The Significance of Environmental Light to Larval Production

Light intensity, spectrum and photoperiod have a significant effect on fish at all life stages (Boeuf and Le Bail 1999, Ruchin 2004, Han et al. 2005, Marchesan et al. 2005). The larval stage of any fish species is exceptionally sensitive to environmental conditions and newly hatched animals are particularly fragile. Light receptivity in larval fish changes during development and this affects feeding behavior, feed intake and survival (Fig. 1).

The effects of light on marine fish larvae have been studied in the laboratory (Barahona-Fernendes 1979, Puvanendran and Brown 1998, Downing and Litvak 1999a and b, Trippel and Neil 2002, Migaud et al. 2008, Yoon et al 2010, Vollset et al. 2011) and the field (Blaxter 1966, 1968, Suthers and Sudby 1996, Gibson et al. 1998). In total, this research indicates that environmental lighting is an important and complex parameter with broad effects on growth and survival of marine fish larvae.

The Effect of Light Intensity on Marine Fish Larvae Performance

The larvae of many marine fish species are born predators, suggesting that the intensity of light in the rearing environment can significantly affect survival and growth. Marine fish larvae rely on visual photoreception to establish the location of prey and poor lighting can cause abnormal eye development, resulting in decreased visual acuity (Rahmann et al. 1979, Zeutius and Rahmann 1984). Therefore, most fish larvae need a minimal threshold of light intensity to survive, which has evolved in relationship to the ability to localize, catch and ingest prey in its natural habitat. Larval-rearing environments in hatcheries usually use artificial lighting conditions that are quite dissimilar to the larvae’s natural environment. Teleost larvae need a minimum light intensity of 0.1 lux to locate prey properly (Blaxter 1986). This is a very general statement; later research has indicated that, under aquaculture conditions, finding the correct environmental lighting for marine fish larvae is a complex issue with several complementary factors to consider.

A Complex Issue: Environmental Lighting Requirements Differ with Species

Peña et al. (2004) studied the effect of environmental lighting on the first feeding stage of spotted sand bass Paralabrax maculatofasciatus. With a fluorescent lighting source, prey capture increased with light intensity. Light intensities of 0, 100, 400 and 700 lux were measured at the air-water interface and capture success was assessed by prey content in individual digestive tracts. Bass larvae were more successful at capturing prey at 400 and 700 lux than at 0 and 100 lux. Because there was no statistical difference in prey capture between 400 and 700 lux, it was postulated that there may be threshold levels of light intensity to activate feeding behavior but, once those thresholds are reached, increases in light levels do not increase feeding activity until an upper threshold negative response occurs. This research clearly showed that lighting in a specific intensity range was a factor in first-feeding activity. Inasmuch as high larval mortality is a common occurrence in aquaculture, there is a need to establish threshold light levels for larval stages of different commercially produced fish species. Compared to conventional lighting sources, LED lights can smoothly reduce intensity from 100 to 0 percent without affecting spectral output.

In the laboratory, an increase in light intensity coincided with greater success rates of prey capture by haddock larvae (Downing and Litvak 1999a). Atlantic cod Gadus morhua larvae held at high light intensity (680 lux) had lower feeding intensity than larvae held at low light intensity (8.5 lux) (Puvanendran and Brown 1998).
Increasing light intensity increased growth of European seabass, but there was an upper limit where light intensity had a negative effect (Barahona-Fernandes 1979). The larvae of different fish species may have different threshold levels of environmental light intensity (both high and low) and lack of knowledge of these thresholds can affect growth and survival.

**Timelines on Eye Structure Development**

Environmental lighting needs change during larval development, further complicating the choice of optimum light intensity ranges for larval fish rearing. In marine fish larvae, the structure of the eye is different at the beginning of the larval stage than at the end (Lyall 1957, Blaxter and Staines 1970, Blaxter 1975, Hairston et al. 1982, Raymond 1985). Rods are not part of the retina of newly hatched larvae. These specialized receptors, needed for vision in low light intensity environments, develop in the retina as larvae grow. First-feeding larvae, therefore, are strictly dependent on cone vision for prey identification and capture. Cone vision requires high levels of light intensity for photostimulation to occur. Consequently a specific light intensity in the environment can affect feed intake quite differently, depending on the age/stage of larvae.

As larval fish body size increases, visual acuity and its reactive distance to prey also increases (Blaxter 1986). Consequently, as larvae grow larger, they are also more successful at prey capture. In contrast, cod larvae reared at low light intensities during larval development had overall lower mortality rates than larvae held at higher light intensities (Puvanendran and Brown 2002). There may be critical junctures where a light intensity that was beneficial previously is no longer applicable or not as beneficial because of developmental changes (i.e. improved visual acuity) as the eye structure develops through larval development, and even through many juvenile stages. Varying light intensity levels for different stages of larval development is easily accomplished with LED lighting systems.

**Prior to First Feeding**

Light levels for marine fish larvae are important even before the start of first feeding. Herring Clupea harengus larvae at the sac-fry stage (prior to first-feeding) have lower activity levels when exposed to high light intensities (Batty 1987). This decrease in activity affects yolk consumption rate and the time to first-feeding. Higher light intensities (Puvanendran and Brown 2002) reduce the activity of fish larvae, thereby affecting the proper time for introduction of prey organisms.

Light intensity prior to first-feeding in larvae subsequently affects the survival and timing of first feeding. Atlantic halibut Hippoglossus hippoglossus yolk-sac fry developed abnormally in the presence of light and high mortality subsequently occurred at first feeding (Bolla and Holmefjord 1988). Therefore, the ability to change light intensity is important at the larval stage after hatch but before first feeding. Dimmable LED lighting systems allow the adjustment of light intensity at this stage to support optimum first-feeding activity (Fig. 2).

**Geographic Variation in Response to Light**

Most current, commercially-produced fish species are not wholly domesticated. Therefore, when devising an optimum lighting treatment for marine fish larvae, important consideration should be given to the specific conditions of the habitat of a particular species. Most marine fish species live in a variety of habitats/environments during their life cycle and have evolved to adapt to the specific physical characteristics of their environment. Light intensity and photoperiod at different latitudes might have an effect on larval growth and survival (Suthers and Sandby 1996). Differences in population performance of larval cod are related to environmental light intensity (Puvanendran and Brown 1998). In that study, cod larvae from two geographically distinct locations spawned at different times during the year. The larvae of one population experienced much higher light intensities in their natural environment than the other. Cod larvae from the populations had different feeding behavior related to environmental light exposure. Application of the natural light conditions of the geographical environment of origin affected larval culture performance.

Responsiveness of a species at the population level has been reported for other environmental parameters (Berg and Moen 1999, Jensen et al. 2000, Wilds and Muoneke 2001, Imsland et al. 2005, Conover et al. 2009, Burt et al. 2011) but the contribution and effect of environmental light on larval survival of different populations remains largely unexplored.

**The Significance of Tank Color to Larval Performance**

Environmental light intensity may improve capture success because it increases the contrast between prey and background (Peña et al. 2004). There is a broad variation in the color of larval rearing units and, for larval vision, the contrast of prey to background is variable depending on tank color. Studies have explored the effect of tank background color on larval performance (Martin-Robichaud and Peterson 1998, Downing and Litvak 1999b, Tamazouzt et al. 2000, Bransden et al. 2005, Monk et al. 2008, Jirsa et al. 2009). Unfortunately these studies have not proven whether the contributing factor(s) to better larval growth was tank color itself, the contrasting effect provided, or a combination of environmental light intensity and light spectrum with the color characteristics of the specific prey organism and tank color. Tank color should be a consideration when establishing environmental lighting conditions.
With LED lighting systems, it is possible to change light intensity and light spectrum in a single light source, and hatchery managers can establish the best light intensity and spectrum for fish reared in tanks with a specific background color. This is site specific but LED lighting allows this kind of customization in environmental lighting.

**Environmental Light and Photoperiod**

Photoperiod is the duration of light exposure during a 24-hour cycle and has an important effect on the growth and survival of marine fish larvae. Larval fish often change in response to light as they develop. Survival of early-stage cod larvae raised with continuous (24-hour) light exposure was significantly greater than that of larvae reared with a 12- or 18-hour photoperiod (Puvanendran and Brown 2002). Initially larvae subjected to continuous light exposure were larger than 12- and 18-hour photoperiod but, after a certain stage of development, photoperiod did not affect growth or survival.

For some species, longer photoperiod in early development stages may create more feeding opportunities, thereby increasing the likelihood that larvae begin exogenous feeding and have a greater success rate of prey capture. Young larvae are particularly fragile, with few internal resources for sustenance if they do not successfully transition to exogenous feeding. Early high success rate of prey capture readily translates to better growth, nutrition and survival. Longer photoperiods often stimulate increased motor activity and increases in muscle development and agility, although this can have a negative effect on growth.

However, continuous light exposure during early larval development is not recommended for all marine fish larvae. There is a variable response to photoperiod length among larvae of different fish species. The first-feeding stage of rabbitfish *Siganus guttatus* had excellent growth under continuous light exposure (Duray and Kohno 1988). The larvae of black porgy *Mylio macrocephalus* had the best survival when reared with a 13-hour photoperiod (Kiyono and Hirano 1981). Growth of European seabass *Dicentrarchus labrax* larvae was greatest with an 18-hour photoperiod (Barahona-Fernandes 1979). For black porgy and European seabass, larvae exposed to continuous light did not perform as well as larvae reared under photoperiod regimes that were more reflective of natural habitats.

Additionally there seems to be an intra-species component to the effect of photoperiod on growth of marine larvae, similar to findings on intra-species response to light intensity, that must also be considered in establishing light exposure regimes for larval fish. Under the same photoperiod regime, cod larvae from the southern range of the species (Scotian shelf region) have a lower growth rate than larvae from the more northern range (Arctic areas) (Suthers and Sundby 1996). Northern cod populations have a much longer summer photoperiod in their natural habitat and, therefore, are more active for longer periods of time and had a greater prey capture success rate. LED lighting systems with programmable controllers allow aquaculturists to specify photoperiod and light intensity levels within lighting blocks. It is no longer necessary for photoperiod exposure to be a matter of simple lights-on/lights-off control.

**Effects of Light Spectrum**

Light spectrum (color) is one of the most important but most neglected components of a lighting treatment. Current research on the effects of light spectrum on performance of marine larvae is fragmented and difficult to interpret because light treatments are not well described with respect to the lighting source used and the method and type of meter used to measure the light spectrum. At present, there is no standardized method for describing light treatments. Physical measurements of light spectrum are made at different places in the rearing environment (i.e. at the air/water interface, at certain water depths or at the tank bottom) and with light measurement tools with highly varying sensitivity because of spectral filters used. Thus, reports on benefits of certain lighting conditions are not easily replicated and overall prescriptive statements are severely limited in their application. Nevertheless, examination of past research provides insights into the effect of light spectrum on the success and performance of marine larvae.

In fish, the light spectrum is detected by the eye and pineal gland (Levin and McNicol 1982, Ekström and Meissl 1997). Light spectrum is important at a very early age of development. Similar to light intensity, light spectrum may be important for successful prey capture, enabling larval fish to better “see” the prey through contrast with the surrounding environment. This is particularly important during the earliest stages of larval growth, when visual acuity is still developing.

Because water is a natural filter of light, the light spectrum received by larvae changes with depth. Larval position in the water column can mean different spectrum experience and different contrast abilities, even within a single rearing unit.

The influence of colored light on growth rate of larval Crucian carp *Carassius carassius*, rotans *Percottus glenii* and guppies *Poecilia reticulata* was evaluated by Ruchin (2004). All larvae were from a single body of water but the fish occupy different ecological niches and have different feeding behaviors and prey items. The light intensity at the water surface was the same for each species, but the color of light in individual niches was quite different. In ponds, guppies live in the upper layers, rotans live in the middle layers and carp live in the benthic layers. There are differences in response to light in different zones experienced by different species of fish.

Using a control lamp, filters were used to subject the fish to different peak color wavelengths. All species performed best with exposure to blue and green wavelengths. Red light had a pronounced negative effect on growth: a 10 percent decrease in guppies, a 9 percent decrease in rotan and a 33 percent decrease in carp. Yellow light had a severe negative impact (21 percent growth reduction) on rotan larvae, but was not as significant with guppies or carp. Guppy performed best with blue light, rotan with blue and green light and carp with green light. Carp mainly feed on benthic organisms and rotan, which lives among thickets of vegetation, feed on zooplankton. Therefore, differences in growth rates of the two fish species may be related directly to the different degrees of contrast between background and prey present in the different microhabitats. The study clearly indicates the importance of light spectrum as an ecological parameter that can significantly affect larval culture performance.

Unlike traditional light sources, LED lights can be built to

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provide a variety of different light color outputs. Figure 3 indicates the spectral output of four LED lamps for aquaculture at 100 percent intensity. The light spectra of each lamp would be perceived as white light but each lamp would have enhanced intensity in a certain span of wavelengths (color) for a certain stage and/or species of fish that produces a favorable response in feeding activity. It is also possible to coordinate use of a LED light with particular wavelength specifications with dimming possibilities so that the lighting system can change with the changing needs of fish larvae. Figure 3 also indicates the spectral change of lamps when dimming occurs.

**Summary**

The production of high numbers of robust fish larvae and subsequent healthy juveniles represent a significant bottleneck in many marine fish hatcheries. The first-feeding period of all fish larvae, in nature and controlled culture conditions, is a critical time. Either larvae are able to identify and aptly respond to food sources in their environment by successfully capturing and ingesting enough to remain nutritionally fit or fail to consume sufficient amounts of food and subsequently die of starvation. Furthermore, pelagic larvae rely on vision to capture prey and use photoreception as a means of determining their position in the water column.

In hatcheries, finding the correct environmental lighting for marine fish larvae is complex, but is an important consideration because survival of 30 percent is not uncommon in larval fish culture. Larvae respond to light in their environment and all three characteristics of artificial environmental light (intensity, photoperiod and wavelength) contribute to successful larval rearing. Furthermore, the required timing and modulation of light intensity and wavelength spectra during larval stages varies with species.

New developments in artificial lighting using LED technology are providing hatchery managers with a broader range of control than offered by traditional lighting sources. These new technologies allow more precise manipulation and measurement of light intensity and spectrum from a single lighting system and enable aquaculturists to isolate, remove or enhance the effects that these parameters may have on larval performance. Consequently LED technology provides an opportunity to enhance larval fish production.

**Notes**

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**References**


