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The effect of spectral composition and light intensity on melatonin, stress and retinal damage in post-smolt Atlantic salmon, *Salmo salar*

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Abstract

Metal halide lights are currently used as standard in commercial Atlantic salmon sea cages as a means of enhancing productivity through grilse inhibition. However, such systems create bright point light sources that are neither environment specific nor species specific and could potentially compromise fish welfare. Light emitting diodes (LEDs) are a new form of lighting technology currently being developed for the fish farming industry that can be tuned to environment and species sensitivities through narrow bandwidth outputs. However, prior to implementing these new high energy alternatives, any potential adverse effects must be determined in fish. The objectives of this study were thus (1) to determine the effect of increasing intensities of blue LED light (0.199–2.7 W m^{-2}, at 0.1 m from the light source) on light perception and stress response, and (2) to examine potential retinal damage under these conditions in post-smolt Atlantic salmon, *Salmo salar*. A white LED light was also tested, as well as a very high intensity metal halide positive control. Results demonstrated firstly that salmon perceived blue LED light (basal melatonin levels maintained) irrespective of intensity. Secondly, fish exposed to high intensity blue LED light showed an increase in plasma cortisol and glucose levels within 3 h, returning to a basal state 24 h post-light onset. This typical acute stress response was not observed in fish exposed to the white LED light and lower blue light intensities which could indicate differential sensitivities to spectral content of the light. No effects on the non-specific immune system (lysozyme activity) were observed. Finally, extensive histological examination of the retina from fish exposed to these various light treatments revealed no signs of damage. This demonstrates the efficiency of the adaptive mechanisms to light developed in fish.

Keywords: *Salmo salar*; Artificial light; LED; Stress; Retina damage; Photoreceptors

1. Introduction

Early maturation is a significant problem in the salmon farming industry as fish channel most of their energy reserves into gonadal development instead of somatic growth resulting in decreased growth and reduced flesh quality (Hansen et al., 1992; Oppedal et al., 1997; Porter et al., 1999; Endal et al., 2000). Photoperiod manipulation is an efficient tool to overcome this problem (Hansen et al., 1992; Taranger et al., 1998, 1999; Endal et al., 2000; Bromage et al., 2001) and as such constant lighting regimes are routinely applied in salmon cages (Bromage et al., 2001). Melatonin is known to be the key light perception hormone produced and released by the pineal gland in

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fish as in higher vertebrates with a daily light/dark rhythm (Ekstrom and Meissl, 1997; Porter et al., 1999; Bromage et al., 2001). In Atlantic salmon, the minimum light intensity required to suppress the rhythmic melatonin production is 0.016 W m^{-2} (Migaud et al., 2006). However, due to the characteristics of lighting systems used and the strong light attraction behaviour of salmon demonstrated in several studies (Juell et al., 2003; Juell and Fosseidengen, 2004; Johansson et al., 2006; Oppedal et al., 2007), fish in a cage will be exposed to a wide range of light intensities depending on their swimming behaviour within the cage system (Juell et al., 2003; Juell and Fosseidengen, 2004).

The manipulation of environmental parameters such as temperature or light unavoidably results in an abrupt change to rearing conditions which may result in a stress response compromising fish welfare and overall growth performances (Barton and Iwama, 1991; Wendelaar Bonga, 1997). Chronic stress events may also affect the long-term physiology of the fish, suppressing immune function (Pickering and Pottinger, 1987, 1989; Pickering, 1993; Harris and Bird, 2000), growth (McCormick et al., 1998; Van Weerd and Komen, 1998; Gregory and Wood, 1999; Weil et al., 2001) and reproduction (Schreck et al., 2001), and can ultimately determine survival. However, it is thought that fish are able to acclimate to persisting stress events with plasma cortisol returning to basal levels following the initial stress response (Pickering and Pottinger, 1989).

Although light has been used in the salmon industry for a number of years, to our knowledge, any potential welfare impact of the use of high energy artificial point source lights has not been studied to date. Three important areas of concern have been identified, the stress response, impact on the immune system and potential eye damage, all of which could compromise fish welfare. Preliminary data have shown, in Atlantic salmon post-smolts reared in tanks that continuous artificial lighting regimes could result in chronic elevations in plasma cortisol levels for up to 3–4 weeks (Migaud et al., unpublished data). This was accompanied by a trend for reduced feed intake, a result in line with the commonly reported “growth dip” in the salmon industry. Since salmon are visual feeders and attracted to light, it is hypothesised that high light intensities could induce retinal damage thus impairing the salmon’s ability to feed normally. Further investigations are clearly required.

Metal halide bulbs are the present source of underwater artificial lighting used in the industry, but in many aspects they are not suitable for fish farming as they are neither environment nor species specific. They create a bright point source of light, involve high running costs and much of their light energy is wasted in the form of unsuitable wavelengths (i.e. longer wavelength yellow-red light) which are rapidly absorbed in the water column and therefore cannot be detected by fish (Loew and McFarland, 1990; Migaud et al., 2006). This does however depend to a large extent on the type of water body and season. Light emitting diodes (LEDs), a new form of lighting technology being developed, can be manufactured to output specific wavelengths and thus can be matched to environment and species. In particular, it has been suggested that LEDs focusing on the blue-green spectrum will be more suitable as these wavelengths generally penetrate seawater more efficiently. Blue light (λ 450 nm) has higher energy content and as such is able to penetrate deeper within the water, reaching depths of up to 150 m in the clearest of waters (Lalli and Parsons, 1995). In addition *in vitro* and *in vivo* studies have suggested trout *Onchorhynchus mykiss* and sea bass *Dicentrarchus labrax* are more sensitive to wavelengths peaking at 450–500 nm (Max and Menaker, 1992; Bayarri et al., 2002; Migaud et al., unpublished). Furthermore, LEDs have lower power requirements, electrical running costs and a longer life span than standard metal halide bulbs. Narrow bandwidth light using such new technologies and especially high energy short wavelength could thus provide much more efficient lighting systems than those currently used in the salmon farming. However, such short wavelengths of light are considered to be much more harmful than longer wavelengths in higher vertebrates (Young, 1988; Dawson et al., 2001). Dawson et al. (2001) found that at irradiances of greater than 30 J cm^{-2}, blue LED light caused retinal photoreceptor damage in young rhesus macaque monkeys. This could be a major concern in salmon due to the strong phototactic behaviour demonstrated in this species, these fish could potentially be exposed to very high irradiance levels when swimming close to the lamps.

The ultrastructure of the fish retina has been well characterised but its sensitivity to light remains unclear. In the fish retina, light is absorbed by photopigments that are contained within two types of photoreceptor cells; rods and cones. Rods are associated with vision under low illumination and are present in large numbers or with larger outer segments in deep sea fish (Wagner and Mattheus, 2002; Wagner et al., 1998). This is thought to be an adaptation to dim, down-welling blue light. In the majority of fish, rods are not thought to be capable of colour discrimination but can distinguish differences in brightness/intensity (Kusmic and Gualtiere, 2000). By contrast, cones are involved in visual