2015; ICES, 2016; Gargan et al., 2017). With the currently high marine mortality rate for wild salmonids, and threatened status of many river stocks, any additional Pressure, such as increased sea lice burdens, is undesirable, and could further erode the conservation status of vulnerable wild populations.

The main treatment methods used in Scotland are experiencing reduced efficacy in dealing with sea-lice on farms. New techniques are being applied, although the long-term success of these is uncertain. The legislative and voluntary frameworks that underpin the management of lice levels on farms are not transparent. They appear neither to be succeeding in controlling sea-lice, nor capable of addressing the environmental effects of the lice.

Additionally, the use of such treatments involving existing chemicals or therapeutants has the potential to have direct negative impacts on local ecosystems.

A.4 Prognosis and mitigation

What is known indicates that current practices for treating sea lice on farms in Scotland have experienced reduced efficacy, and thus increased numbers of lice are occurring in the wild, in turn increasing the risk to wild salmonid populations. Even without an increase in Scottish production of salmon, this risk can be expected to increase in the future, unless the decreased efficacy due to increased resistance to treatments is addressed. Alternative methods and technologies to manage lice on farms including biological and mechanical controls are one option, but these also present additional farming and environmental challenges (as discussed in the case of wrasse and lumpfish).

Sea lice abundance on farms Management measures could continue to be improved and developed to reduce sea lice numbers on fish farms, and measures to support such activities encouraged, promoted and required.

Existing sea lice management Measures could be put in place to ensure all historical and current information on sea lice levels is accessible for independent analysis and scrutiny, thus providing the basis for the assessment of the long-term efficacy and sustainability of existing approaches to sea lice control.

New approaches Measures could be implemented that promote the development of alternative, longer-term solutions to the reduction of sea lice levels in respect of rearing approaches, fish husbandry methods, cleaner fish, new eco-friendly therapeutants, and selective breeding and strain development. The further development of novel husbandry approaches (such as fallowing and reducing time spent in marine cages) potentially offer more sustainable solutions. The same is true of including selective breeding for sea lice resistance in farm strains, or the development of new more resistant strains from wild strains known to have a naturally higher resistance

Biophysical modelling It has been demonstrated in Scotland that biophysical modelling offers an approach that could improve the control of infection risks between farms for sea-lice and other diseases (Adams et al, 2012a; Adams et al., 2015; Adams et al., 2016). Similar sea-lice modelling approaches have been developed and are currently implemented by the Norwegian government (Nilsen et al. 2017). For such models to be fully developed and productive in Scotland there is a requirement to make real time farm sea-lice data available.