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Low intensity light of different colours modifies Atlantic salmon depth use

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ABSTRACT

Underwater anti-maturation-lights have recently been exploited to position sea-caged Atlantic salmon (*Salmo salar* L.) deeper at night in an effort to reduce infections by salmon lice (*Lepeophtheirus salmonis*) in surface layers. However, anti-maturation-light use is impermanent because lighting during decreasing day-lengths stimulates sexual maturation which is detrimental for fish welfare, growth and meat quality. The effects from lights on maturation are related to both light intensity and light spectrum. Here, we explored caged salmon depth use in response to lights of four low intensities (0.01, 0.10, 1.0 and 10.0 μE as measured 1 m from the lamps) and seven different colours (broadband white LED lamp and narrow spectrum violet, blue, green, yellow, red and deep red LED lamps). Triplicate sea cages (12 × 12 m and 11 m deep) holding approximately 5000 fish of 1.5 kg were exposed to each light positioned at 10 m depth for one night. Echo sounders registered fish vertical positioning on nights of light treatments and no light (control nights) before and after each light exposure. Results showed that submerged lights generally caused fish to maintain their day-time swimming depth near 10 m (light depth) during the night, as opposed to the typical migration of salmon to upper cage depths at dusk observed on control nights. Quantities of fish staying deep decreased with lowered light intensity, but even 0.1 μE had effects. All light colours, except deep red, significantly affected swimming depth, with a trend of increased effect at lower wavelength colours. Temperature stratification strengthened light effects when warmer water was near the lamps and weakened effects in the case of warmer water near the surface. This study opens up the potential of using low intensity lights at decreasing day-lengths that may not affect sexual maturation and remain suitable for guiding salmon away from surface waters rich in lice infective stages.

1. Introduction

Ambient light and water temperature are the two key parameters modulating the vertical position of Atlantic salmon (*Salmon salar* L.) in sea cages (Oppedal et al., 2007, 2011). Both factors can vary with depth, and the vertical position of schooling salmon is often a trade-off between staying at the most preferred light intensity and temperature (Oppedal et al., 2011; Føre et al., 2013). In natural light conditions, Atlantic salmon typically descend at dawn, swim relatively deep during the day, ascend at dusk and swim closer to the surface at night (Oppedal et al., 2011). However, inhabiting the surface at night threatens fish health because these waters are associated with increased amounts of salmon pancreas disease viruses (Stene et al., 2013) and salmon lice (*Lepeophtheirus salmonis*) copepodites (Johannessen, 1977; Heuch et al., 1995). Hevrøy et al. (2003) found that salmon held at 0–4 m depth developed higher infestation levels than salmon held below 4 m and similar findings have been reported in studies comparing deep and shallow swimming salmon (Huse and Hom, 1993; Osland et al., 2001). Night-time swimming at surface depths, therefore, contributes to salmon lice infections which remains a major obstacle for industrial on-growing of salmon in sea cages (Torrissen et al., 2013). Salmon lice present a direct welfare problem for infected salmon (Stien et al., 2013), a substantial economic cost for the industry (Costello, 2009a; Rosenberg, 2008), and expand copepodite production which may damage nearby wild salmon populations (Costello, 2009b).

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Several new technologies are under development to reduce infection pressure from salmon lice. Two working principles are "keeping lice away from the salmon" by blocking the copepodite rich upper waters from entering the sea cage or "keeping salmon away from the lice" by impelling salmon to swim deeper. Examples are skirts around the upper part of cages (Stien et al., 2012), submerged cages (Dempster et al., 2008, 2009; Korsøen et al., 2009, 2012), submerged feeding and deep underwater lighting (Frenzl et al., 2014). The study by Frenzl et al. confirmed that submerged anti-maturation-lights attract salmon to the illuminated water depths during the night and showed that the number of salmon lice was significantly lower for these fish compared to fish in control cages with surface lights.

Anti-maturation-lights are high intensity white lights commonly used by the industry from midwinter and 4–6 months forward in time as a management tool to reduce the incidence of sexual maturation (Hansen et al., 1992; Taranger et al., 1998; Porter et al., 1999; Oppedal et al., 1997, 2006; Lekang, 2007; Leclercq et al., 2010). It is theorised that anti-maturation-lights provide a seasonal photoperiodic advancement, bypassing spring, making salmon perceive it is too late in the year to complete a successful spawning and therefore sexual maturation is arrested prior to the initiation of exogenous vitellogenesis and its associated energy commitment to reproduce (Taranger et al., 1999, 2010). Early sexual development in immature fish does, however, progress from the previous autumn and has been shown to be positively stimulated by extending summer lighting condition (autumnal light application) in turn increasing subsequent maturation rate (Taranger et al., 1998; Duncan et al., 1999; Oppedal et al., 2006). High water temperatures, as often seen during autumn, combined with night lights can trigger sexual maturation even in newly transferred smolt, with fully sexually mature individuals developing by the following spring (Fjelldal et al., 2011). High intensity anti-maturation-lights stimulate maturation if applied under decreasing daylength, and therefore, cannot be used as a general year-round method to modulate salmon swimming depth for salmon lice avoidance.

The chemical mechanism in the "decision" to initiate or arrest sexual maturation in salmon is not well understood. It is known that photoperiod information is translated into a chemical signal by the pineal gland, which is directly photosensitive and produces the indoleamine hormone, melatonin, during darkness (Gern and Greenhouse, 1988; Randall et al., 1995). In nature the resulting day–night changes in plasma melatonin profiles reflect changes in day length and are believed to provide the fish with precise seasonal information (Randall et al., 1995; Porter et al., 1999, 2001; Bromage et al., 2001; Falcón et al., 2010; Migaud et al., 2010). When exposed to artificial light the amplitude of melatonin level changes from daytime base levels decreases (Porter et al., 2001). This effect on amplitude is weakened, however, at decreasing light intensities with very low intensities (~0.01 μE) showing no effect (Porter et al., 2001). Laboratory experiments show that the intensity threshold for when the pineal gland is no longer stimulated varies with spectral content (Migaud et al., 2006; Vera et al., 2010); being far less effective in suppressing nocturnal melatonin at the red wavelength (~650 nm) than the shorter wavelengths (blue, ~450 nm and green, ~550 nm). However, the above mentioned studies were performed in small fully lit tanks or directly on the pineal gland and are not directly transferable to conditions in a sea cage, where inherently both the lighting intensity and the spectral content will vary with distance from light source, position and occlusion.

This study aimed to determine the lowest intensity of seven different coloured lights (white, violet, blue, green, yellow, red and deep red) needed to maintain daytime deep swimming of salmon in a sea cage throughout the night, with the view to identify the light intensity and colour most effective at maintaining the salmon stock away from copepodites rich surface sea water. Investigating the effects on maturation from the tested low intensity light sources is outside the study scope. We will however discuss the results in relation to a study by Leclercq et al. (2011) who followed salmon in sea cages with different lighting systems from winter to summer solstice and found a minimum threshold of ~0.06 μE (0.012 W m^{-2}) for light to influence maturation of salmon in a sea cages.

2. Material and methods

2.1. Location and experimental fish

The experiment was conducted at the Institute of Marine Research, Austevoll Research Station in western Norway (60°N) from January to April 2013. Trials were conducted in three (12 m × 12 m and 11 m deep) sea cages with Atlantic salmon of Aquagen stock produced at the Institute of Marine Research, Matre. At the start of the experiment cage 1 held 5540 individuals of 1.40 kg (estimated average weight), cage 2 had 5040 salmon of 1.50 kg and cage 3 had 4660 individuals of 1.65 kg, corresponding to biomass densities of 4.9, 4.8 and 4.9 kg m^{-3}, respectively.

2.2. LED-lights

Custom made lamps with Light Emitting Diodes (LEDs) were produced by AKVA Group ASA (Norway) and Professor Helvik at the University of Bergen (Norway). The lamps (h = 64.5 cm, ϕ = 12.0 cm) had white, violet, blue, green, yellow, red or deep red coloured rows of LEDs. The irradiance spectrums (Fig. 1) of the different lamp colours were described using a spectrophotometer (Houch & Gousego/Optronic Laboratories, OL 756, USA) and the total irradiance measured in a seawater tank 1 m from the respective lamps (Table 1).

2.3. Experimental setup

In the absence of light, salmon across all three experimental cages swam deep during the day and close to the surface at night. On designated nights (Table 2) three lamps with the same intensity level and spectrum were placed in the centre of each cage at 10 m depth in order to see if this would get the salmon to swim deep also during the night. The nights of light exposure were during periods (including control nights) with little or no moonshine, and when there was no conflict with necessary management procedures.

For each light exposure and control night, the average percentage of fish in the upper 6 m was measured by echo sounder during darkness (standardised to be between 22:00 and 02:00 local time). Control nights were timed shortly before and after sets of one to

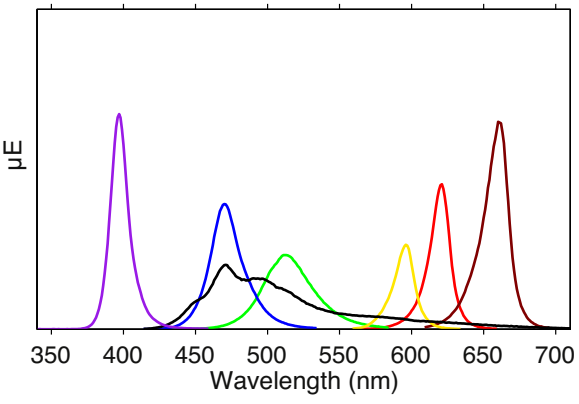

Fig. 1. Normalised irradiance spectrums for lamp colours: white (black line) (peak at 470 nm, range: 425–700 nm), violet (400 nm, 370–430 nm), blue (470 nm, 440–515 nm), green (495 nm, 475–560 nm), yellow (595 nm, 575–610 nm), red (620, 590–640 nm) and deep red (660, 620–680 nm).