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Assessing topical treatment interventions on Scottish salmon farms using a sea lice (*Lepeophtheirus salmonis*) population model

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ABSTRACT

At a time when sea lice control is a major issue for salmon aquaculture worldwide it has become imperative that scant veterinary medicinal resources for the treatment of fish on farms should be conserved and used effectively. This communication reports the use of the mathematical simulation model *SLiDESim* to investigate how best to administer cypermethrin bath treatments on Scottish salmon (*Salmon salar* L.) farms to control the challenge from lice (*Lepeophtheirus salmonis*) during a two-year production cycle. It was found that these topical treatments are most effective when administered in pairs approximately six weeks apart. Timing of treatment is critical and depends on the number of treatments administered over the production cycle. For 4, 5 or 6 treatments during a two-year production cycle, *SLiDESim* indicated that the first pair of treatments is best initiated in autumn of the first year of production with the second pair starting between 13 and 18 weeks later. This strategy can produce considerable gains in the predicted reduction of sea lice levels when compared with those historically observed when using cypermethrin on Scottish farms. The effects of altered efficacy were also explored using the model and indicate that even a moderate reduction in treatment efficacy can have considerable impacts on lice control over a production cycle. The *SLiDESim* computer model provides a framework to explore the more efficient use of veterinary treatments for the control of sea lice on salmon farms.

1. Introduction

The appropriate management of sea lice on salmon farms continues to be a challenge in every region of the world where significant salmonid aquaculture takes place. Substantive impacts both in terms of production loss and direct treatments costs continue to be associated with infestations by this ectoparasitic crustacean (Grant, 2002). A recent review of these impacts estimated the annual cost of sea lice to be €305M Euro across the globe, with the cost to Scottish industry being around €34M Euro per annum (Costello, 2009). In addition to cost there are concerns in some regions that sea lice from farmed sources represent an important disease risk to wild populations and that the therapeutants used for their control on farms may cause negative environmental impacts (Pillay, 2004). It is therefore important that methods be developed which ensure best practice for the use of veterinary medicines in the control of sea lice on salmon farms. This paper illustrates the use of mathematical modelling techniques to explore various treatment strategies within the framework of salmon farming in Scotland. Specifically it considers the application of the synthetic pyrethroid bath treatment, cypermethrin (Excis®, Novartis), for the control of *Lepeophtheirus salmonis* — the lice species of most concern to Scottish aquaculture (Revie et al., 2002).

Over the past three decades a range of treatment interventions have been available to the aquaculture industry. Initially these were from the organophosphate class of chemicals and were used as bath treatments, but during the past decade the dominant veterinary medicine, administered as an in-feed, has been emamectin benzoate (SLICE®, Intervet/Schering Plough). In a recent study reviewing the sea lice situation in Scotland from 1996 to 2006 it was found that emamectin benzoate had become a dominant treatment type (Lees et al., 2008a). However, it was also found that in the second year of production, in particular, there was significant use of cypermethrin. In addition there has been growing concern around the globe that sea lice populations are developing tolerance to emamectin benzoate (Bravo et al., 2008; Lees et al., 2008b,c). While there are no peer-reviewed reports from Norway, it is suspected that the number of local sea lice populations characterised by such tolerance is increasing in some Norwegian fjords where farming takes place. Most recently the Canadian regulatory authorities have granted emergency access to bath treatment following evidence from

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the veterinary profession that areas in New Brunswick are exhibiting similar tolerance issues to emamectin benzoate (Beattie, personal communication, June 17th 2009). While these developments have attracted considerable attention over the past few years they are not unexpected; similar lice tolerance issues arose with respect to the various classes of bath treatment which preceded them (see, for example, Denholm et al., 2002; or Fallang et al., 2004).

The potential for using mathematical models to investigate sea lice population dynamics on salmon farms has been explored in a number of publications (Tucker et al., 2002; Stien et al., 2005) as well as by a number of the present authors (Revie et al., 2005). However, little work has been carried out to apply these models to sea lice treatments and unlike some of the spatial and temporal models reported (Krkošek et al., 2006; Murray and Gillibrand, 2006) the approach taken in the *SLiDESim* (*S*ea *Li*ce *D*ifference *E*quation *Sim*ulation) model is farm-focussed. The *SLiDESim* model uses mathematical simulations to explore how the monthly sea lice burdens in the first and second years of production on a farm are influenced by the number, frequency and efficacy of cypermethrin treatments and to establish optimal treatment strategies. Although the model is suitable for site-specific farm use, this communication examines what happens to sea lice levels on an 'average' Scottish farm (based on mean monthly lice levels taken from historic data on farms using cypermethrin). While a range of treatment types can be simulated within the model this paper considers only the use of topical Excis treatments, with options ranging from between four and six applications during a two-year production cycle, to evaluate the effectiveness of various treatment strategies. The robustness of these strategies to deviations in the timing of treatments, as well as the effect of different treatment efficacies on the overall sea lice burden, is investigated.

2. Materials and methods

2.1. The model

The mathematical model of Revie et al. (2005) for *L. salmonis* abundance on Scottish farms was used in this study. This model represents the population of sea lice on a typical salmon farm in Scotland during a production cycle. It consists of six compartments as shown in Fig. 1 with compartments for each of the following life-cycle stages: eggs/planktonic stages, chalimus, preadults, adults, gravid females and a further compartment to model the arrival of infective copepodids from external sources. Each compartment reflects the density of lice per fish and is modelled using delay differential equations to enable the population dynamics to accommodate appropriate biological development times.

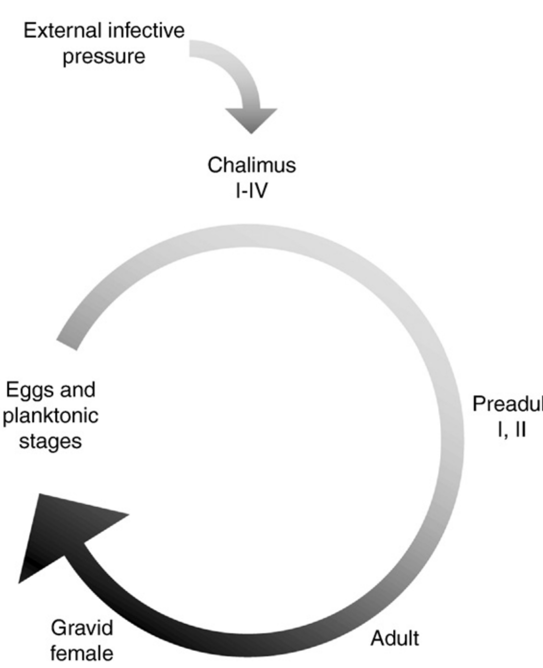

Fig. 1. The key stages of *L. salmonis* life-cycle associated with infestation of salmon parasites as represented within the model.

The model has been parameterised using various estimates. Development times have been established from biological studies. Estimates of chalimus mortality, mobile mortality, the flow of chalimus from gravid females (through egg, nauplii and copepodid stages) and the rate of external infective copepodid challenge have been refined using a model fitted to a national data set for sea lice abundance on over 40 Scottish farms using cypermethrin topical treatment between 1998 and 2001 (Revie et al., 2005).

2.2. Treatments

The effect of topical bath treatments is simulated using a knock-down factor. This factor reduces the chalimus and mobile populations at the beginning of the treatment week based on the level of efficacy defined for a given treatment. The sensitivity of the sea lice populations to different treatment efficacies is investigated by changing the estimates of knock-down, while the effect of different treatment strategies is assessed by modelling the use of between 4 and 6 topical bath treatments at various times during the production cycle.

2.3. Software implementation

The model has been implemented as a graphic user interface-driven application, *SLiDESim*, and is suitable for use on any PC running the *Windows* operating system. *SLiDESim* can be used for a range of functions such as measuring the effects of changing biological population parameters or the assessment of different treatment types such as bath versus in-feed treatments when treatment persistence and half-life are specified. However, the primary purpose of this instantiation of the model is to explore the effect of altering the timing and/or efficacy of bath treatments which may be introduced at any week in the production cycle. The fraction of the site treated within that week can be specified together with the assumed efficacy of the medication as shown in Fig. 2. The results from *SLiDESim* are presented graphically; but can also be exported for use in other applications. Results from simulated investigations may be saved and archived.

2.4. The optimisation metric

A key feature for investigating the effect of treatment interventions was the adoption of a suitable metric which could be used to measure the overall infection outcome given varying treatment strategies. It was important that this metric could be efficiently calculated as numerous runs of the simulation model are required to explore optimal intervention conditions. The metric chosen in this study is termed the "infection burden" (IB), and is defined as the sum of the monthly average chalimus and mobile sea lice per fish, over the two-year production period:

$$IB \equiv \sum_{i=1}^{24} (C_i + M_i) \quad (1)$$

where C_i and M_i are the mean monthly abundances of chalimus and mobiles respectively. This calculation is crudely equivalent to summing the area shown under the lines (chalimus and mobiles) shown in Fig. 2.

The objective of the optimisation was thus to obtain the smallest value of IB, through adjustments in the timing and number of treatments. As *SLiDESim* solves the population equations numerically and the number of treatments was small, an exhaustive search could be carried out quickly without any need for complex optimisation methods. The predicted IB of simulated treatment programmes can then be