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Manipulation of farmed Atlantic salmon swimming behaviour through the adjustment of lighting and feeding regimes as a tool for salmon lice control

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ABSTRACT

This paper describes a study in which environmental manipulation of salmon swimming depth was tested in an attempt to reduce farm infection of Atlantic salmon, *Salmo salar* by the salmon louse, *Lepeophtheirus salmonis*. The effects of submerged artificial lighting (positioned at 10 m depth) in combination with submerged feeding (delivered at 5 m depth) were tested with respect to salmon swimming depth and sea lice infection, following the hypothesis that *L. salmonis* infection in a commercial salmon population is reduced when exposed to deep lighting and feeding. This is based on two assumptions, firstly that planktonic *L. salmonis* larvae principally remain in surface waters (top 4 m) and secondly, that deep lighting and feeding attract salmon to deeper water depths. Results from commercial scale trials confirmed that salmon swimming behaviour is altered under submerged feeding conditions with fish attracted to the feeding corridor during the feeding process. When the fish reached satiation or feeding ceased, they returned to the surface waters during the day. Submerged lighting attracted the fish to the illuminated water depths during the night. During the day, natural light overruled these effects to some extent. The number of *L. salmonis* on fish exposed to deep submerged lighting was significantly lower than the number of lice found on salmon in cages with surface lighting during the summer months. Submerged feeding showed no advantage over surface feeding with respect to the number of *L. salmonis* found in these trials. The results of the study suggest that swimming depth manipulation can be used at a commercial scale to reduce salmon lice burdens on Atlantic salmon stocks.

1. Introduction

Sea lice are among the most economically costly parasites of marine farmed salmonids (Costello, 2009). The annual cost of two sea lice species, *Lepeophtheirus salmonis* (Krøyer, 1837) and *Caligus elongatus* (Nordmann, 1832), including harvest losses and therapeutant costs, has been estimated at €300 million globally, which is equivalent to 0.1 to 0.2 € kg^{-1} fish produced or 6–10% of the total production value (Costello, 2009; Rae, 2002). Sea louse control is therefore critical if productivity is to be maximised. To date, use of veterinary drugs remains a key component of integrated control strategies (Rae, 2002). This is problematic as, for instance, the UK is restricted in the number of licensed anti-sea lice medicines available and the few therapeutants available are largely becoming less effective due to development of drug resistance by the parasite (Shinn and Bron, 2012). The current study tested an alternative control strategy which relies upon manipulation of fish swimming depth.

The life-cycle of salmon lice consists of eight host-associated stages, and two free swimming nauplius stages (Heuch et al., 1995; Pike, 1990). It has been suggested that sea lice larvae remain within the first four metres of the water surface by performing short swimming bursts (Heuch et al., 1995; Hevrøy et al., 2003; Johannessen, 1978; Murray and Gillibrand, 2006). The upward swimming behaviour of lice larvae counters their negative buoyancy; however, copepodids do seem to show diurnal vertical migration (Aarseth and Schram, 1999; Heuch et al., 1995). The principal cue employed to make contact with swimming fish is the vibration of passing hosts, detected using an array of mechanoreceptors (Bron et al., 1993a; Heuch et al., 2006). Additionally, *L. salmonis* may also use phototactic cues, such as shadow and potentially light reflection from the scales of host fish, to colonise the host (Bron and Sommerville, 1998; Bron et al., 1993a; Genna et al., 2005).

In an earlier small scale trial, infection rate was observed to increase in fish swimming at shallow depths compared to deeper water (Hevrøy et al., 2003). Similarly, another study showed that salmon kept in cages

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with deep net pens (20 m depth) had lower louse infection than salmon kept in shallow pens (6 m; Huse and Holm, 1993). This depth preference of the sea louse larvae may therefore provide an opportunity for sea lice control on salmon farms through the manipulation of salmon swimming behaviour and depth (Oppedal et al., 2011).

Salmon swimming behaviour is mainly dictated by environmental factors such as seasonal and daily changes in lighting conditions, temperature, salinity and oxygen, as well as by the mode of feeding employed in a commercial setting (Oppedal et al., 2011). Salmon are positively phototactic and therefore they seek out light sources in order to display their preferred schooling swimming behaviour (Dempster et al., 2009; Juell and Fosseidengen, 2004; Juell et al., 2003; Oppedal et al., 2007). Naturally, salmon follow a diel swimming rhythm, following ambient light patterns with migration downwards in the water column at dawn and return to surface waters at dusk and through the night (Bjordal et al., 1993; Fernö et al., 1995; Juell and Fosseidengen, 2004; Juell and Westerberg, 1993; Oppedal et al., 2001). Photoperiod regimes acting through the use of high intensity submerged lights, which are routinely used to suppress early sexual maturation in Atlantic salmon during the on-growing phase, impact directly on fish swimming behaviour, with schooling at night around the submerged light units (Oppedal et al., 2007). Strategic deployment of submerged lights can therefore be employed to attract fish to specific water layers (Juell and Fosseidengen, 2004; Juell et al., 2003; Oppedal et al., 2007).

Commercially reared salmon are normally fed a pellet diet through surface spreading and the fish respond by changing swimming speed and direction, showing horizontal and vertical scattering towards the pellets (Ang and Petrell, 1998). The fish will remain up in the water column in the feeding corridor until satiated (Ang and Petrell, 1998; Fernö et al., 1995; Juell et al., 1994). Appetite and feeding are the strongest behavioural cues in fish with regard to swimming behaviour and they usually override any sub-optimal conditions, whether environmentally or artificially induced (*e.g.* phototaxis or water temperature) (Oppedal et al., 2007).

In the current study, the effects of submerged artificial lighting (placed at 10 m depth) in combination with submerged feeding (delivering feed at 5 m depth) were tested to examine elective salmon swimming depth and associated sea louse infection. The submerged lighting was installed to attract fish to deeper water levels during night time and the submerged feeding was installed to attract salmon away from a surface feeding corridor below the nominal principal infective louse layer. The hypothesis being tested was that sea lice infection in a commercial salmon population could be reduced by exposure to deep lighting, and further decreased by deep lighting and deep feeding This is based on two assumptions suggested by previous studies, firstly that infective sea louse copepodid larvae remain in the water surface layer and secondly that deep lighting and feeding can be employed to attract salmon to deeper water depths.

2. Materials & methods

2.1. Fish stock and farm set up

Eggs were produced and incubated by Landcatch Natural Selection (Hendrix Genetics) until transferred at the eyed stage to the Inchmore Marine Harvest Hatchery. On 5th April 2011, smolts (75.9 ± 7.6 g) were transferred into seawater at Marine Harvest Ardentoul salmon farm. Fish were on-grown according to current industry standards. On the 9th December 2011, fish were transferred to Marine Harvest Duich salmon farm (57° 14′ 55.93″ N, 5° 29′ 57.24″ W) and stocked into cages with a mean stocking density of 5.35 ± 1.23 kg/m^3. The health status of the fish stock was monitored as per Marine Harvest standard protocol. The fish health status was checked at three week intervals by two qualified veterinarians. No evidence of disease was reported in the stock prior to the experiment.

2.2. Farm set up

The mean water depth at the Loch Duich salmon farm is 30 m and the farm has 12 circular cages (100 m circumference circular Polarcirkel™ cages, Akva) in two separate cage groups of 6 pens each with nets (Nylon, 29 mm, MøreNot) of a working depth of 16 m. All pens are normally equipped with surface spreading feeders (Rotor spreaders CF90, Akva) connected with feed pipes to an automated feed control unit and storage system at the "SEA-CAP" feed barge. Daily feeding to satiation was carried out according to standard commercial practice and guidelines.

All cages were exposed to constant light from January to April 2012 using four 400 W metal halide submersible lights (BGB Engineering Ltd.) per pen. The lights were deployed evenly across the pen and held at 4 and 8 m depths, in order to prevent maturation according to standard industry practice for Atlantic salmon. Water temperature during seawater grow-out ranged between 4 and 12 °C. Fish were fed to satiation using a standard commercial diet (Biomar ELR 12 mm 16PF).

2.3. Experimental set up

On the 23rd March 2012, the lights for the experimental pens (6 pens with a mean of 45,078 ± 1165 fish pen^{-1}) were adjusted from the standard light depths (at 4 and 8 m) to the experimental light depths.

Two pens were equipped with 4 lights each at 1.5 m depth. Four pens were equipped with 4 lights placed at 10 m depth (Fig. 1). The

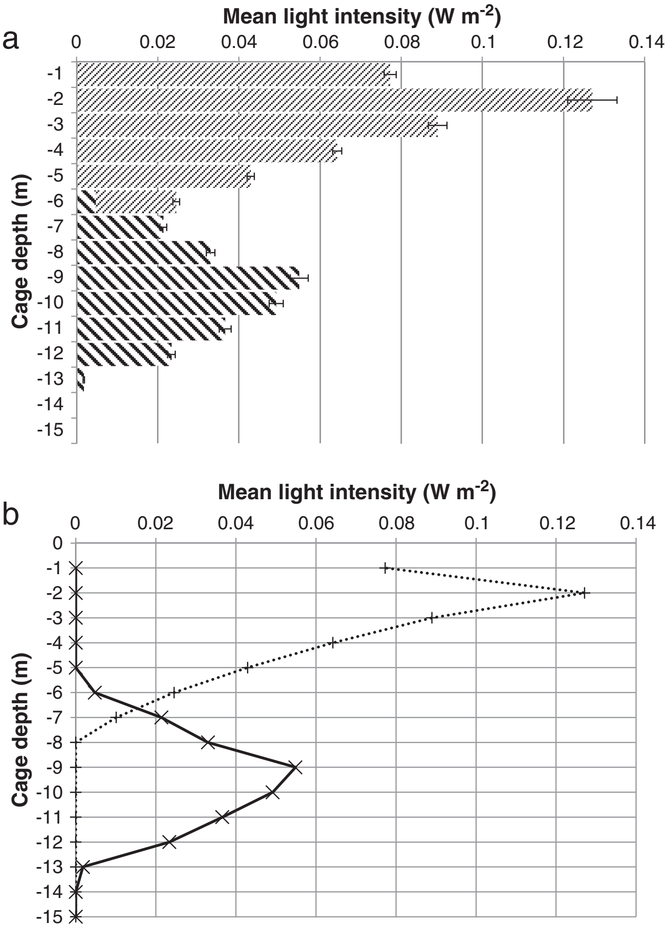

Fig. 1. a & b. Mean light intensity (W m^{-2}) at different depths during night time (7th June 2012) for the experimental lighting regimes with fish present. Narrow hatching & dotted line: pens with shallow lights (1.5 m depth); wide hatching & solid line: pens with deep lights (10 m depth). Graphs show mean ± SE.