

The Importance of Environmental Light to the Culture of Marine Fish Larvae

by Dr. Juliette Delabbio
Director of Research and Development
ONCE Innovations Inc.
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INTRODUCTION:

Light intensity, spectrum and photoperiod have a significant effect on fish at all life stages (Boeuf and Le Bail, 1999; Han et al., 2005; Marchesan et al., 2005; Ruchin, 2004). The effects of light on marine fish larvae have been studied in both the laboratory (Barahona-Fernandes, 1979; Downing and Litvak, 1999; Migaud et al., 2008; Puvanendran and Brown, 1998; Trippel and Neil, 2002; Yoon et al., 2010), and in the field (Blaxter, 1966, 1968; Gibson et al., 1998; Suthers and Sundby, 1996). The larval stage of a fish is exceptionally sensitive to environmental conditions, and the newly hatched animal is particularly fragile. Research has indicated that environmental lighting for larval fish under culture is an important and complex parameter with broad effect on the survival and growth of the animal. To optimize performance in marine larvae aquaculture, an environmental lighting system should be designed to address 1) the specific lighting requirements of the species under culture, 2) the site-specific rearing conditions which affect the animal's response to light (Henne and Watabe, 2003; Pena et al., 2004; Villamizar et al., 2011), and 3) the human activities related to fish culture.

This paper will discuss the application of artificial lighting in aquaculture, specifically examining light intensity, light spectrum and photoperiod in relationship to marine larvae culture. New developments in artificial lighting using light emitting diodes (LED) technology are giving researchers a broader range of control beyond traditional lighting sources. The new technologies will allow more precise manipulation and measurement of the light intensity and spectrum from a single lighting system and help isolate the effects these may have on the species

LIGHT INTENSITY

The intensity of the light in the rearing environment of marine fish larvae can be a significant factor in survival and growth. The larvae of many marine fish species are born predators. These larvae rely on visual photoreception to establish the location of prey for feeding. Blaxter (1986) stated that teleost larvae need a light intensity of 0.1 lux to properly locate prey. Furthermore, pelagic larvae not only rely on vision to capture prey but these larvae use photoreception as a means of determining their own positioning in the water column.

The first-feeding period for all fish larvae, both in nature and in 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 alternatively, fail to consume sufficient amounts of food and subsequently die of starvation. In aquaculture, the first-feeding stage of many fish species is considered a bottleneck to increased aquaculture production with high mortality and reduced growth often reported (Björnsdóttir et al., 2012; Villamizar et al., 2011).

In aquaculture, finding the correct environmental lighting for marine fish larvae is complex. For instance, it is recognized that most fish larvae need a minimal threshold of light intensity to survive. This threshold intensity has evolved in relationship to

the larva's ability to localize, catch and ingest prey in its natural habitat. Larval-rearing environments in aquaculture usually present an array of artificial lighting conditions that are quite dissimilar to the larvae's natural environment, but for first-feeding success, the larvae must still be able to adequately see, hunt and capture its food.

Pena et al. (2004) studied the effect of environmental lighting on the first feeding stage of spotted sand bass (*Paralabrax maculatofasciatus*). Light intensity was found to have a significant effect, with prey capture increasing with light intensity. In this study, light intensities of 0, 100, 400 and 700 lux (measured at the air/water interface) were used. Capture success was assessed on an individual basis by prey content in the digestive tract. Pena et al. found that larvae were more successful at capturing prey at 400 and 700 lux lighting levels rather than at 0 and 100 lux. There was no statistical difference in prey capture between light intensities of 400 and 700 lux, suggesting that there may be threshold levels of light, where after which, feeding activity does not increase incrementally. The research clearly indicated that lighting in a specific intensity range was a factor in first feeding activity.

The feeding habits of first-feeding Atlantic cod larvae (*Gadus morhua*) were studied by Puvanendran and Brown (1998) under two light intensities, low lighting at 8.5 lux and high lighting at 680 lux. The cod larvae held at the high light intensity demonstrated lower feeding intensity. On the other hand, a study (Downing and Litvak, 1999) on the larvae of haddock, another north Atlantic marine fish, showed a different response in feeding activity under laboratory conditions, with an increase in light intensity coinciding with higher success rates of prey capture. Studies on light intensity and growth of European sea bass, (Barahona-Fernandes, 1979) demonstrated that light intensity contributed to better growth, but there was an upper limit where too high of light intensity had a negative effect.

Complicating the questions of species-specific lower and upper threshold light intensity and optimum light intensity ranges for larval fish, is the fact that lighting needs can change during larval development. Researchers have found that there are structural changes in the fish's eye during larval development (Blaxter, 1975; Blaxter and Staines, 1970; Hairston et al., 1982; Lyll, 1952; Raymond, 1985).

At the beginning of the larval stage, the structure of

the fish's eye is different than it is at the end of the larval stage. Rods are not part of the retina of newly hatched larvae. These specialized receptors, which are needed for vision under low lighting conditions, develop in the retina as the larvae grow. First-feeding larvae therefore, are strictly dependent on cone vision for prey identification and capture and cone vision requires high levels of light intensity for photostimulation to occur. Consequently, a specific light intensity in the environment affects feed intake differently depending on the age/stage of the larvae.

Since the eye structures continue to develop throughout the larval stage of most fish, and even through many of the juvenile stages, there may be critical junctures where a light intensity that was of benefit previously, is now, because of developmental changes (i.e. improved visual acuity) no longer applicable. Baxter (1986) observed that as a larval fish's body size increased, the visual acuity of the animal and its reactive distance to prey also increased. In parallel, this study also found that as the larvae grew in size they were also more successful at prey capture. In contrast, Puvanendran and Brown (2002) reported that cod larvae reared in low light intensities had lower mortality rates overall when compared to larvae held at higher light intensities during the entire larval stage. The required timing and direction in modulation of light intensities during the larval stage may be different for different species and is an area for future research.

Notably, some light availability during the larval stage has been shown to be necessary for proper development of vision in two fish species. Light deprivation during the early stages of development of a Tilapia (*Haplochromis burtoni*) and rainbow trout (*Oncorhynchus mykiss*) caused the eyes of the fish to develop abnormally and subsequently resulted in decreased visual acuity (Rahmann et al., 1979; Zeutsius and Rahmann, 1984).

However, there may be a maximum as well as a minimum light intensity requirement for healthy larval culture prior to first-feeding. Batty's (1987) studies on herring (*Clupea harengus*) larvae found that lower activity levels were present in newly-hatched larvae at the sac-fry stage, (prior to first-feeding), when these fish were exposed to high light intensities. Although not affecting foraging and feeding behavior at this stage, this decrease in activity with increased light intensity would affect yolk consumption rate, time to first feeding and therefore time for introduction

of prey organisms. Not surprising then, the environmental light intensity, prior to first-feeding in larvae, has been shown to have a subsequent effect on survival of larvae at first feeding. For instance, Atlantic halibut (*Hippoglossus hippoglossus*) yolk sac-fry developed abnormally in the presence of light (Bolla and Holmefjord, 1988) and subsequently, there was high mortality at the first-feeding stage.

LIGHTING REQUIREMENTS BASED ON THE SPECIES NATURAL HABITAT

In assessing a lighting treatment for marine larvae, consideration should be given to the specifics of the habitat where the fish originates. Most marine fish species live in a variety of habitats/environments throughout their life cycle and have evolved to adaptively respond to the specific physical characteristics of their environment. Suthers and Sundby (1996) speculated on the effect that light intensity and photoperiod at different latitudes might have on larval growth and survival. Subsequently, population differences in light intensity for cod larvae were demonstrated by Puvanendran and Brown (1998), with the differences in larvae growth and survival under different light intensities being attributed to "the different conditions of the environments that the organisms were collected from." (p. 212). Larvae used in this study came from two cod populations which spawned at different times during the year, so the larvae of one population experienced much higher light intensities in their natural environment than the other. In aquaculture, variance in responsiveness within a species at the population level has been reported for a number of other environmental parameters (Berg and Moen, 1999; Burt et al., 2011; Conover et al., 2009; Imsland et al., 2005; Jensen et al., 2000; Wilds and Muoneke, 2001). However, the occurrence of an intra-species phenomena is rarely considered with respect to light treatments.

TANK BACKGROUND AND CONTRAST

In addition to the development of different structures in the eye of the larval fish, Pena et al. (2004) discussed the fact that increased light intensity might improve capture success because it increases the contrast between the prey and the background. This is a particularly interesting point for aquaculture where facilities use a broad variation of colors for their larval rearing containers, and therefore, the background for larval vision is quite different. There have been several research studies done on tank background and how it affects larval performance (Martin-Robichaud and

Peterson, 1998; Downing and Litvak, 1999; Tamazouzt et al., 2000; Bransden et al., 2005; Monk et al., 2008; Jiras et al., 2009). However, these studies have not proven whether the contributing factor(s) to better larval growth was the color of the tank itself and/or the contrasting effect it provided depending on the environmental light intensity, light spectrum and color characteristics of the prey organism. Research examining the co-components of lighting character and tank background is needed in this area.

PHOTOPERIOD

Separate from light intensity, photoperiod (duration of light exposure during a 24-hour cycle) has been shown to be important to marine larvae growth and survival. Puvanendran and Brown (2002) in their studies on photoperiod and larval cod found that larvae had changing light response through development. In the early stages of development, the cod larvae raised on a 24-hour light exposure had a significantly higher survival rate than those reared on a 12-hour photoperiod or 18-hour photoperiod. Initially, the larvae from continuous light exposure weighed more and were greater in length than 12-hour and 18-hour light treatments; but in time, after a certain stage of development, the difference in light treatment did not affect growth rate or survival.

It might be speculated that longer photoperiods in the earlier stages of development create more feeding opportunities, increasing the chances that the larvae would begin exogenous feeding and have a greater rate of success at prey capture. Young larvae are particularly fragile, with little internal resource to sustain them if they are not successful in exogenous feeding. An early higher success rate at prey capture readily converts to better growth, nutrition and survival. Longer periods of light exposure often provoke increased motor activity and even though this can have a negative effect on growth, it can also be beneficial, stimulating increases in muscle development and agility.

But not all species of marine fish show highest growth and survival with continuous light in the early larval stages. Researchers have found that there is a varying response to photoperiod length among larvae of different fish species. The first feeding stage of rabbit fish (*Siganus guttatus*) showed excellent growth performance under continuous photoperiod (Duray and Kohno, 1988) while Kiyono and Hirano (1981) found that the larvae of black porgy (*Mylio macrocephalus*) had the highest survival rate when

reared under a 13-hour photoperiod and Barahona-Fernandes (1979) found that the larvae of European sea bass (*Dicentrarchus labrax*) had the highest growth under an 18-hour photoperiod. For black porgy and European sea bass the larvae subjected to continuous light did not perform as well as larvae reared under photoperiod conditions which were more natural to the fish's habitat.

Similar to research findings with light intensity, there seems to be an intra-species component to photoperiod effect on growth of marine larvae. Under the same photoperiod regime, cod larvae (*Gadus morhua*) from the southern range of the species range (*Scotian shelf region*) had a lower growth rate than larvae from the more northern range (Arctic areas) (Suthers and Sundby, 1996). Notably, the northern cod populations, in their natural habitat, have a much longer summer photoperiod, and therefore are more active for longer periods of time, thus increasing their prey capture success rate.

Therefore, it seems obvious that the natural photoperiod of an organism must be considered when determining the optimum photoperiod for larval survival and growth in aquaculture operations. And in consideration of this, there may be significant differences in photoperiod response even within species depending on the breadth of geographical range of the species.

LIGHT SPECTRUM

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, both in the lighting source used, and the method and type of meter used to measure the spectrum. At present, this research arena has no standardized method for describing light treatments, thus measurements of light spectrum are taken at different places in the rearing environment (i.e. at the air/water interface, at certain water depths or at the bottom of the tank) and with light measurement tools with highly varying sensitivities. Thus, results are not easily replicated and overall prescriptive statements are severely limited in their application. Nevertheless, an examination of some of the past research gives some insight into spectral effect of lighting on the success and performance of marine larvae.

Light spectrum is detected by the eye and pineal gland of fish (Ekstrom and Meissl, 1997; Levin and

McNicol, 1982). It is known that light spectrum is important at a very early age of development. It is speculated that similar to light intensity, light spectrum is important for successful prey capture, enabling the 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 at different depths of water. Therefore, larval placement in the water column can mean different spectrum experience and different contrast abilities even within a single rearing unit.

Ruchin (2004) looked at the influence of colored light on growth rate of larval carp (*Carassius carassius* L), rotans (*Perccottus glenii*) and guppies (*Poecilia reticulata* Peters). All larvae used in the experiment were from a single body of water. However, the fish species came from different ecological niches and had different feeding behaviors and prey items. Thus, the light intensity at water's surface would be the same for each species, but the color of the light in the individual niches would be quite different. Carp live in benthonic layers of lentic ponds, while rotans live in the mid layers of these ponds, and guppies live in the upper layers of water bodies. Ruchin's work showed there were differences in response to different colored zones in different species of fish. He used a control lamp, and then with filters subjected the different species to different peak color wavelengths. Overall, all species performed best with the blue/green wavelengths. Red light showed a pronounced negative effect; a 10 percent decrease in growth in guppies, a 9 percent decrease in rotan growth rate and 33 percent reduction in growth of larval carp. Yellow light had a severe negative impact on the growth rate of rotan larvae (21 percent lower growth rate than control light) but was not as significant with guppies or carp. Although this study was done with freshwater larval fish, the study clearly indicates the importance of light spectrum as an ecological parameter, and one that can significantly affect larval performance.

What is most interesting about the results of Ruchin's study is that the carp performed better under green light, rotan under blue and green light and the guppy under blue light. Positive growth rates with these highest ranked lighting spectra were varied with

carp showing a 42 percent increase from the control while rotan showing only a 21-23 percent increase. These carp mainly feed on benthic organisms while rotans live among thickets of vegetation feeding on planktonic organisms. The ability to distinguish the prey from the surrounding environment would be quite different for these two different fish species and therefore the difference in growth rates may be directly related to the compatibility of the light spectrum to create the necessary contrast.

Is the select spectrum and intensity only correct for the background of that rearing tank?

The question of the appropriateness of the light spectrum/intensity at the early stages of development of larval fish is therefore a question of whether there is an optimum light spectrum/intensity for that specific fish, or, is there an optimum light spectrum/intensity for the specific rearing conditions the fish is placed in, since contrast, not visual acuity, is the primary enhancer of success in prey capture at the early stages of larval development. As indicated earlier, contrast between the tank background and prey is particularly important at the first-feeding stage of larval fish when the animal is learning how to capture its food. Ruchin's study was performed in glass aquaria. Would his results have been the same with another tank background? More so, many studies on environmental lighting and its affect on larval survival and first-feeding activity fail to describe the color of the holding tank. Consequently, the application of these research findings is limited since an important environmental parameter has been overlooked.

Additionally, many research reports on the use of light treatments to improve fish performance are incomplete in their description of their methodology; they do not adequately describe all of the parameters in the lighting environment that are of significance. Research has shown that the larval fish's 1) development at the yolk-sac stage 2) level of activity at first-feeding 3) ability to "see" prey at initiation of first-feeding and 4) changing visual needs due to changes in the structure of the eye are all affected by the characteristics of the light in the environment. Characterizing light in the environment requires a description of the light intensity, light spectra and photoperiod and the color of the holding unit.

UTILIZING LED LIGHTING FOR THE CULTURE OF LARVAL FISH

Newly-developed LED lighting technology allows researchers to investigate lighting in aquaculture facilities in a much more rigorous manner than previous studies. The new technologies provide a broad range of adjustments in light intensity and spectrum in a single lighting system, something that was not possible with traditional lighting sources. Since light receptivity in larval fish changes as the animals develop, the creation of more complex lighting systems that incorporate all of the elements of lighting are quite significant to improvement of product quality in most aquaculture species. Coupling knowledge of the animal's response to light with more precise manipulation of the light with LED lighting systems should provide higher levels of survival and better growth in larvae. The end result could be invaluable in supporting the expansion of several candidate species for aquaculture.

Dr. Juliette Delabbio is Director of Biological Research and Development at ONCE Innovations Inc. Dr. Delabbio has worked in farming enterprise for over thirty years and been involved in a number of livestock industries. She has taught farming principles for two decades and directed research activities in the US, Canada and overseas. One of her research specialties is manipulation of the aquaculture environment to enhance animal production. Dr. Delabbio's educational experience includes Ph D. from Virginia Tech, M,Sc from University of New Brunswick, M,Ed from University of New Brunswick, and B,Sc from University of Guelph. Currently, ONCE Innovations is involved in a series of collaborative research projects with the objective of optimizing LED lighting systems to enhance animal performance.

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