THE EFFECT OF VARYING LIGHT INTENSITIES AND TANK COLOUR ON THE GROWTH, FORAGING BEHAVIOUR AND SURVIVAL OF ATLANTIC COD (*Gadus morhua*) LARVAE

JENNIFER GRACE ELIZABETH MONK

The Effect of Varying Light Intensities and Tank Colour on the Growth, Foraging Behaviour and Survival of Atlantic Cod (*Gadus morhua*) Larvae

By

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a thesis submitted
to the school of Graduate Studies
in partial fulfillment of the
requirements for the
degree of Master of Science
Aquaculture Program
Memorial University of Newfoundland
August 2008

St. John's Newfoundland

Abstract

One of the problems encountered with intensive production of Atlantic cod (*Gadus morhua*) is inconsistent growth and survival from hatch through metamorphosis. This could be attributed in part to a poor understanding of the optimal culture conditions required for large-scale commercial production. Studies to date have indicated that cod larvae reared under higher light intensities perform better than larvae reared under lower light intensities. The present study examined the growth, survival and foraging behaviour of Atlantic cod larvae reared under varying light conditions and tank colour. Weekly length and weight measurements were taken, and foraging behaviour was observed twice a week and the orientation frequency, number of capture attempts, number of capture misses as well as the length of time spent swimming versus the amount of time the larvae spent motionless were recorded.

In the first experiment, cod larvae were reared in three different light intensity regimes: treatment 1 used 2200 lux from 3 – 58 days post hatch (dph), treatment 2 used 2200 lux from 3 – 27 dph and 600 lux

from 28 – 58dph, treatment 3 used 2200 lux from 3 – 39 dph and 600 lux from 40 – 58 dph. The results demonstrated that larvae reared in treatment 2 had better growth at the end of the experiment in terms of standard lengths (17.7 mm) and dry weights (0.068 mg) than the larvae reared in treatments 1 (12.3 mm, 0.0338mg) and 3 (14.1 mm, 0.040 mg). Larvae reared in treatment 2 were also shown to be more efficient foragers than larvae from the other two treatments, based on the Modal Action Pattern (MAP) analysis. However, there were no significant differences in the survival between the three treatments. The results of this study indicated that beyond 27 dph it is not optimal to rear larvae under high light intensities and that the light intensity could be reduced at an earlier stage than previously thought.

In the second experiment, larvae were reared in tanks with black walls and either light (beige) or dark (black) bottoms under the light regime from experiment one that provided the best growth. Results showed no significant differences in the growth, foraging behaviour or survival of Atlantic cod larvae in response to tank bottom colour indicating that larvae can be reared in lighter bottomed tanks without

any detrimental effects to the behaviour, growth and survival of the larvae. This finding is beneficial to the culturists as light coloured tank bottoms provide the opportunity to monitor larval development and behaviour closely.

Publications:

Monk, J., Puvanendran, V. and Brown, J.A. 2006. Do different light regimes affect the foraging behaviour, growth and survival of larval cod (*Gadus morhua* L.)? Aquaculture 257, 287 – 293.

Monk, J., Puvanendran, V. and Brown, J.A. 2008. Does different tank bottom colour affect the growth, survival and foraging behaviour of Atlantic cod (*Gadus morhua*) larvae? Aquaculture 277: 197-202.

Acknowledgements

I would like to take this opportunity to acknowledge all the people that made this work possible, some of whom were the driving force and motivation behind it.

Mom and Dad, you have been in my corner from day one, supporting me in whatever it was that I chose to do. Thank you so much for giving me the courage to chose the path I wanted to take. This would not have been possible without your unconditional love and support. I love you both.

Nan and Pop, you have always been there with support, love and encouragement throughout my life in everything that I did. This was especially true throughout my education. Thank you so much for the financial support and encouragement you've both given me over the years. I love you.

Wendy and John, you both are the driving force behind me. I am so proud of you both that you make me want to strive to be a better person. Thank you both for supporting me with that dry sense of humour you both have that keeps everything in perspective. I love you both.

Juan, you were always there helping and encouraging me throughout this as you have been with everything that I do. You knew when to push me but most importantly you knew when to back off when I needed a break from it. Thank you for everything you do on a daily basis to make my life happier and easier. I love you. Besitos.

Joe, you were more than a supervisor, you were a friend and a mentor. You were the type of person we should all strive to be like. Thank you so much for encouraging me in that unique way that only you could and teaching me to keep things in perspective when things got tough, we miss you more than I can ever express.

Puvy, you are more than a supervisor to me, over the years working together you have become a good friend and a colleague that I have so much respect for. You have given me valuable knowledge and a work ethic that will be a great benefit to me throughout my career.

Laura, I can't thank you enough for stepping up and taking on the role of supervisor when I needed you. You were there to help and guide me through the final trying stages of this thesis and I couldn't have gotten through it with out you. Thank you so much.

The JBARB staff; you guys are awesome. You were all there to support me, and help me out with my experiments, understand when I needed time off to complete my course work and didn't expect anything in return. This work would not have been possible without you.

Duane, I thank you for agreeing to become part of my committee. There was no hesitation when I asked you to fill the vacated spot. You were of invaluable assistance to me and your suggestions throughout the revision process were most helpful.

Thanks to the Atlantic Innovation Fund / ACOA who provided the funding for this work.

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Dph – Days post hatch

MAPS - Modal Action Patterns

PNR – Point of No Return

s.e. – Standard Error

1.0 Introduction and Overview

In recent years, Atlantic cod *(Gadus morhua)* has been identified as a species that has great potential for commercial aquaculture production. As a result, research has focused on the development of methods and protocols directed towards successful mass production. It is suggested that the bottleneck to commercialization of marine finfish is the mass production of juveniles (Tilseth et al., 1992). One of the major problems encountered with intensive cod production is inconsistent survival and growth rates from hatch through to metamorphosis and weaning. A clear understanding of physical and biological constraints acting upon the larvae is essential to create protocols that maximize growth and survival under culture conditions (Downing and Litvak, 1999). If the problem of early growth and survival of Atlantic cod is to be resolved then further examination of the husbandry issues affecting the early life stages of larval cod should be prioritized. Light and tank background colour are important husbandry parameters that affect larval foraging, growth and survival (Planas and Cunha, 1999; Puvanendran and Brown, 2002).

1.1 Light

The limited success of intensive rearing of many marine finfish species to date is due in part to a poor understanding of the optimal culture conditions. In order to produce a large number of healthy juveniles, rearing conditions need to be better understood and consequently modified. Light is one of the least understood and most important physical parameters of the finfish rearing environment (Planas and Cunha, 1999) which influences the development from the egg stage to sexually mature adults (Mangor-Jensen and Waiwood, 1995; Hansen et al. 2001).

There have been a number of studies on the light requirements of different marine species. These studies have demonstrated that most marine fish larvae are visual feeders (Blaxter, 1986). When both olfactory and visual cues are present, the chemical stimulus is fundamental in causing the fish to orient towards the prey, whereas vision becomes important for ingestion once the fish are in close proximity to the prey (Mills et al., 1984). It appears that the early

larval stages require a "threshold" light intensity to initiate feeding with feeding incidence increasing as light intensities increase (Blaxter, 1986). Changes in light intensity may also result in a shift to feeding on food items that have different characteristics (size, motion, transparency, etc.). Mills et al. (1984) observed that young yellow perch *(Perca flavescens)* fed on large daphnids at low light intensity and shifted to smaller prey as light intensity increased.

Studies have shown that larval response to a particular characteristic of light is species specific. Bolla and Holmefjord (1988) reported that Atlantic halibut (*Hippoglossus hippoglossus)* yolk sac larvae develop abnormally in the presence of light. Saka et al. (2001) reported that Gilthead sea bream *(Sparus aurata)* performed better under low light intensities, while Downing and Litvak (1999) reported larval haddock (*Melanogrammus aeglefinus)* performed better at higher light intensities. The determination of ideal light conditions for culturing larval finfish is further complicated by the fact that there may be different light requirements for different populations of the same species. Puvanendran and Brown (1998) reported that two

populations of Atlantic cod larvae grew and survived differently under the same light conditions. The response of finfish larvae to light could also be stage specific (Bolla and Holmefjord, 1988; Puvanendran and Brown, 2002). Boeuf and LeBail (1999) suggested that fish should be reared within a light range that is appropriate for the developmental stage and the species, as too much light can be stressful and too little light could affect their foraging.

There have been a number of studies mentioned previously on the light requirements of different marine species (Bolla and Holmefjord, 1988; Puvanendran and Brown, 1998; Downing and Litvak, 1999; Saka et al. 2001). These studies have shown that larval response to a particular characteristic of light is species specific. Blaxter (1986) stated that most marine fish larvae are visual feeders and as such require a minimum amount of light in order to initiate feeding once the yolk sac has been depleted and they are making the critical switch from endogenous to exogenous feeding. Intensities below this minimum intensity will result in a failure to forage, causing starvation and eventual death. Mills et al. (1984) stated that while olfactory

stimuli played an important role in enabling larval orientation towards the prey, vision was ultimately responsible for successful capture of the prey.

Despite an impressive amount of research on the early life history of Atlantic cod larvae, only a few studies have examined the effects of light on growth and survival. Research has been conducted on the effect of light intensity on starving Atlantic cod larvae (Skiftesvik, 1994), the growth of yolk sac larvae (Solberg and Tilseth, 1987), the feeding incidence of the first feeding larval stage (Huse, 1994), and the differential responsiveness of larvae from two populations to varying light intensities (Puvanendran and Brown, 1998). Puvanendran and Brown (2002) also investigated the effects of light intensity on growth and survival of a single population of larval Atlantic cod, and they reported a higher survival rate in Atlantic cod larvae reared under high light intensities (2400 lux) than their counterparts reared under lower light intensities (600 lux). In their study, larvae reared under low light intensities also showed reduced growth when compared to those reared under higher light intensities.

However, lack of significant differences in the growth rates of larvae among the treatments after 28 dph indicated that a lower light intensity might be sufficient or even optimal to obtain maximum growth and survival during late larval stages. However, it was not known from their study at what developmental stage the light intensity should be decreased, or by how much, in order to obtain optimal growth and survival. Therefore, the foraging behaviour, growth and survival of cod larvae in response to three different light intensity regimes at different developmental stages was investigated in the present study to determine if lower light intensity at the later larval stages would be beneficial.

1.2 Tank Background Colour

If growth and survival in culture conditions are to be maximized then the physical and biological factors that affect the development of the larvae need to be examined, understood and adjusted for each individual species. One such physical parameter that has been examined for a number of species is background colour. The effects of tank background colour and light intensity on larval fish foraging,

growth and survival are contradictory (Ostrowski, 1989; Chatain and Ounais-Guschemann, 1991). In choosing a light regime for larval culture, it is not sufficient to consider just light intensity, but also how the light disperses and reflects in response to tank background colour. The reflection and dispersion properties will consequently affect the contrast between the prey and background of the tank. In a fish tank, the light is usually provided from a single direct source. When light enters the water, part of it is absorbed and part of it is reflected and scattered by particles. With the light source above the tanks being highly directive, the reflective properties of the tank walls and bottom become very important (Naas et al., 1996). In the sea, the horizontal and downward vertical visual background is dark, while prey and predators reflect light and appear lighter than the background, giving good contrast (Naas et al., 1996). Naas et al. (1996) recommended using black tanks because they provide a light regime that best represents natural conditions. They argued that in nature and in black tanks the dispersion and scattering of light particles make prey appear bright in contrast to a dark background. In white tanks, reflection of light on the sides and bottom may create an

excessively bright environment that may interfere with the vision of the larvae and consequently prey capture. Conditions that maximize contrast between prey and environment should facilitate detection and the capture of food by larvae, particularly during the critical switch from endogenous to exogenous feeding. This contrasting visual field would allow the larvae to maximize their foraging success through a series of events that include prey encounter rate, attack frequency and the consequent capture of prey (Wanzenbock and Schiemer, 1989). Many culturists also recommend the use of dark tanks for marine finfish larval rearing because the larvae tend not to accumulate along the walls, resulting in less damage to the fish due to abrasion (Naas et al., 1996). Naas et al. (1996) stated that the black tanks seemed to be the best system to provide an illusion of natural conditions. The phototactic response of fish larvae, that causes them to swim towards a genetically programmed optimal illumination, may well lead them to a reflecting tank wall or bottom (Naas et al., 1996; Martin-Robichaud and Peterson, 1998; Tamazouzt et al., 2000). If this hypothesis is true then the light walled, light bottomed tanks may be a trap. However, they also suggested that a

black walled tank with a light bottom might be an interesting alternative to consider. This new set-up would provide a lighting gradient toward the center of the tank, which would potentially bring the larvae away from the walls via positive phototaxis. This behaviour should ultimately prevent damage to the larvae due to tank abrasion.

Optimal background colour for larviculture, like light intensities, varies among species. Studies have shown that black walled tanks were suitable for rearing herring (*Clupea harengus*) (Blaxter, 1968) and turbot (*Scophthalmus maximus*) (Howell, 1979) larvae and larval striped bass (*Morone saxatilis*) reared in black walled tanks started feeding earlier than larvae reared in white tanks (Martin-Robichaud and Peterson, 1998). Conversely, haddock (*Melanogrammus aeglefinus*) larvae, did not grow and survive well when raised in a black walled tank in combination with low light intensity (Downing and Litvak, 1999) and Chatain and Ounais-Guschemann (1991) reported better growth of gilthead sea bream (*Sparus aurata*) reared in white tanks, but higher survival in black tanks. However, all these studies examined the effects of background tank colour using a similar colour

for the bottom and side of the tanks and to my knowledge did not examine a combination of different wall and tank bottom colours. A study examining different combinations of bottom and tank wall colours (for example lighter and darker bottom colours with black side walls) could provide more insight into the effect of background colour on the behaviour, growth and survival of marine finfish larvae. If a species does indeed perform better in a lighter bottomed tank, then this would be advantageous from a husbandry perspective, because larvae would be more easily detected in light coloured than in dark coloured tank bottoms thus better facilitating larval observation and the monitoring of larval development. Many larval marine fish are positively phototactic which causes them to orient towards reflective surfaces (Naas et al., 1996; Martin-Robichaud and Peterson, 1998; Tamazouzt et al., 2000), which would cause the larvae to aggregate to the walls of light coloured tanks. Martin-Robichaud and Petersen (1998) reported that striped bass were distributed more heterogeneously throughout the water column in black tanks and tended not to accumulate at the edge of the water surface and along the tank walls as they did in the white tanks.

While there has been a considerable amount of research done on larval rearing with background colour, most of it was done with light and dark tank bottoms and walls but to the author's knowledge there has been little research comparing the same coloured walls with different coloured bottoms. With this in mind, the aim of the present experiment was to determine if larvae reared in light bottom tanks with black walls performed differently than larvae reared in black walled tanks with black bottoms.

1.3 Vision

For visually dependent planktivorous larvae, small eye size at the beginning of exogenous feeding when yolk reserves are being depleted can place constraints on visual function and consequently on foraging. Within the constraint of small eye size, photopic acuity is optimized at the expense of sensitivity by the presence of a "cone only" retina (Pankhurst and Hilder, 1998). The cone only retina limits visual function to near surface waters in nature where light intensities are high. Rods and double cone photoreceptors develop within the retina following the development of single cones (Pankhurst and

Eagar, 1996). As the fish grow, this has implications for vision dependent behaviours due to the fact that cones and rods have different functional roles in fish vision. Cone photoreceptors are associated with acute visual resolution and colour contrast discrimination under photopic conditions (Ali and Klyne, 1985) while rods are specialized for non-acute visual discrimination under very low light intensity. Having a cone only retina, the visual function of pelagic larval fish is limited. This limits their visual function and consequently, they require high light intensities to detect and capture prey successfully (Pankhurst and Hilder, 1998). It is important for pelagic fish larvae that are dependent upon vision for feeding and other behaviours to be able to accommodate the visual demands associated with the habitat or environmental shift to deeper waters during their ontogenic development. The ontogenic shift in vision that usually occurs around metamorphosis has been attributed to changes in retinal morphology whereby the ratio of rods to cells in the inner nuclear layer and the cells in the ganglionic layer increase causing an increase in resolution capabilities under lower light conditions (Shand, 1997).

Several studies have indicated that most marine larvae at hatch have only a pure cone retina and that rods are added to the retina as the larvae grow (Brancheck, 1984) and the timing of the appearance of the rods depends on the species (Blaxter, 1986). Because rods facilitate vision under dark conditions (Blaxter and Staines, 1970), it has been speculated that larval cod may have developed rods in their retina by 28 dph (Puvanendran and Brown, 2002). This will enable larvae at low light to feed and grow at similar rates to larvae reared in higher light intensities after this point. With this in mind, treatment two of the first experiment examined the effect of lowering light intensity at 28 dph.

1.4 Foraging Behaviour and Growth

If feeding, growth, and survival are to be optimized, both behavioural and physiological aspects of the larvae need to be considered. If we simply look at growth, important patterns of behaviour that influence development, growth and survival may be overlooked. Behavioural observations provide a better explanation of the growth and survival of larval finfish (Laurel et al., 2001; Rabe and Brown, 2001; Brown et al., 2003). There are a number of parameters used to measure the growth of larvae. Monitoring the increase in size of the fish will give an indication of the overall success of the larvae in terms of feeding and growth. The examination of growth, however, is complicated by a number of variables that influence the ability of the larvae to grow and survive. This includes, but is not limited to, temperature, dissolved oxygen, prey density, size and quality, and the factors to be examined in this study, light and tank background colour. These factors are somewhat easy to control under experimental conditions. However, in a commercial hatchery, where everything is conducted on a larger scale, it may be necessary to alter protocols to make large

scale production more feasible. By understanding the conditions in which larval fish forage most successfully, we will be better equipped to implement rearing protocols that will enhance mass production of cod on a commercial scale.

First feeding of cod larvae occurs around 3-5 dph (Skiftesvik, 1992). The larvae then begin feeding on small zooplankton, and they must successfully capture these prey items to obtain the necessary energy and nutrient reserves that are required upon the depletion of the yolk sac. Yin and Blaxter (1987) found that the peak feeding rate and intensity in yolk sac larvae occurred on the day that the yolk sac became fully absorbed. They also observed that larvae would reach "a point of no return" (PNR) if the larvae did not initiate feeding within 3-5 days after the yolk sac is depleted. Beyond this point, the larvae will not initiate feeding and will not survive. Usually, a lack of prey of suitable concentration, type and/or size is the major cause of mortality, due to starvation, during the first few weeks after hatching. Puvanendran and Brown (1999) observed that cod larvae reared in prey densities of less than 1000 prey L^{-1} do not survive to

metamorphosis while unfavourable prey size at different larval stages would also cause larval mortality (Puvanendran et al., 2004).

Cod larvae are saltatory predators, meaning that their search for prey occurs when they are stationary and they search within the entire volume of the search space (Hunt von Herbing and Gallager, 2000). If the larva is not successful in catching prey, it will swim a short distance before it searches again. This pattern falls somewhere between cruising predators that move continuously throughout the water while searching for prey, and ambush predators that do not move for extended periods but remain still and wait for prey items to enter their search area (O'Brien et al., 1986, 1989, 1990).

The process of capturing prey requires energy (Griffiths, 1980). For larvae to grow and survive they must, to a certain extent, be able to balance the amount of energy reserves obtained from the prey with the energy expended to capture it. Hunt von Herbing and Gallager (2000) found that in Atlantic cod larvae the percentage of successful

attacks on prey increased with fish size. In all size classes successful attacks had smaller attack distances and faster attack speeds. Because unsuccessful attacks expend energy, smaller first feeding larvae seemed to prefer slow swimming prey, whereas larger larvae had higher swimming speeds and captured larger and faster prey. Therefore, throughout the larval development period one would expect to see ontogenic changes in foraging behaviour. The changes in the behaviour of larval cod start with the onset of exogenous feeding, where the level of activity increases but the swimming speed decreases (Skiftesvik, 1992). Munk (1995) reported that cod larvae seem to be quite flexible in their foraging behaviour. As the prey density decreased, the swimming activity and the responsiveness to prey increased, and prey size selectivity decreased.

The accessibility of zooplankton prey to visually feeding larvae is a function of the reaction distance to particular prey. Visual acuity and reactive distance increase with increasing light intensity (Blaxter and Staines, 1970). Increased visual acuity and reactive distances increases the prey encounter rate and thus enhances foraging

efficiency (Mills et al., 1984). Thus reduced light intensities probably influence the relative ability to detect the prey, the reactive distance, encounter rate, and searching abilities (Puvanendran and Brown, 2002).

Previous studies (Downing and Litvak, 1999; Cerqueira and Brugger, 2001; Puvanendran and Brown, 2002) showed that light intensity and tank background colour affect the foraging behaviour, growth and survival of finfish larvae. Thus in the present study, the foraging behaviour, growth and survival of larval Atlantic cod in response to three varying light intensity regimes and two different tank bottom colours were monitored with an aim to provide a better understanding of larval cod performance. It is expected that the present study would ultimately determine which light regime and bottom colour would provide maximum growth and survival of larval Atlantic cod.

2.0 Materials and Methods

2.1 General Rearing Conditions

Atlantic cod broodstock were held in captivity at the Ocean Sciences Centre of Memorial University of Newfoundland. During the summers of 2003 and 2004 fertilized eggs from two single egg batches of communal spawning broodstock were collected in an overflow collector attached to the tank. The first batch was incubated and used for experiment 1(light intensity) and the second batch was incubated and used for experiment 2 (background color). Both batches were incubated in 250 L incubators with a conical bottom with the flow set at 2-3 liters per minute and each incubator had gentle aeration to keep the eggs circulating. Temperature was maintained at 5 - 6°C and eggs were incubated under twenty-four hours of light photoperiod, with an intensity of approximately 400 lux (Puvanendran and Brown, 1998). Any dead eggs were removed daily from the bottom of the incubators. When 100% of the eggs hatched, larvae were transferred to $3m^3$ tanks that were 1.8 meters in diameter and 1.5 meters high. The tanks were stocked at a density of 50 larvae L^{-1}

(Puvanendran and Brown, 2002). Temperature in all tanks was maintained at approximately 10.5°C.The tanks were filled with seawater filtered to 20 microns using sand filtration. The flow rates were set at 2 – 3 L min^{-1} initially and were increased as needed, on every tank on the same day throughout the experimental period to a maximum of 10 L min^{-1} at 50 dph. Ten litres of microalgae (T-*Isochrysis* sp.) was added to the tanks daily for the first 14 days. The tanks were under 24 hour light (Puvanendran and Brown, 2002) using flourescent light bulbs (day light). Larvae were fed rotifers (*Brachionus plicatus)* enriched with T-*Isochrysis* sp. for the first ten days of the experiment and rotifers enriched with Algamac 2000® for the next thirty days. They were then switched to a mixture of enriched rotifers and *Artemia* for 5 days, then just enriched *Artemia* for the final five days. The *Artemia* were on a three day enrichment rotation, of DC DHA selco®, Algamac 2000® and Krill protein. Prey densities were maintained at 4000 prey L^{-1} and adjusted 3-4 times a day (Puvanendran and Brown, 1999). Prior to each feeding, a 1L sample was taken from each tank and the amount of prey L^{-1} was counted and the densities were adjusted accordingly.

2.2 Experimental Groups

2.2.1 Light Intensity Regime

The first experiment was set up to investigate the effect of three different light regimes on the foraging behaviour, growth and survival of Atlantic cod larvae. Three treatments with two replicates were assigned based on the light regime (using two General Electric 32 watt bulbs (32T8·SPX35) that they would receive during the 58 - day experimental period. Initially, all six tanks received low light (300 lux) until 3 dph. The light regime was then adjusted as follows: (i) 2200 lux from 3-58 dph (treatment 1) which was the current protocol, (ii) 2200 lux from 3-27 dph and 600 lux from 28-58 dph (treatment 2) which was chosen based on the results obtained by Puvanendran and Brown (1998) where they obtained significant differences in growth under high light intensities up to 28 dph but no significant differences after 28dph and (iii) 2200 lux from 3-39 dph and 600 lux from 40-58 dph (treatment 3) which was chosen due to a larger prey item (*Artemia*) being introduced at this time. During this experiment light intensity was measured using a lux meter (SPER Scientific

840006) which measures the amount of visible light per square meter on a surface. This is based on a subjective impression of brightness. While some larval rearing experiments measure irradiance as well as light brightness a different meter, which was unavailable to us is required to take this measurement.

2.2.2 Tank Bottom Colour

The second experiment was set up to investigate the effect of tank bottom colour on foraging behaviour, growth and survival of cod larvae. Two treatments were set up with two replicates for an experimental period of 58 days. In treatment 1, the larvae were reared in tanks with black walls and light bottoms. In treatment 2, the larvae were reared in tanks with black walls and black bottoms. All tanks were subjected to an identical lighting regime. Initial light intensity was set at 300 lux, gradually increased to 2200 lux from 3-27 dph and then decreased to 600 lux from 28-56 dph. This light regime was chosen based on the favourable results obtained from the first experiment.

2.3 Data Collection

On 1 dph, 20 larvae from each tank (40 per treatment), were arbitrarily chosen for morphometric measurements and dry weights. Thereafter, 20 larvae from each tank were sampled every seven days throughout the experiment. Using a Pixera® viewfinder camera mounted on a dissecting microscope, larvae were photographed and the digital images were analyzed to obtain standard lengths (length measured from tip of snout to end of notochord) using Matrox Inspector® software, which was calibrated using a calibration slide prior to each use. Three groups of 10 larvae per tank were rinsed with ammonium formate and suction filtered on a dried, pre-weighed Ahlstrom glass microfibre filter paper (grade 131, 2.5 cm in diameter) and dried in an oven for 24 – 48 hours at 65°C. Dry weights were measured to the nearest 0.0001 mg using an analytical scale. At the end of each experiment, the number of surviving larvae in each tank was recorded.

Behavioural observations were recorded from day 1 to day 55 dph for both experiments and were terminated when the majority of the larvae had completed metamorphosis. Metamorphosis was determined externally by the disappearance of a continuous finfold and formation of discrete fins. Twice a week, just after feeding, five larvae per tank were randomly chosen and visually followed, one at a time, for two minutes each, using the Focal Animal Technique (Altman, 1974). The occurrence of four Modal Action Patterns (MAP) (orient, success, miss and pass) or two activities (swim or motionless) (Puvanendran and Brown, 1998) were recorded using an event recorder (Psion Workabout® 1998, Psion Industrial) and the Observer® behavioural software package (version 2.0 Noldus Information Technology). A single key was pre-assigned to each MAP or activity (Table 2.1). These data were summarized and analyzed for duration and frequency using the Observer® program. During this time, the general dispersal pattern of the larvae in the water column was also noted; however, it was not quantified. All observations were made between 1000 hrs and 1200 hrs by one person (JM).

The attack frequency was determined by:

Number of Attacks = (number of successful attempts + number of unsuccessful attempts)

The capture success was determined by:

Capture success = (number of successful attempts / number of attacks) x 100

(Puvanendran and Brown, 1998).

Table 2.1: Modal Action Patterns (MAPs) for larval Atlantic cod adapted from Puvanendran and Brown (1998).

Modal Action Pattern	Description
Swim	Forward movement of larvae through the water column accomplished by caudal fin action.
Motionless	Larva is not actively swimming.
Orient	Larva is stationary and aligns itself toward a prey item.
Attempt	Larva lunges toward a prey item.
Capture	Prey item is ingested by larva.
Miss	An attempt is made but prey is not captured.
Pass	Larva orients towards prey item but does not attempt to capture, then swims in different direction.

2.4 Data Analysis

For both morphometric and behavioural data, the results for each tank in each treatment were analyzed individually, using two-way

analysis of variance (ANOVA, $p \leq 0.05$) to determine if there were differences within treatments when accounting for the interaction of treatment and age. If no tank effect was found then the data were pooled and assessed for differences among the three light intensity regimes using one-way analysis of variance (ANOVA, $p \leq 0.05$). All data were tested for normality by examining residual values. Newman – Kuels test and critical ranges were used for subsequent post-hoc comparisons among different light treatments to determine which means differed.

3.0 Results

3.1 Light Intensity Regime

Larvae reared in treatment 2 showed a noticeable increase in growth beyond 28 dph. There were significant differences among treatments in mean standard lengths ($F = 13.67$, $df = 2$, $p < 0.001$; Fig. 3.1.1) and dry weights ($F = 5.80$, $df = 2$, $p < 0.003$; Fig. 3.1.2) of the larvae. Larvae reared in treatment 2 had greater mean standard lengths (17.7 mm) than larvae from treatment 1 (12.3 mm; $p < 0.0001$) and treatment 3 (14.1 mm; $p < 0.0001$). There was, however, no

significant difference in standard length between larvae in treatments 1 and 3 (p = 0.3393). Larvae from treatment 2 had significantly larger mean dry weights (0.068 mg) than larvae from treatment 1 (0.0338 mg; p = 0.008) and treatment 3 (0.040 mg; p = 0.003) and again no significant difference between treatment 1 and 3 (p = 0.9881).

The results of the behavioural data showed significant differences in the swimming duration of in all three treatments (F = 325.81, df = 2, p < 0.0001; Fig. 3.1.3). Larvae in treatment 1 spent the most time swimming while treatment 2 spent the least amount of time swimming The amount of time spent swimming became immediately less when the intensity was decreased in treatment 2 at 28 dph. There were also significant differences in the number of times the larvae oriented towards prey among the three treatments (F = 97.96, df = 2, p < 0.0001; Fig. 3.1.4.) Larvae in treatment 2 oriented least frequently towards prey and larvae in treatment 1 oriented towards prey most frequently. Consequently, there were also significant differences in the number of prey captured (F = 186.77, df = 2, p < 0.0001; Fig 3.1.5) again with larvae in treatment 2 capturing the least number of

prey items and larvae in treatment 1 capturing the most prey items. This was also the case with number of prey capture misses ($F = 16.044$, $df = 2$, $p < 0.0001$; Fig 3.1.6). Larvae in treatment 2 missed prey less often while larvae in treatment 1 missed more frequently. There was also a significant difference in the number of times larvae oriented towards the prey item but made no attempt to capture it ($F=6.90$, $df = 2$, $p = 0.0011$; Fig. 3.1.7). General observations indicated that when the light intensity was reduced in treatments 2 and 3 these larvae became less active and were better dispersed throughout the water column. These larvae made less prey capture attempts (Fig. 3.1.8) but missed less frequently than larvae reared under a high intensity. Overall, the light regimes had a significant effect on the capture success ($F = 4.00$, $df = 2$, $p = 0.0189$; Fig. 3.1.9). There were significant differences in the capture success of larvae between treatment 1 and treatment 2 ($p = 0.0130$) but there was no significant difference in the capture success of larvae in treatments 1 and 3 ($p = 0.1247$) or treatments 2 and 3 ($p = 0.1962$).

There were no significant differences in the survival of the larvae in all three treatments ($F=3.8033$, $df = 2$, $p = 0.1504$; Fig. 3.1.10) at the end of the experiment. Larvae in treatment 1 (high light throughout) had 3.7% survival, larvae in treatment 2 (light reduced at 28dph) had 4.0% survival and those in treatment 3 (light reduced at 40dph) had 4.2% survival.

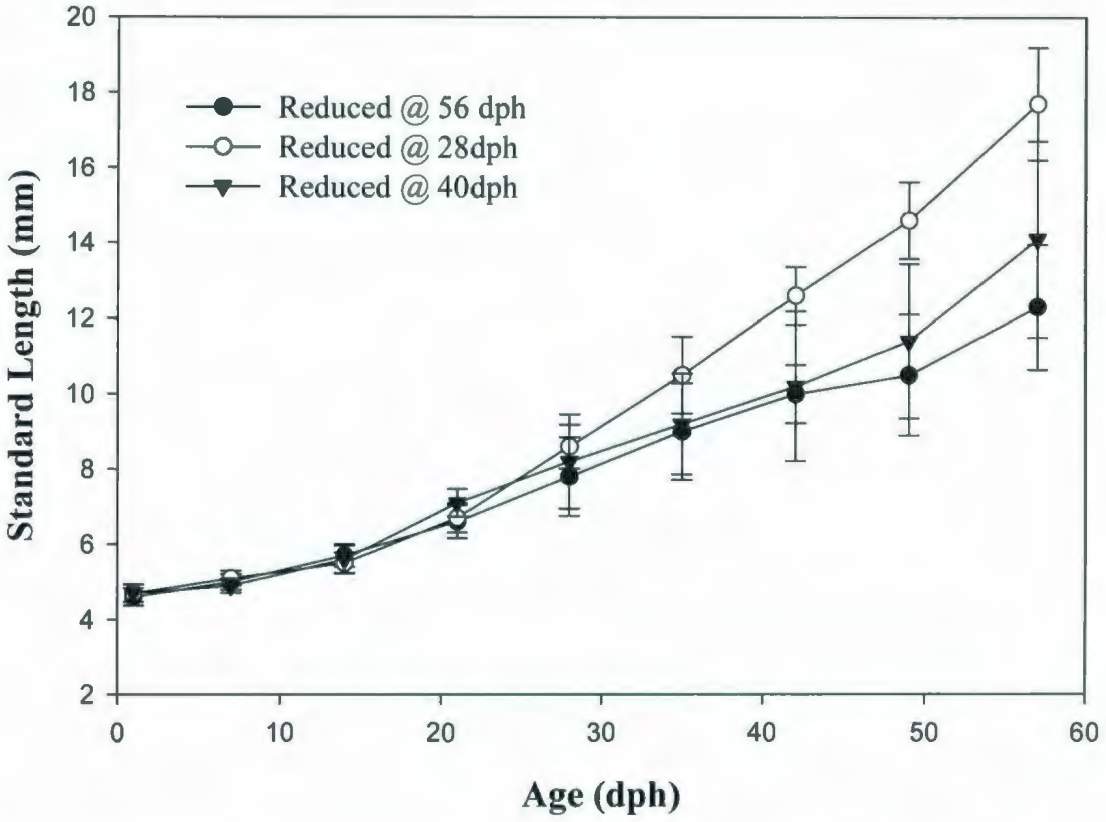

Figure 3.1.1: Standard length (mm) (mean ± s.e) of Atlantic cod larvae reared in three different light regimes. (●) Treatment 1: 2200 lux from 3-58 dph. (○) Treatment 2: 2200 lux for 3-27 dph and 600 lux from 28-58 dph. (▼) Treatment 3: 2200 lux for 3-39 dph and 600 lux from 40-58 dph.

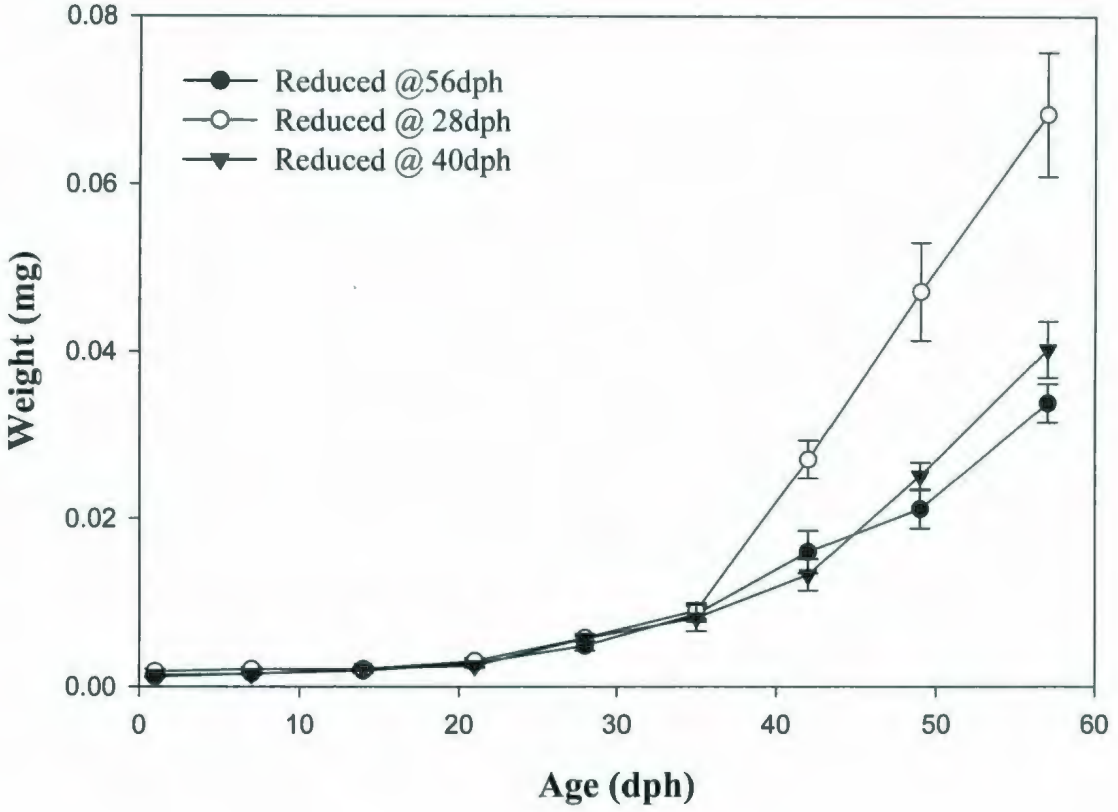

Figure 3.1.2: Dry weights (mg) (mean ± s.e) of Atlantic cod larvae reared under three different light regimes. (●)Treatment 1: 2200 lux from 3-58 dph. (○) Treatment 2: 2200 lux for 3-27 dph and 600 lux from 28-58 dph. (▼) Treatment 3: 2200 lux for 3-39 dph and 600 lux from 40-58 dph.

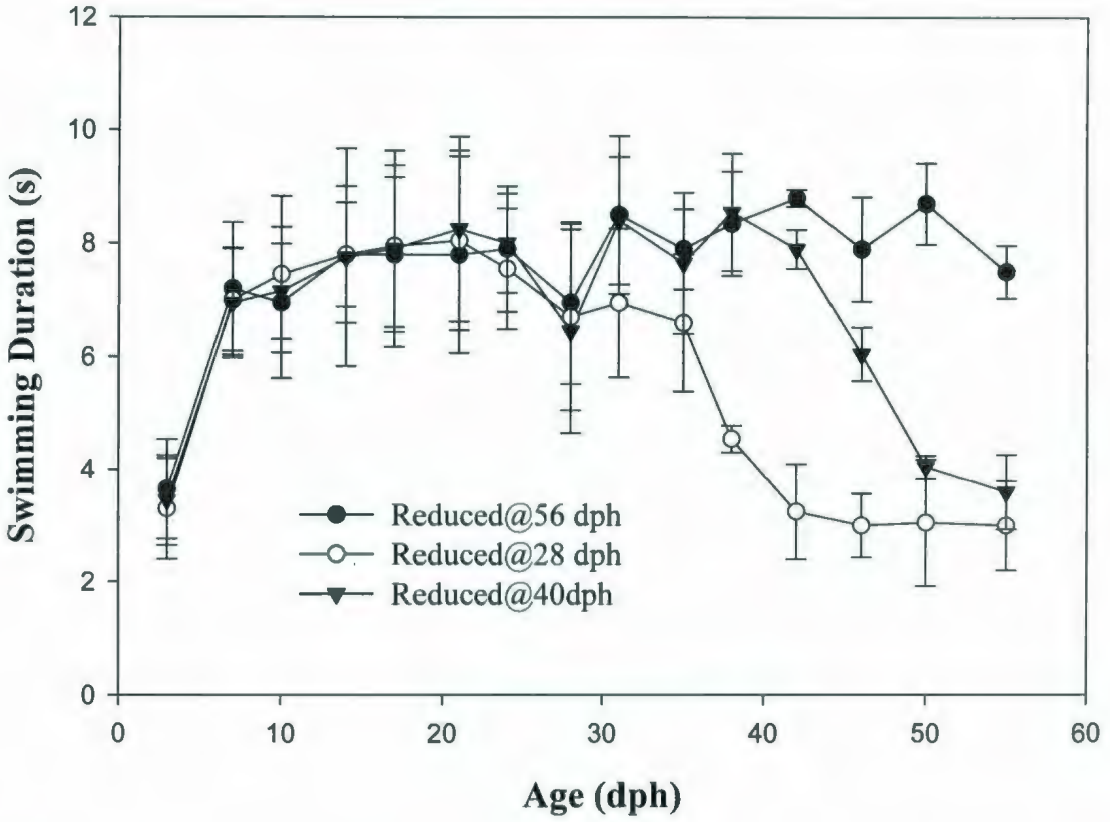

Figure 3.1.3: Swimming duration (s) (mean ± s.e) of Atlantic cod larvae reared under three different light regimes. (●) Treatment 1: 2200 lux from 3-58 dph. (○) Treatment 2: 2200 lux for 3-27 dph and 600 lux from 28-58 dph. (▼) Treatment 3: 2200 lux for 3-39 dph and 600 lux from 40-58 dph.

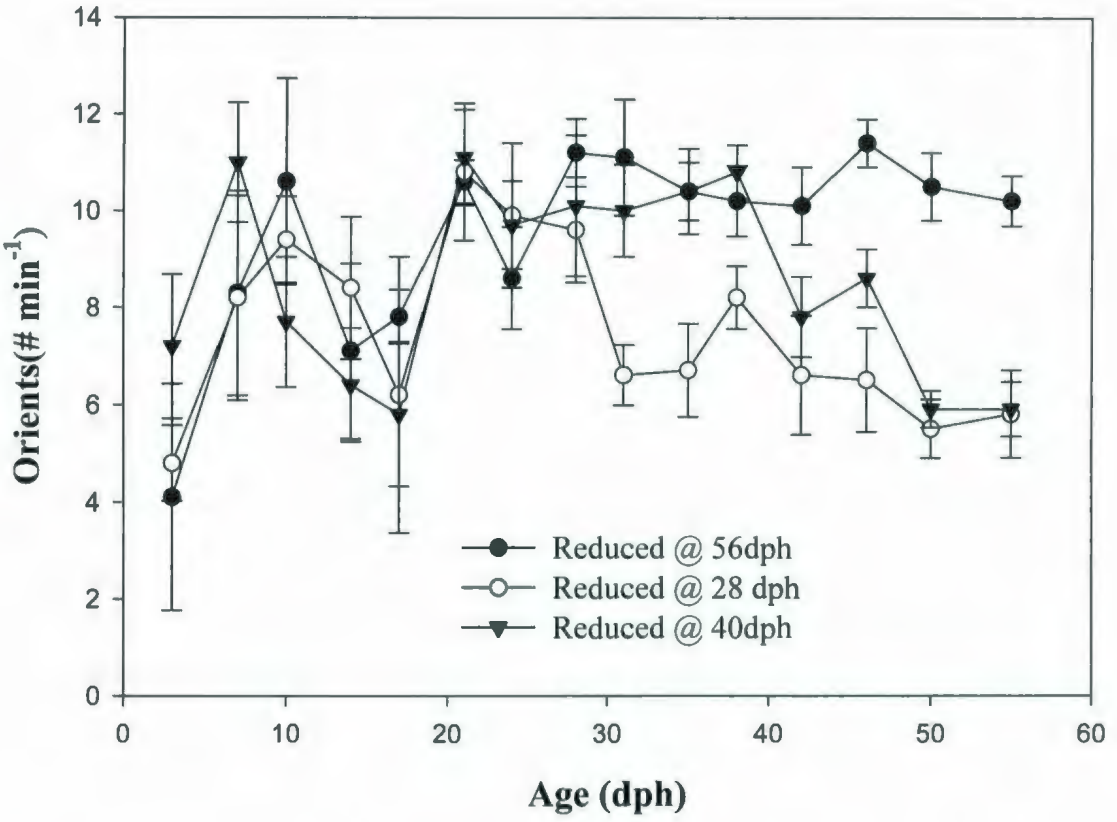

Figure 3.1.4: Orients (number min $^{-1}$)(mean ± s.e) of Atlantic cod larvae reared under three different light regimes. (●) Treatment 1: 2200 lux from 3-58 dph. (○) Treatment 2: 2200 lux for 3-27 dph and 600 lux from 28-58 dph. (▼) Treatment 3: 2200 lux for 3-39 dph and 600 lux from 40-58 dph.

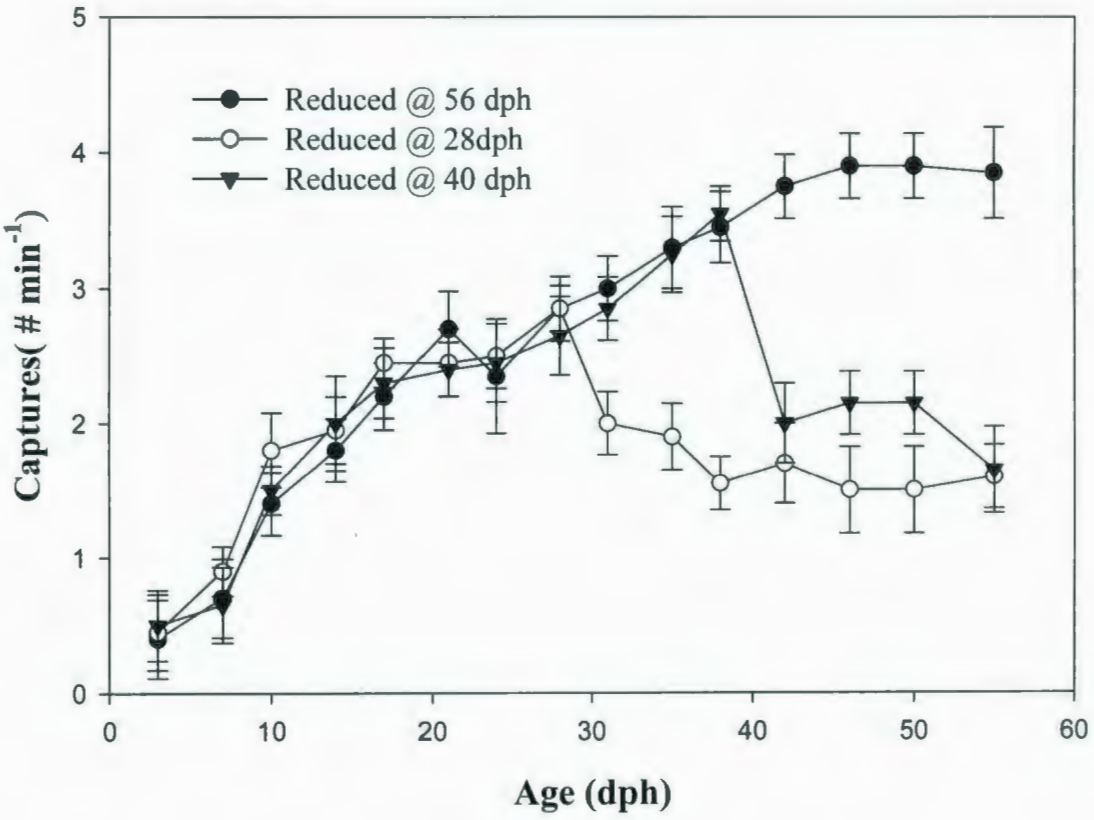

Figure 3.1.5: Captures (number min $^{-1}$) (mean ± s.e) of Atlantic cod larvae reared under three different light regimes. (●) Treatment 1: 2200 lux from 3-58 dph. (○) Treatment 2: 2200 lux for 3-27 dph and 600 lux from 28-58 dph. (▼) Treatment 3: 2200 lux for 3-39 dph and 600 lux from 40-58 dph.

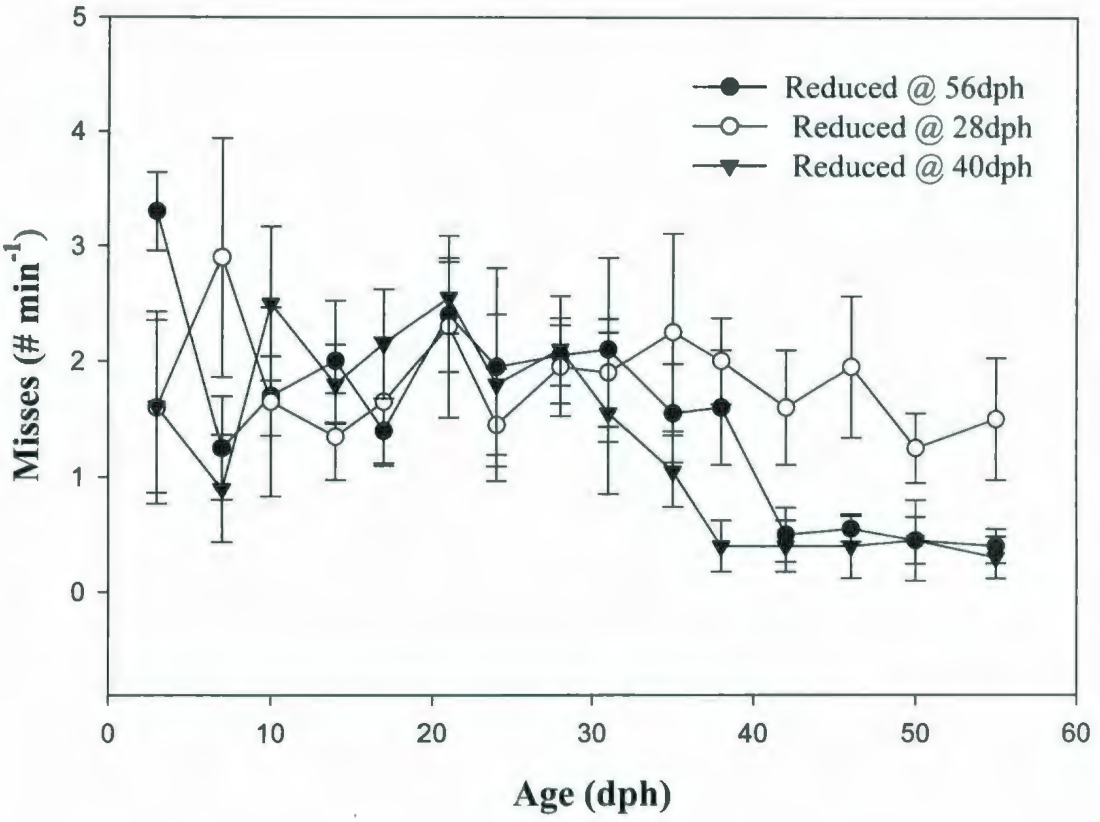

Figure 3.1.6: Misses (number min $^{-1}$) (mean ± s.e) of Atlantic cod larvae reared under three different light regimes. (●) Treatment 1: 2200 lux from 3-58 dph. (○) Treatment 2: 2200 lux for 3-27 dph and 600 lux from 28-58 dph. (▼) Treatment 3: 2200 lux for 3-39 dph and 600 lux from 40-58 dph.

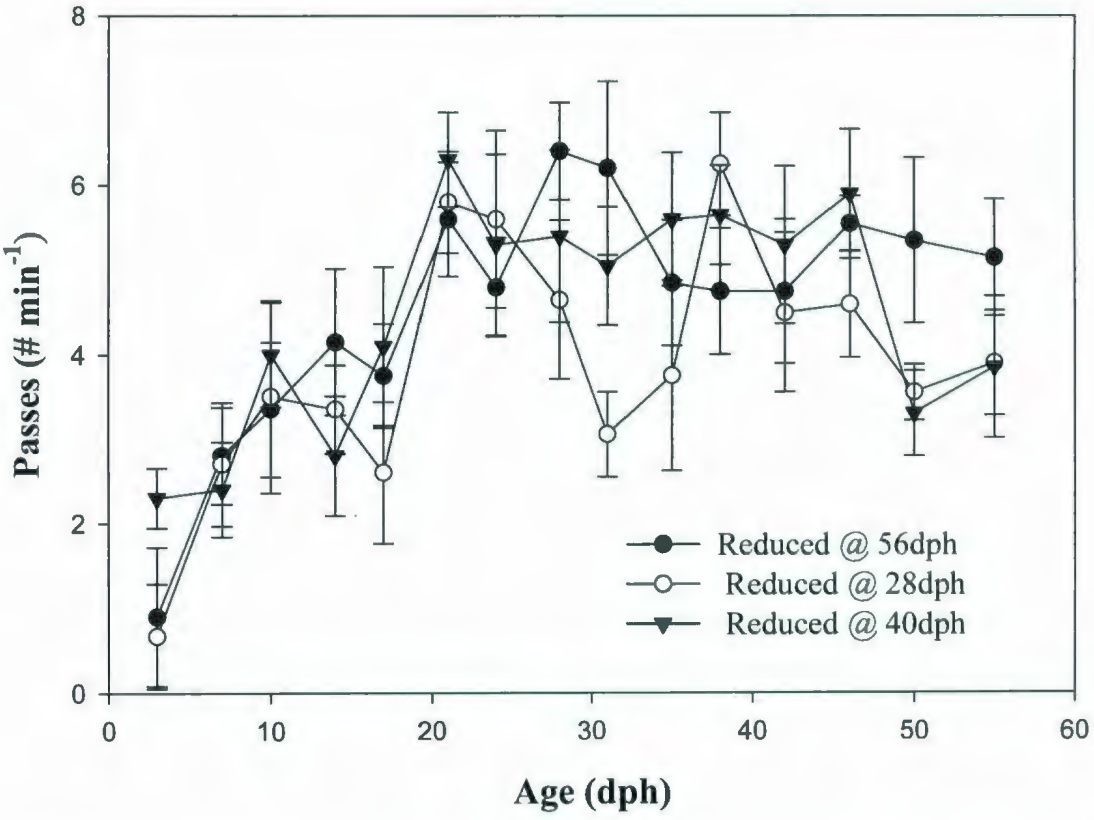

Figure 3.1.7: Passes(number min $^{-1}$) (mean ± s.e) of Atlantic cod larvae reared under three different light regimes. (●) Treatment 1: 2200 lux from 3-58 dph. (○) Treatment 2: 2200 lux for 3-27 dph and 600 lux from 28-58 dph. (▼) Treatment 3: 2200 lux for 3-39 dph and 600lux from 40-58 dph.

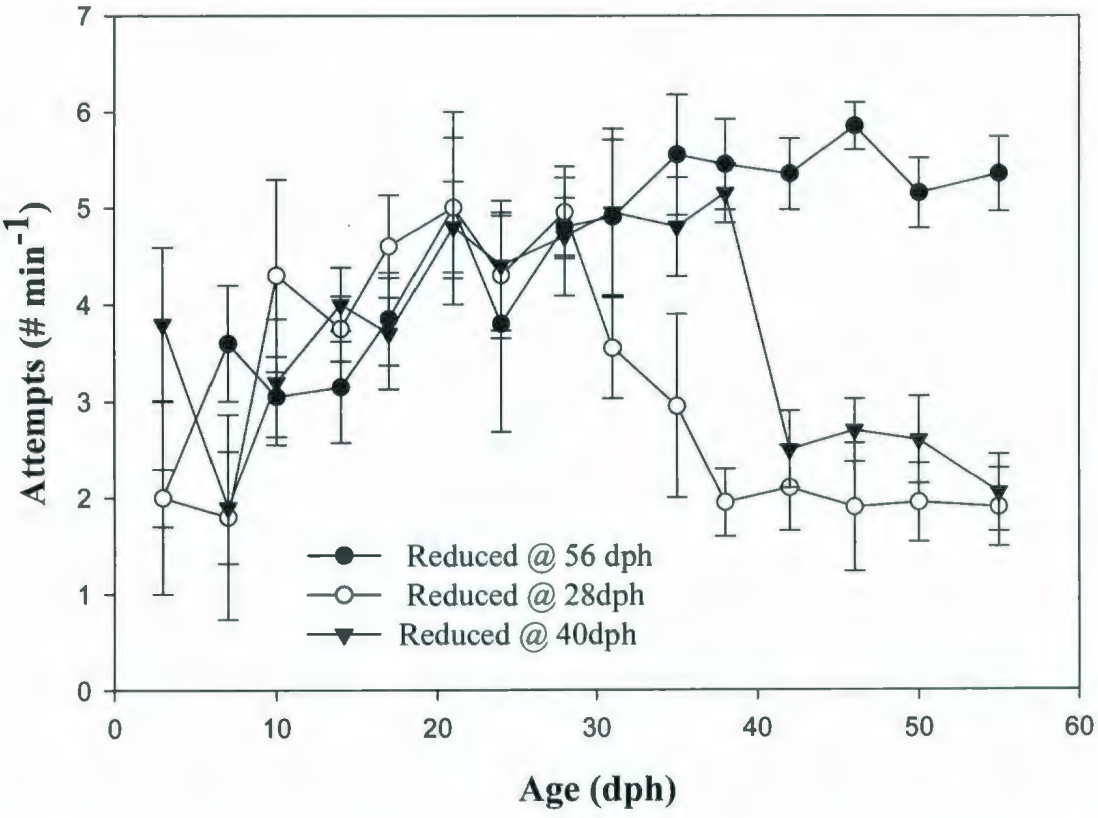

Figure 3.1.8: Attempts (number min $^{-1}$) (mean ± s.e) of Atlantic cod larvae reared under three different light regimes. (●) Treatment 1: 2200 lux from 3-58 dph. (○) Treatment 2: 2200 lux for 3-27 dph and 600 lux from 28-58 dph. (▼) Treatment 3: 2200 lux for 3-39 dph and 600 lux from 40-58 dph.

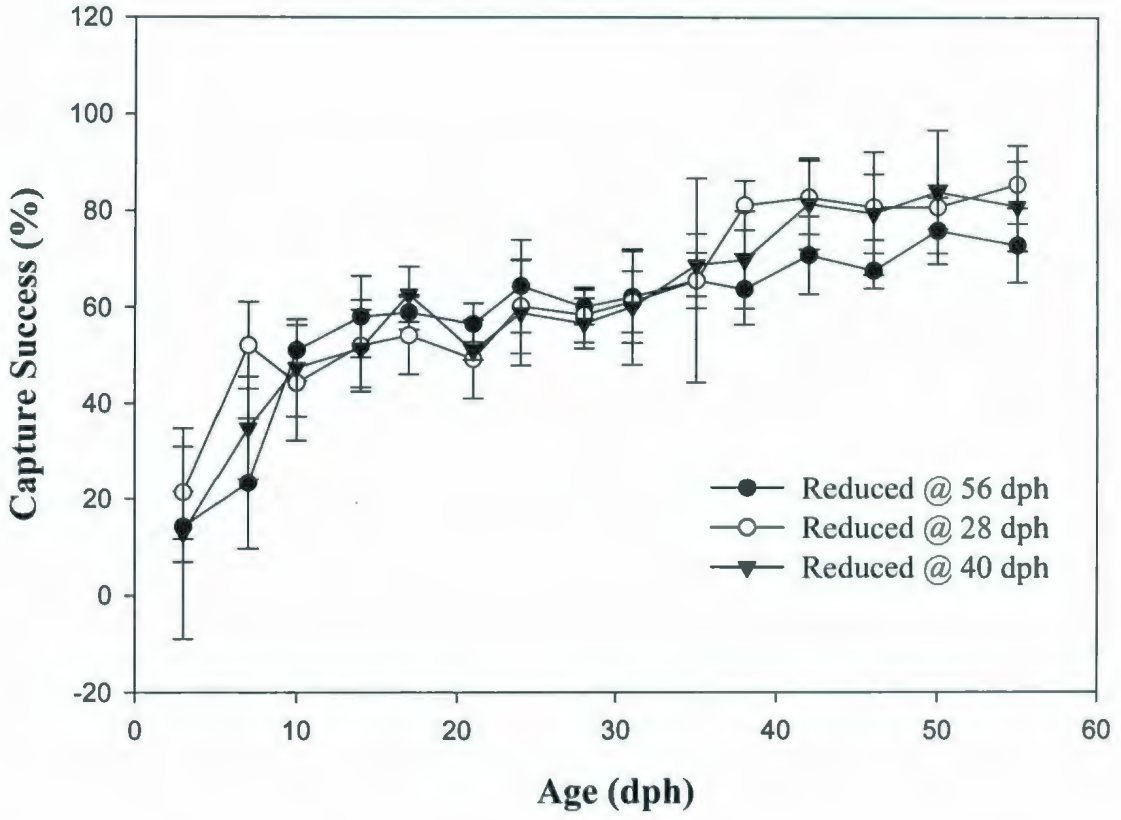

Figure 3.1.9: Capture success (%) (mean ± s.e) of Atlantic cod larvae reared under three different light regimes. (●) Treatment 1: 2200 lux from 3-58 dph. (○) Treatment 2: 2200 lux for 3-27 dph and 600 lux from 28-58 dph. (▼) Treatment 3: 2200 lux for 3-39 dph and 600 lux from 40-58 dph.

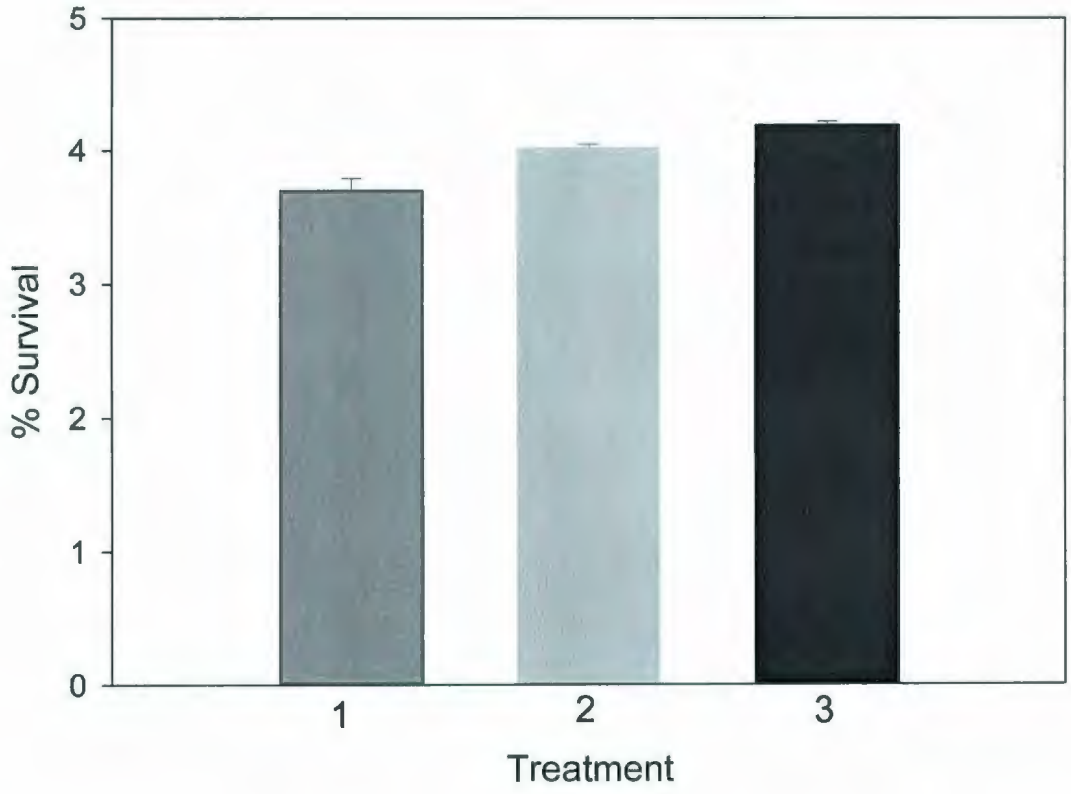

Figure 3.1.10: Survival(%) (mean ± s.e) of Atlantic cod larvae reared under three different light regimes. Treatment 1: 2200 lux from 3-58 dph. Treatment 2: 2200 lux for 3-27 dph and 600 lux from 28-58 dph. Treatment 3: 2200 lux for 3-39 dph and 600 lux from 40-58 dph

3.2 Tank Bottom Colour

There were no significant differences in the growth data of the cod larvae between all treatments. Larvae cultured in the light bottomed tanks grew equally as well as larvae cultured in the dark bottomed tanks and overall there were no differences among the mean standard lengths of both treatments ($F = 1.88$, $df = 1$, $p = 0.059$; Fig. 3.2.1). The only exception was at 56 dph when larvae cultured in the light bottomed tanks were significantly larger than their counterparts reared in the dark bottomed tanks ($p = 0.0079$). There was also no significant difference between the mean dry weight of cod larvae from both treatments ($F = 0.5841$, $df = 1$, $p = 0.79$; Fig. 3.2.2).

The results of the foraging data also showed similar trends as the morphometric data. There were no significant differences among any of the foraging behaviour of the larvae cultured in the light bottomed tanks and the larvae reared in the dark bottomed tanks. There were no significant differences between the treatments in the length of time the larvae spent swimming ($F = 0.14$, $df = 1$, $p = 0.99$; Fig. 3.2.3).

There were also no significant differences in the number of orients toward prey ($F = 0.44$, $df = 1$, $p = 0.95$; Fig. 3.2.4) or the number of attempts made to capture prey ($F = 1.51$, $df = 1$, $p = 0.11$; Fig. 3.2.5). Similarly, no significant differences were seen between treatments in captures ($F = 1.02$, $df = 1$, $p = 0.43$; Fig. 3.2.6), misses ($F = 1.18$, $df = 1$, $p = 0.29$; Fig. 3.2.7), passes ($F = 0.48$, $df = 1$, $p = 0.94$; Fig. 3.2.8) and capture success ($F = 1.07$, $df = 1$, $p = 0.38$; Fig. 3.2.9) of larvae. Finally, the number of surviving larvae in the treatments was also not significantly different ($F = 6.23$, $df = 1$, $p = 0.13$, Fig. 3.2.10).

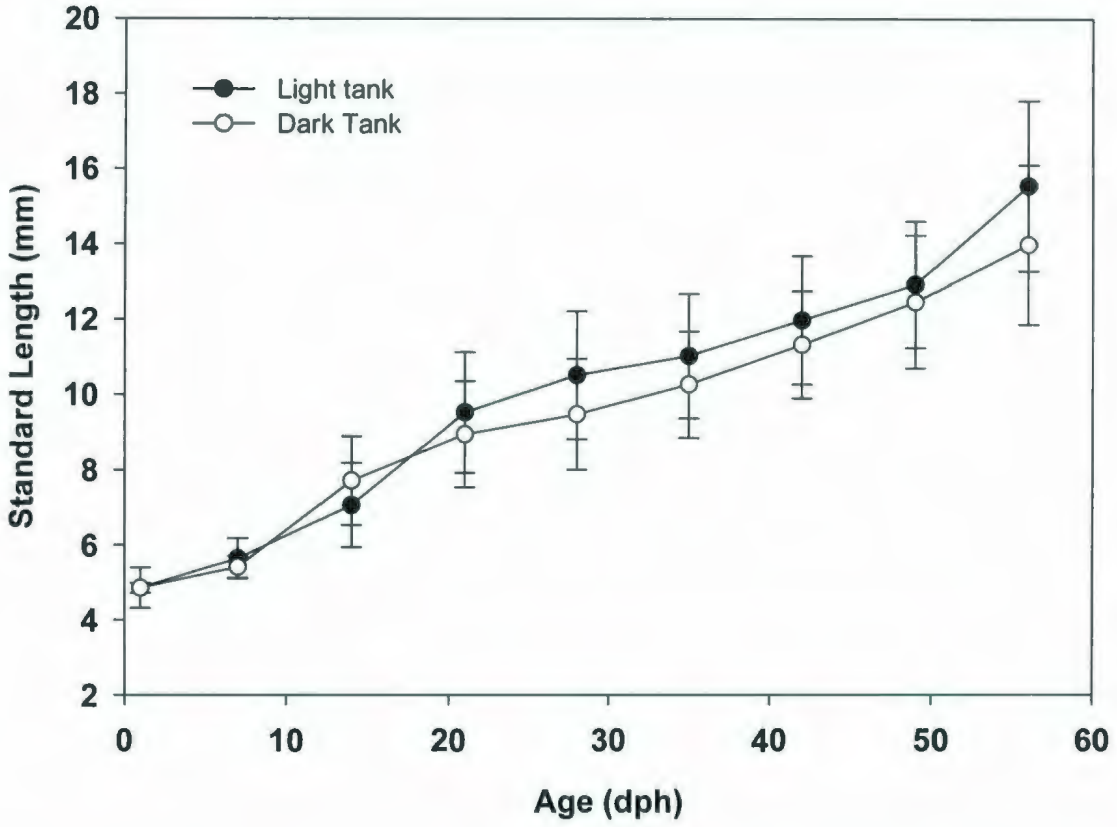

Figure 3.2.1: Standard length (mm) (mean ± se) of Atlantic cod larvae reared in two different coloured tank bottoms. (●) Treatment 1: black bottomed and black sided tanks. (○) Treatment 2: beige bottomed and black sided tanks.

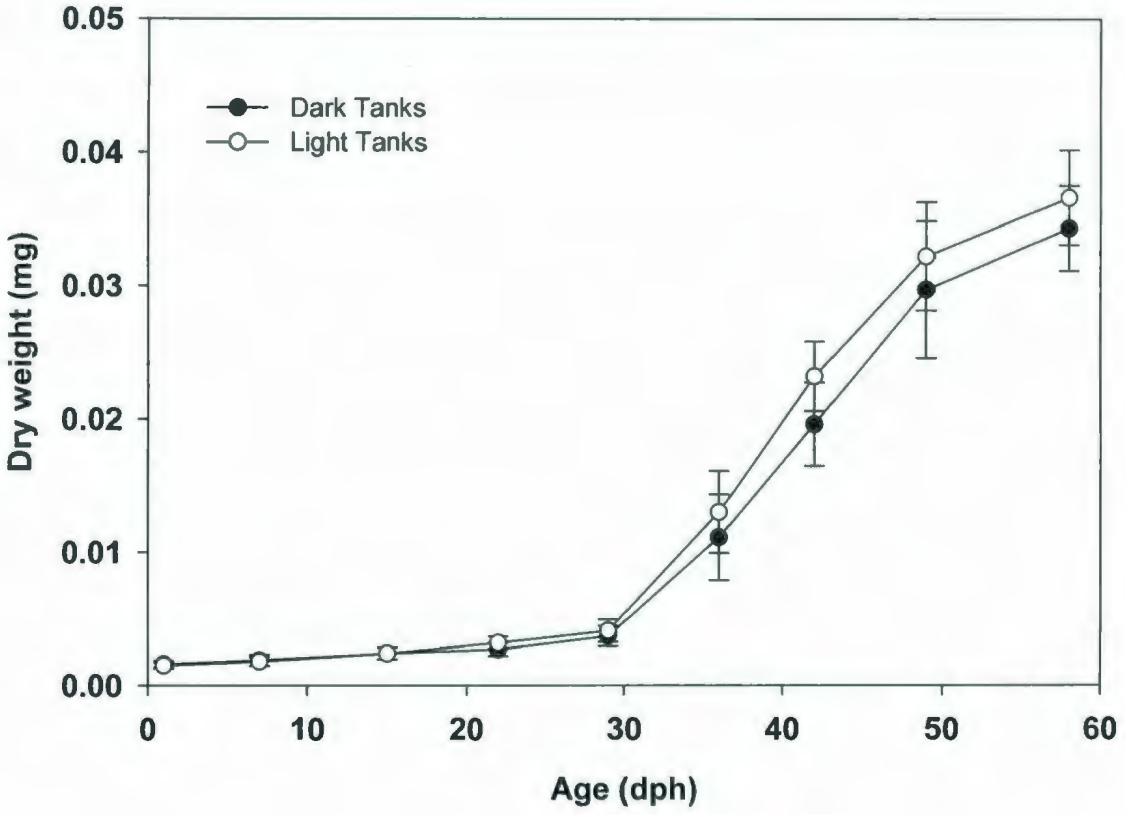

Figure 3.2.2: Dry weight (mg) (mean ± se) of Atlantic cod larvae reared in two different coloured tank bottoms. (●) Treatment 1: black bottomed and black sided tanks. (○) Treatment 2: beige bottomed and black sided tanks.

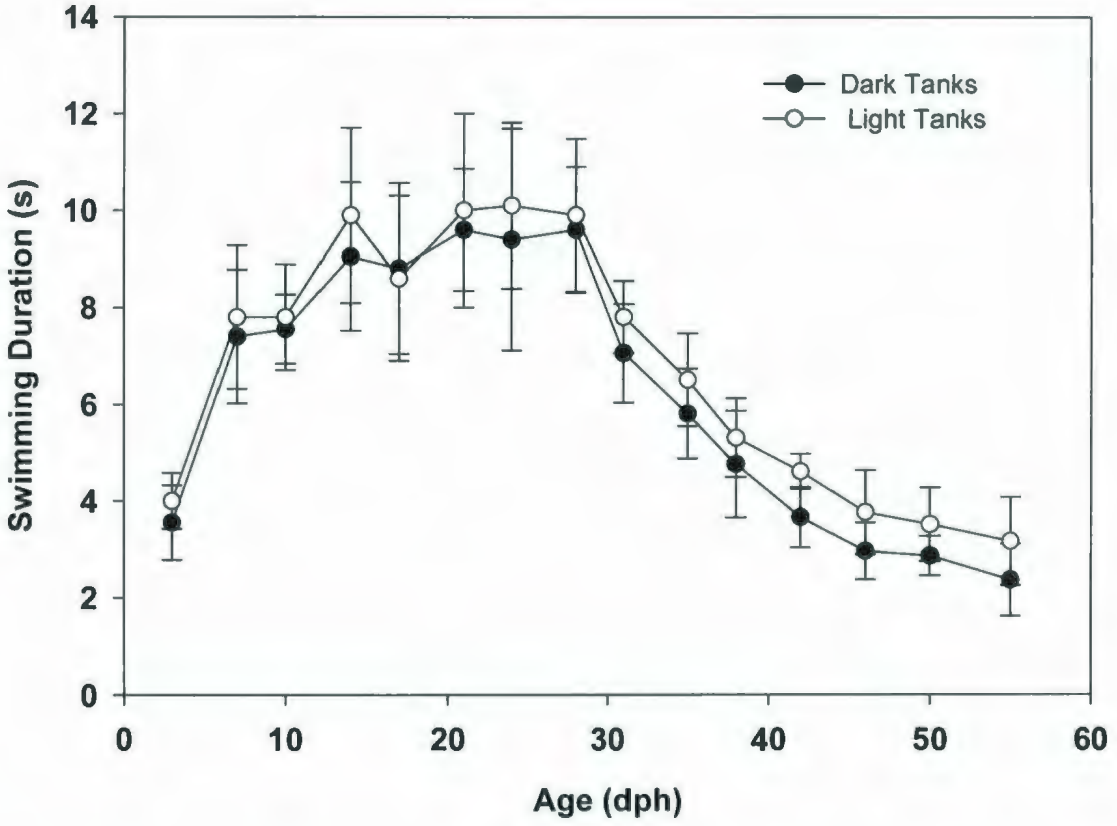

Figure 3.2.3: Swimming duration (s) (mean ± se) of Atlantic cod larvae reared in two different coloured tank bottoms. (●) Treatment 1: black bottomed and black sided tanks. (○) Treatment 2: beige bottomed and black sided tanks.

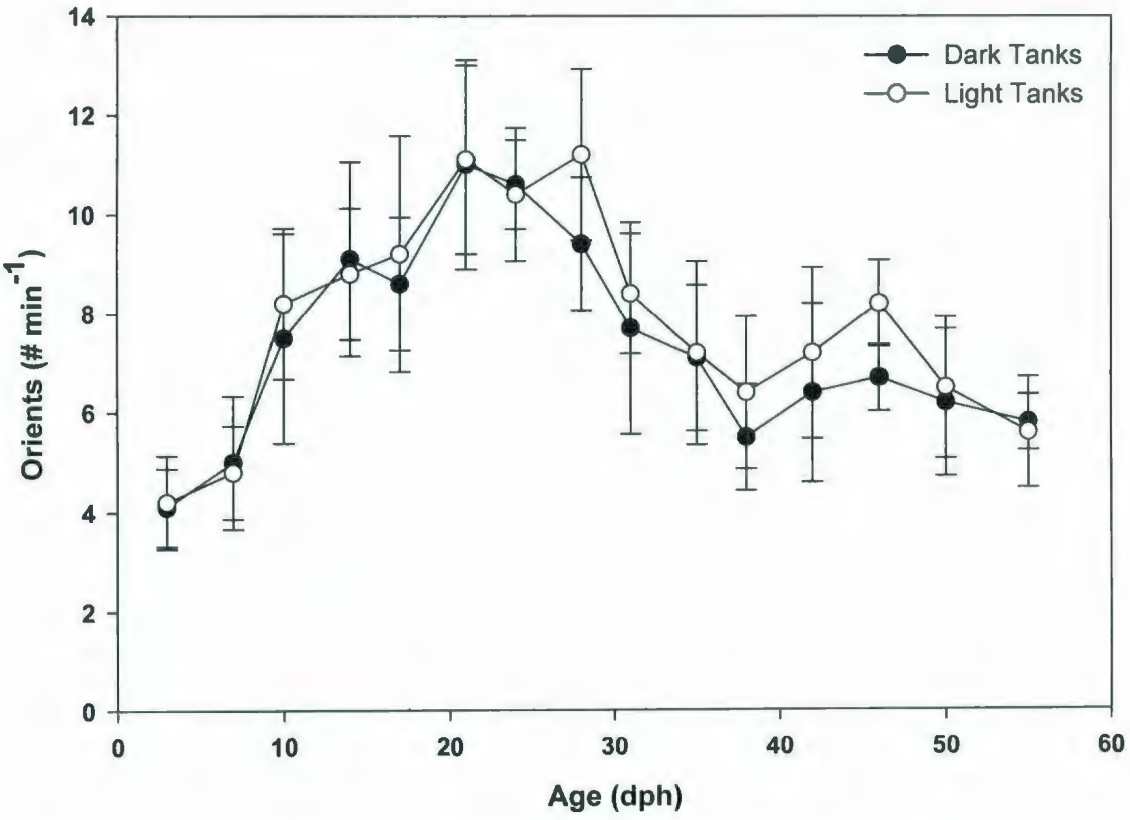

Figure 3.2.4: Orients (number min^{-1}) (mean ± se) of Atlantic cod larvae reared in two different coloured tank bottoms. (●) Treatment 1: black bottomed and black sided tanks. (○) Treatment 2: beige bottomed and black sided tanks.

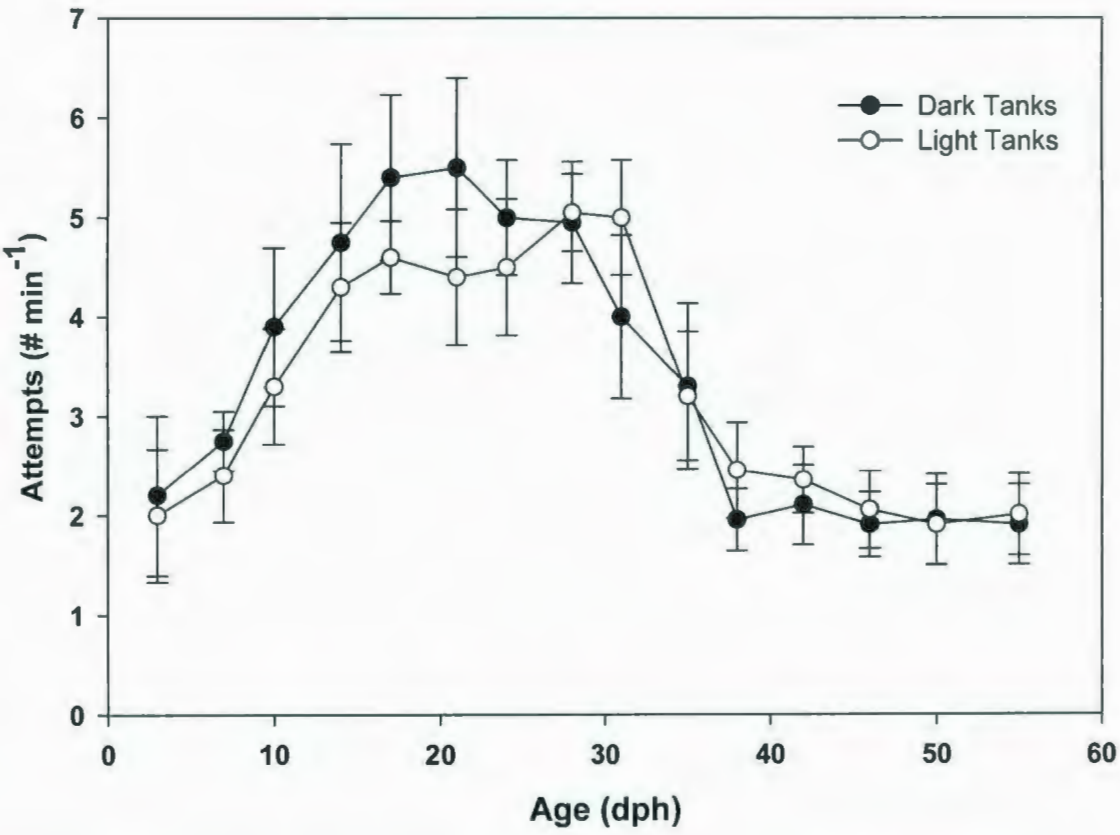

Figure 3.2.5: Attempts (number min^{-1}) (mean ± se) of Atlantic cod larvae reared in two different coloured tank bottoms. (●) Treatment 1: black bottomed and black sided tanks. (○) Treatment 2: beige bottomed and black sided tanks.

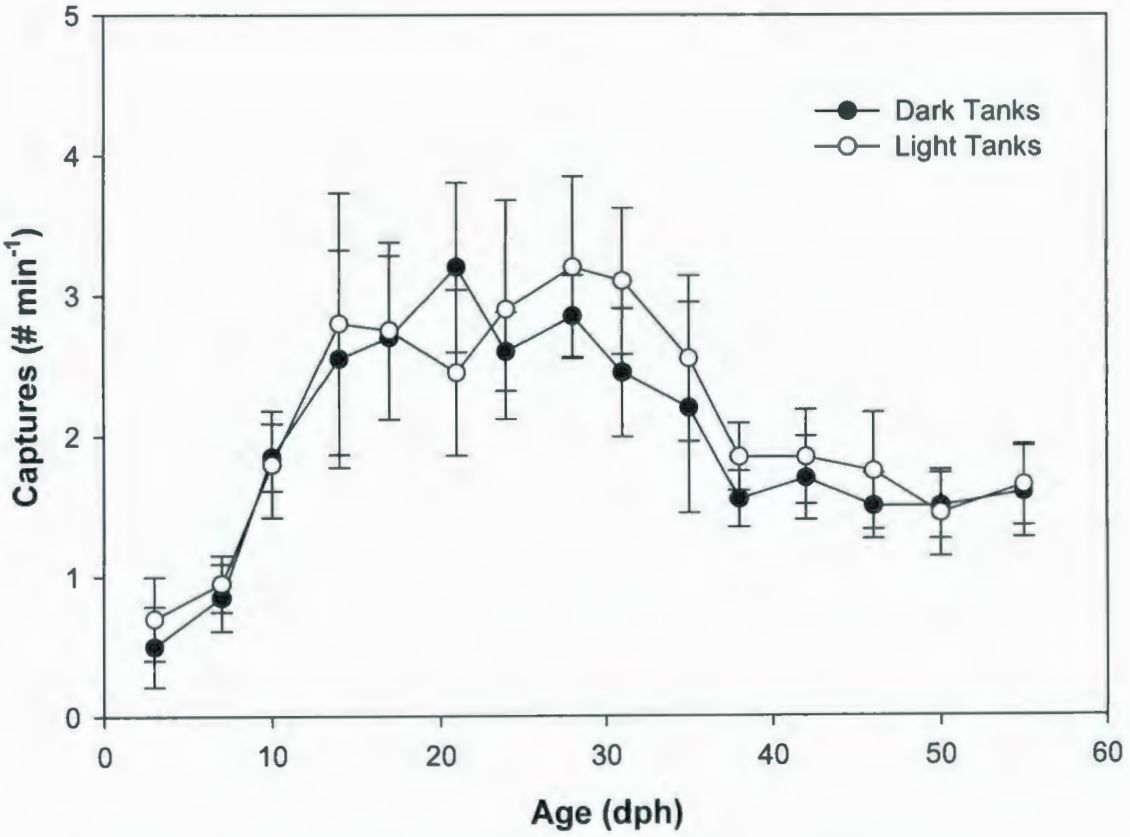

Figure 3.2.6: Captures (number min^{-1}) (mean ± se) of Atlantic cod larvae reared in two different coloured tank bottoms. (●) Treatment 1: black bottomed and black sided tanks. (○) Treatment 2: beige bottomed and black sided tanks.

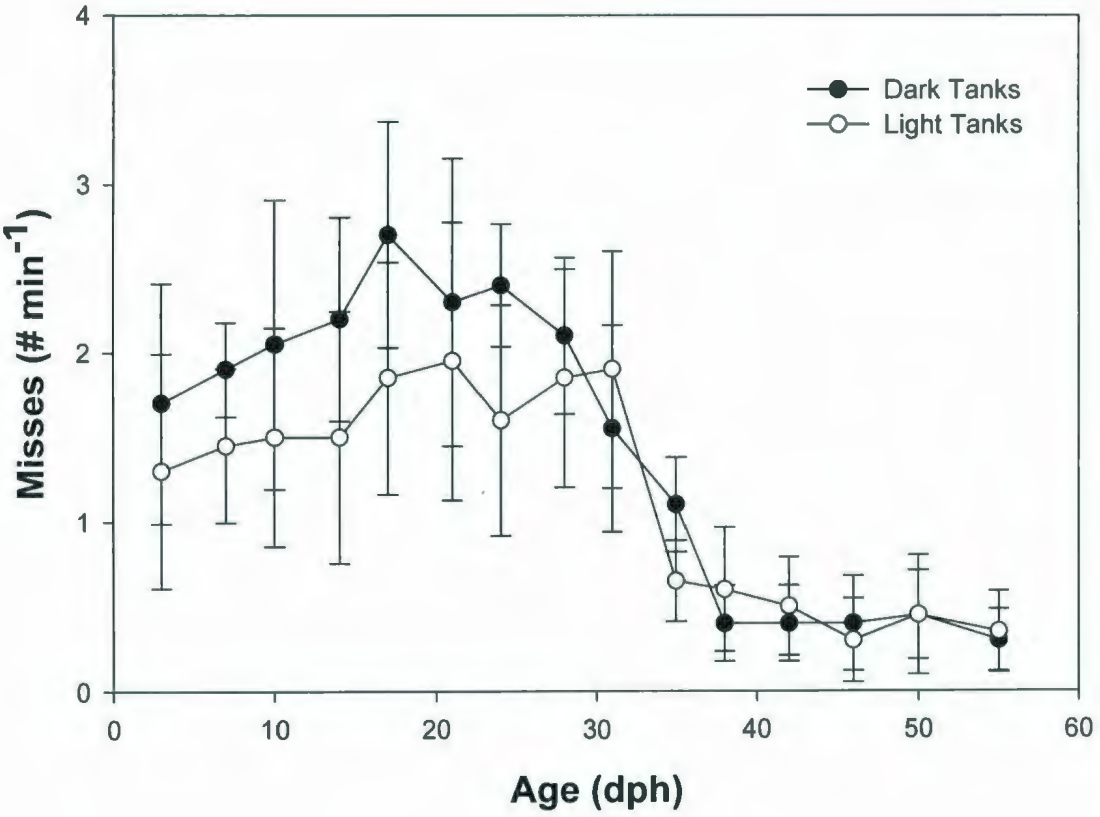

Figure 3.2.7: Misses (number min^{-1}) (mean ± se) of Atlantic cod larvae reared in two different coloured tank bottoms. (●) Treatment 1: black bottomed and black sided tanks. (○) Treatment 2: beige bottomed and black sided tanks.

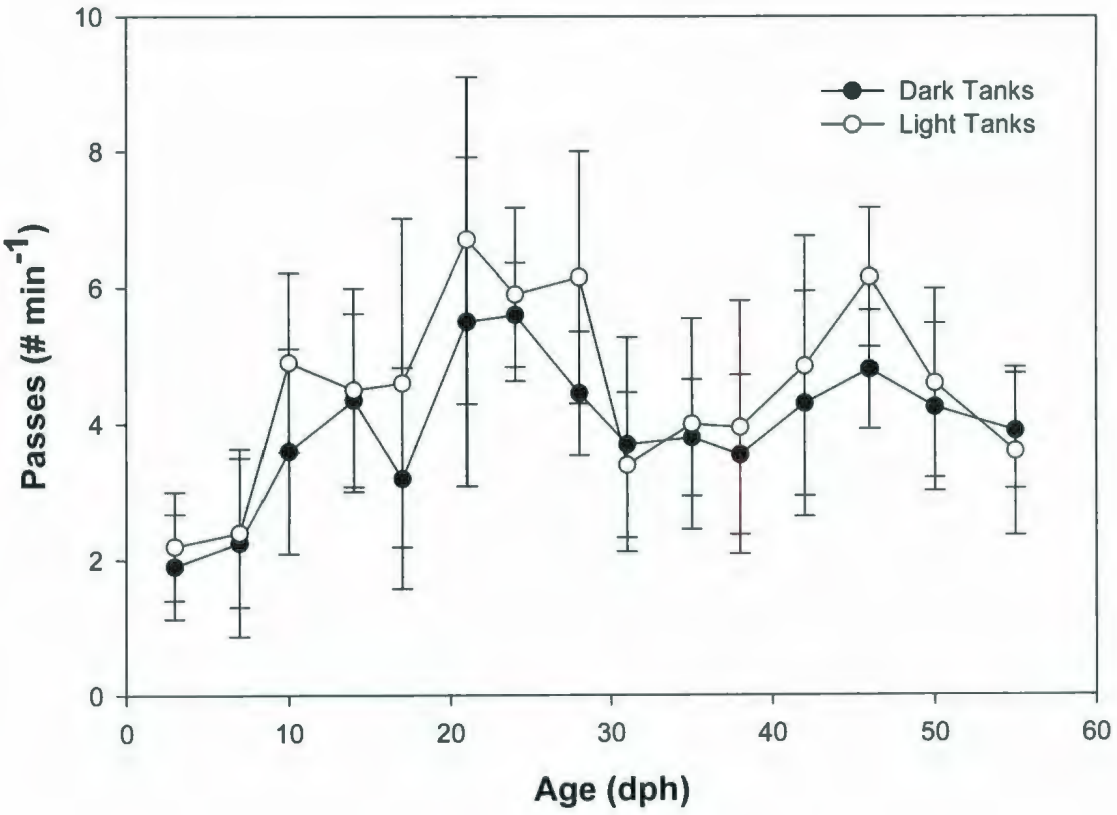

Figure 3.2.8: Passes (number min^{-1}) (mean ± se) of Atlantic cod larvae reared in two different coloured tank bottoms. (●) Treatment 1: black bottomed and black sided tanks. (○) Treatment 2: beige bottomed and black sided tanks.

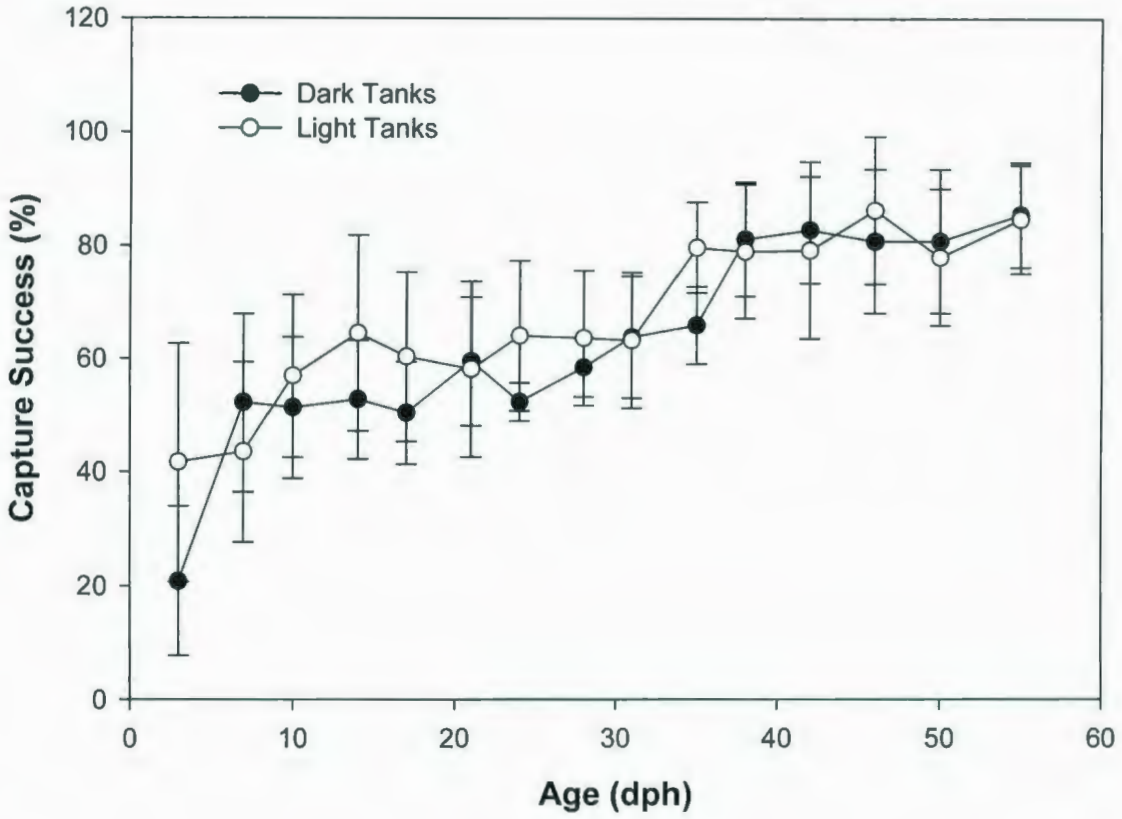

Figure 3.2.9: Capture success (%) (mean ± se) of Atlantic cod larvae reared in two different coloured tank bottoms. (●) Treatment 1: black bottomed and black sided tanks. (○) Treatment 2: beige bottomed and black sided tanks.

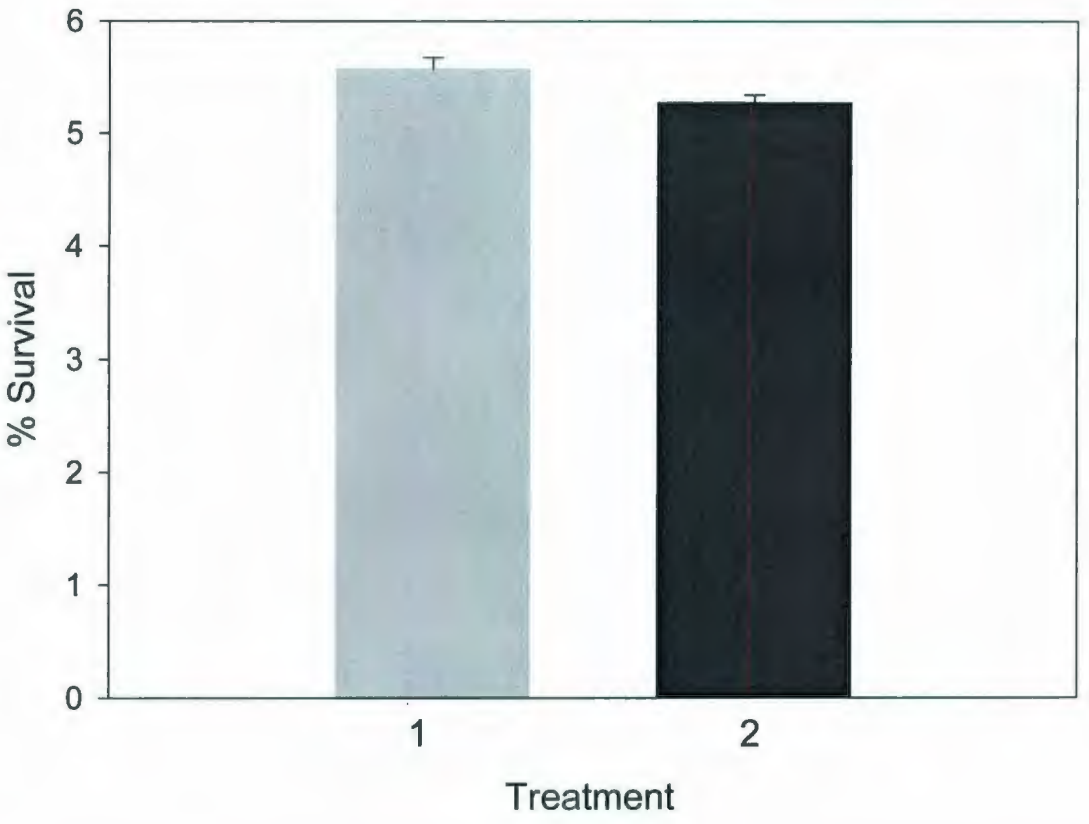

Figure 3.2.10: Survival (%) (mean ± se) of Atlantic cod larvae reared in two different coloured tank bottoms. Treatment 1: black bottomed and black sided tanks. Treatment 2: beige bottomed and black sided tanks.

4.0 Discussion

4.1 Light Intensity Regime

In experiment 1, larvae reared in treatment 2 (light reduced from 2200 lux to 600 lux at 28dph) had better growth in terms of standard length and dry weight when compared to larvae reared in treatment 1 (2200 lux from 3-58 dph) and treatment 3 (light reduced from 2200 lux to 600 lux at 40dph). The results are consistent with the results obtained by Puvanendran and Brown (2002). They reported a significant difference in the growth between cod larvae reared under high light and larvae reared under low light until 28 dph, but no significant differences in the growth of the larvae after 28 dph.

Light intensity is important in fish culture and fish must be reared within a light range that is appropriate for the developmental stage of the species (Boeuf and Le Bail, 1999). While it appears that fish larvae require a threshold light intensity to initiate feeding (Blaxter, 1986), the feeding incidence increases with increasing light intensities (Puvanendran and Brown, 2002). Boeuf and LeBail (1999) stated that at a certain age too much light could create a stressful environment and, in some cases, may even be lethal for young fish. Previous

studies indicated that reduced light can have a calming effect on other species such as fat snook (*Centropomus parallelus*) larvae (Cerqueira and Brugger, 2001), as well as larval Atlantic salmon (*Salmo salar)* and sea bass (*Morone saxatilis)* (Chesney, 1989). The results of the present experiment showed that treatment 2 produced larger larvae and more efficient foragers, indicating that reducing the light intensity during a later developmental stage would be beneficial for the larvae. The results indicated that when the light intensity was reduced in treatment 2 at 28 dph and in treatment 3 at 40 dph, the larvae spent less time swimming. Swimming in larval fish is energetically demanding (Dowling et al., 2000) and larger larvae would have a smaller Reynolds number, a dimensionless number representing the ratio of inertial to viscous forces, proportional to fish size, swimming speed, water density and inversely proportional to the dynamic viscosity (Hunt Von Herbing, 2002), which would enable them to reduce the foraging cost (Hunt von Herbing et al., 2001). Therefore, in my study, the energy conserved through reduced swimming could have been directed towards growth of the larvae in treatments 2 and 3. Once the light intensity was decreased, the larvae became better dispersed throughout the water column. The

reduced activity levels, coupled with better dispersal, could have reduced the encounter rate with other larvae and consequently would have decreased competition. This dispersal pattern was evident throughout the day even prior to feeding. It was also observed that more prey (both rotifers and *Artemia*) concentrated near the surface of the water column under high light intensities, compared to low light intensities indicating that the light affects both the larvae and the prey causing them to become better dispersed in the water column under a lower light intensity. A high concentration of prey in a given area increases the concentration of larvae, which can increase confusion and may limit prey consumption (Gulbrandsen et al., 1996; Landeau and Terborgh, 1986). An even distribution of larvae in the water column at various times during the day indicates that this dispersal pattern is not solely caused by the dispersion of the prey items.

The results showed that larvae reared in treatments 2 and 3 did not capture as much prey as the larvae reared in treatment 1. The larvae in treatments 2 and 3 also oriented less toward prey and made less attempts to capture prey in lower light. Exposure to high light intensities has been shown to increase larval swimming and food

searching activity (Batty, 1987). Increased swimming increased the predator's encounter rate with prey. Larvae in treatment 1 had higher prey encounters and eventually had increased prey captures compared to larvae in treatments 2 and 3. The possibility exists that an increase in predator-prey interactions would cause increased attempts to capture prey. This was indicated by the difference among treatments in the orientation frequency toward prey. Since cod larvae are saltatory predators (Hunt von Herbing and Gallager, 2000) any attempts to capture prey are energetically expensive. These attempts would be considerably more expensive if they result in failure to capture the prey item. The results showed that larvae reared in treatments 2 and 3 were more efficient in capturing prey than the larvae reared in treatment 1. Thus, larvae reared under low light not only conserved energy by swimming less; they would have also conserved energy by attempting to capture less prey. This increase in capture success could possibly be attributed to the extra energy that these fish have conserved from reduced swimming, reduced confusion due to less crowding of the prey in lower light, or reduced competition and aggression that the larvae experienced due to reduced encounters with other larvae.

The results indicated that in treatment 2, cod larvae captured prey more successfully beyond 28 dph and failures in capturing the prey were minimal. Marine fish larvae are mainly visual feeders and have cone cells in the retina at first feeding (Huse, 1994). During development, many pelagic fish larvae and juveniles shift to deeper water (Shand, 1993) where light intensities are considerably lower. This ontogenetic shift to deeper water coincides with changes in retinal morphology. As the larvae grow and develop, vision switches from single cone vision to double cone vision, and the cone, rod and ganglionic cell densities change (Shand, 1997). It has been proposed that the proportion of rods to ganglionic cells play a significant role in resolution under lower light conditions (Shand, 1997). In many fish this ontogenetic shift in vision occurs as the larvae become older, and usually occurs around the time of metamorphosis (Shand, 2000). Puvanendran and Brown (2002) speculated that larval cod may have developed this shift in their retina by 28 dph, thus enabling larvae at low light to feed and grow at a similar rate to fish reared under high intensity. Visual acuity and reactive distances increase with larval size (Blaxter and Staines, 1971; Shand, 2000) coinciding with

changes in visual capabilities. Morphological constraints also lessen as fish grow, in part due to increased mouth gape, larger gut capacity and increased manoeuvrability (Gill and Hart, 1996) and this enables an increase in successful prey captures. Mills et al. (1984) reported that young yellow perch (*Perca flavescens*) selectively fed on large daphnids at a low light intensity but switched to smaller prey as intensity increased. This indicates that as the larvae grow they may require less light to detect prey items. Thus decreasing the light intensity at 28dph will provide a less stressful, less distracting environment for the larvae to forage, while still providing sufficient light to enable efficient foraging, which in turn enables the larvae to direct more energy towards growth.

The present results showed no significant differences in the survival of the larvae among the three treatments. The difference in size, however, may play a significant effect on survival during the grading process, which occurs usually between 60 and 65 dph. This is a very stressful procedure and usually results in a number of mortalities. Past experience in our culture facility indicates that larger cod larvae show a higher survival through this process.

It is important to note that many larval rearing experiments conducted measure light in microeinsteins as well as lux. Microeinsteins measures the quantity of radiant energy in Avogadro's number of photons whereas lux measures the amount of visible light in accordance with the colour sensitivity of the human eye and as a result certain wavelengths may go undetected. The conversion between lux to microeinsteins depends upon the light source.

4.2 Tank Bottom colour

The results of experiment 2 demonstrated that Atlantic cod larvae can be cultured in both black and light bottomed tanks without any significant differences in the growth, foraging behaviour or survival of the larvae. These results are consistent with results obtained by Downing and Litvak (1999) who reported that the growth of larval haddock was not impaired in white tank treatments compared to dark tank treatments. These results are also consistent with results obtained by Papoutsoglou et al. (2000) who indicated no differences in the body weight of scaled carp in response to black, green and white backgrounds. Duray et al. (1996) also found that grouper larvae can be reared in both tan and black tanks. However, due to the

contradictory results obtained for other marine finfish species on a combination of background tank colours, the optimal background colour and lighting should be examined and tailored for each individual species. Most of the previous experiments examined the larval growth and survival in response to dark tank walls and bottoms or light tank walls and bottoms. To my knowledge, no studies have investigated larval response to dark walled tanks in combination with light coloured bottoms. This study investigated the behaviour, growth and survival of larval cod between tanks with dark walls and bottoms to tanks with dark walls and light coloured bottoms, and found no significant differences in the growth, foraging behaviour or survival between Atlantic cod larvae reared in these two treatments.

The results of this experiment are of great significance to cod culturists as this will enable the use of lighter bottomed tanks, which in turn will better enable the culturist to observe the larvae and monitor the behaviour and development, without any adverse effect on larval growth and survival.

The probability of prey detection in fish is proportional to reaction distance (Confer and Blades, 1975). There are a number of factors that influence reaction distance in larval fish, including predator size (Blaxter and Staines, 1970), physical conditions of the rearing environment such as light level, background colour and turbidity, and prey characteristics such as size, mobility, contrast and colour (Utne-Palm, 1999). Visibility of a prey depends upon the ability of the fish to detect contrast between prey and background (Utne-Palm, 1999). Thus, it is suspected that larval fish, with their smaller reaction distance, would benefit from the increased prey contrast provided by a dark background. Increased visual contrast will result in enhanced prey detection at close range. High visual contrast of prey items, achieved by a dark background, improved prey consumption in larvae of yellow perch, *Perca flavescens* (Hinshaw 1985) and striped bass, *Morone saxatilis* (Martin-Robichaud and Petersen, 1998). Fish larvae tend to keep a horizontal position in the water column (Hunt von Herbing and Gallager, 2000). Thus, as discussed previously, a foraging larva would be able to detect rotifers and *Artemia* against a dark wall with a light coloured tank bottom. According to Naas et al. (1996), a tank with a black wall and light coloured bottom could

provide a light gradient towards the center of the tank, thus, keeping the larvae away from the walls. This combination (i.e. dark walls and light coloured bottoms) will provide optimal culture conditions, in terms of larval feeding. At the same time, the light coloured bottoms will be beneficial to culturists as it will better enable them to monitor larval behaviour, development and tank conditions during the critical early larval stages.

In the present experiment cortisol levels in response to different background colours was not measured. However, several other studies examined tank background colour and stress in fish and showed that lighter or white backgrounds tend to increase the stress level and affect the social interactions of fish (Arends et al., 2000; Höglund et al., 2002; Rotllant et al., 2003). Rotllant et al. (2003) showed that red porgy (*Pagrus pagrus)* that were previously adapted to dark background tanks handled stress better in crowded conditions compared to fish previously adapted to white backgrounds. In our experiment, considering that the prey contrast may not be different which was suggested by similar foraging behaviours, growth and survival in both treatments, the difference in tank bottom colour might

not have caused any stress to larval cod from both treatments., It may, however be beneficial to examine this in a future experiment to determine if larvae exposed to light bottom tanks are indeed stressed since elevated stress levels over a prolonged period may cause increased incidents of disease.

5.0 Conclusion

When rearing Atlantic cod larvae, reducing the light intensity at 28 dph would provide a less distracting environment which would, in turn, provide the larvae with the opportunity to become more efficient foragers and to direct excess energy toward growth. Thus, reducing light at an earlier stage than was previously thought will improve growth and shorten the critical early larval period for Atlantic cod. Furthermore, Atlantic cod larvae can be reared in tanks that have dark sides and light bottoms, with similar growth, foraging behaviours and survival to larvae reared in tanks with dark sides and dark bottoms. This finding indicates that the culturist can use a light bottom colour without any adverse effect on the growth, survival and foraging behaviour of the developing cod larvae which will enable enhanced monitoring of larval development.

6.0 Summary

Atlantic cod *(Gadus morhua)* has been identified as a species that has much potential for commercial production. However, there are several constraints such broodstock nutrition, the mass production of healthy juveniles, and early maturation that are currently affecting the

commercialization of this species. The mass production of healthy juveniles has been identified as one of the major constraint and has been attributed to low and inconsistent survival and growth rates during the larval stage. A better understanding of the optimal larval culture conditions of this species will help in overcoming this problem. One such culture condition that required further investigation was that of lighting in the culture tanks. Light intensity and tank background colour interact with each other to change the environment in the culture tanks through the dispersal and reflection of light, thus, it is important to consider both light intensity and tank background colour when choosing a light regime for larval culturing. It is not sufficient just to consider light intensity, but also how the light would be dispersed and reflected in response to tank background colour. The reflection and dispersal properties consequently affect the contrast between the prey and background of the tank. In a research or laboratory environment, many of the culturing conditions and protocols are established. However, in a commercial hatchery, where everything is conducted on a much larger scale, it may be necessary to alter and refine protocols to make large-scale production more feasible. By understanding the conditions in which larval fish forage

more successfully, it is easier to implement rearing protocols that will enable the mass production of cod on a commercial scale. With this in mind, all experiments conducted in this study were carried out using large commercial size tanks and foraging behaviours were observed to complement the growth data to better understand how tank colour and light intensity affect larval performance. The present study investigated the growth, foraging behaviour and survival of Atlantic cod larvae in response to three varying light intensity regimes and two different tank bottom colours to determine which light regime and tank bottom colour would provide maximum growth and survival. The results indicated that larvae reared in a light regime that provided high light (2200 lux) until 28 dph and then a reduced light intensity (600 lux) had better growth in terms of standard length and dry weight when compared to larvae reared in high light (2200 lux) for the entire experimental period (56 dph) or larvae reared under high light to 40 dph and then reduced light for the remainder of the experimental period. The results of this experiment also showed that larvae reared in 2200 lux were also more efficient foragers, which indicates that reducing the light intensity at an earlier developmental stage than previously thought is beneficial for the larvae. The behavioural results

indicated that when the light intensity was reduced the larvae spent less time swimming and became better dispersed throughout the water column. When the light was reduced at 28 dph the larvae spent less time swimming, made less attacks on prey and missed less frequently. This strategy would have enabled the larvae to conserve energy foraging and to invest it in their growth.

In response to differing tank bottom colour there were no significant differences in the foraging behaviour, growth or survival between the larvae reared in black bottomed or light bottomed tanks. These results are of great significance to cod culturists as this will enable the usage of lighter bottomed tanks, without any adverse effect on the larvae, which will better enable the culturist to monitor larval behaviour, development and tank conditions during the critical early larval stages. Thus, the set up of dark walls and light bottoms will provide optimal culture conditions in that the black walls will provide a good background for prey contrast to help the larvae with prey detection.

7.0 Future Research

While the results of the present study provide Atlantic cod culturists with some interesting information regarding the optimal light rearing conditions and background colour when culturing larval cod, there are other factors that need to be considered. One area that could be investigated further are other combinations of light intensities with tank colours i.e. light bottoms and walls in combination with high and low light intensities as the light will be reflected differently in tanks with lighter walls than in those with darker walls. An alternative set-up that may be worth examining in more detail would be whether there are any differences in the growth, survival and foraging behaviour between larvae reared in tanks with light bottoms and black walls and larvae reared in tanks with light walls and light bottoms. It would also be a good idea to look at cortisol levels in relation to background colour to identify if one environment is more stressful to the larvae than the other.

8.0 References

Ali, M.A. and Klyne, M.A. 1985. Vision in Vertebrates. Plenium Press: New York, 272pp.

Altman, J., 1974. Observational study of behaviour: sampling methods. Behaviour 91: 449-459.

Arends, R.J., Rotllant, J., Metz, J.R., Mancera, J.M., Wendelaar Bonga, S.E. and Flik, G., 2000. α-MSH acetylation in the pituitary gland of the sea bream (*Sparus aurata* L.) in response to different backgrounds, confinement and air exposure. Journal of Endocrinology 166: 427-435.

Batty, R.S. 1987. Effect of light intensity on activity and food searching of larval herring, *Clupea harengus*: a laboratory study. Marine Biology 94: 323-327.

Blaxter, J.H.S. 1968. Rearing herring larvae to metamorphosis and beyond. Journal of the Marine Biological Association of the United Kingdom 48: 17-28.

Blaxter, J.H.S. 1986. Development of sense organs and behaviour of teleost larvae with special reference to feeding and predator avoidance. Transactions of the American Fisheries Society 115: 98-114.

Blaxter, J.H.S. and Staines, M. 1970. Pure cone retina and retinomotor responses in larval teleosts. Journal of Marine Biology Association of the United Kingdom 50: 449-460.

Bolla, S. and Holmefjord, I. 1988. Effect of temperature and light on development of Atlantic halibut, *Hippoglossus hippoglossus,* larvae. Aquaculture 74: 355-358.

Boeuf, G. and LeBail, P. 1999. Does light have an influence on fish growth? Aquaculture 177:129-152.

Brancheck, T. 1984. The development of photoreceptors in the zebrafish II: Function. Journal of Comparative Neurology 224: 116-122.

Brown, J.A., Minkoff, G., and Puvanendran, V. 2003. Larviculture of Atlantic cod (*Gadus morhua*): progress, protocols and problems. Aquaculture 227: 357-372.

Cerqueira, R.C. and Brugger, A.M. 2001. Effect of light intensity on initial survival of fat snook (*Centropomus parallelus* Pisces: Centropomidae*)* Larvae. Brazilian Archives of Biology and Technology 44: 343-349.

Chatain, B. and Ounais-Guschemann, N., 1991. The relationships between light and larvae of *Sparus auratus.* In: P. Lavens, P. Sorgeloos, E. Jaspers, and F. Ollevier (Editors), Larvi '91 – Fish and Crustacean Larviculture symposium, August 27-30 1991, Ghent, Belgium European Aquaculture Society, Special Publication 15: 310-313.

Chesney, E.J. Jr. 1989. Estimating the food requirements of striped bass larvae, *Morone saxatilis:* effects of light, turbidity and turbulence. Marine Ecology Progress Series 53: 191-200.

Confer, J.L. and Blades, P.I. 1975. Omnivorous zooplankton and planktivorous fish. Limnology and Oceanography 20: 571-579.

Dowling, N.A., Hall, S.J. and Mitchell, J.G. 2000. Foraging kinematics of barramundi during early stages of development. Journal of Fish Biology 57: 337-353.

Downing, G and Litvak, M.K. 1999. The effect of photoperiod, tank colour and light intensity on growth of larval haddock. Aquaculture International 7: 369-382.

Duray, M.N., Estudillo, C.B. and Alpasan, L.G. 1996. The effect of background color and rotifer density on rotifer intake, growth and survivalof the grouper (*Epinephelus suillus)* larvae. Aquaculture 146: 217-224.

Gill, A.B.and Hart, P.J.B. 1996. How feeding performance and energy intake change with a small increase in the body size of the three spined stickleback. Journal of Fish Biology 48: 878-890.

Griffiths, D. 1980. Foraging Costs and Relative Prey Size. The American Naturalist 116: 743-752.

Gulbrandsen, J., Lien. I.and Holmefjord, I. 1996. Effects of light administration and algae on first feeding of Atlantic halibut larvae, *Hippoglossus hippoglossus* (L.). Aquaculture Research 27: 101-106.

Hansen,T., Karlsen, Ø., Taranger, G. L., Hemre, G.I., Holm, J. C. and Kjesbu, O.S. 2001. Growth, gonadal development and spawning time of Atlantic cod (*Gadus morhua*) reared under different photoperiods. Aquaculture 203:51-67.

Hinshaw, J.M. 1985. Effects of illumination and prey contrast on survival and growth of larval yellow perch *Perca flavescens*. Transactions of the American Fisheries Society 114: 540-545.

Höglund, E., Balm, P.H.M. and Winberg, S., 2002. Behavioural and neuroendocrine effects of environmental background colour and social interaction in Arctic charr (*Salvelinus alpinus*). Journal of Experimental Biology 205: 2535-2543.

Howell, B.R. 1979. Experiments on the rearing of larval turbot, *Scophthalmus maximus* L. Aquaculture 18: 215-225.

Hunt von Herbing, I. 2002. Effects of temperature on larval fish swimming performance: the importance of physics to physiology. Journal of Fish Biology 61: 865-876.

Hunt von Herbing, I. and S. Gallager. 2000. Foraging behaviour in early Atlantic cod larvae *Gadus morhua*, feeding in a protozoan and copepod naupilus. Marine Biology 124: 593-606.

Hunt von Herbing, I., Gallager, S.M.. and Halteman, W. 2001. Metabolic costs of pursuit and attack in early larval Atlantic cod. Marine Ecology Progress Series 216: 201-212.

Huse, I. 1994. Feeding at different illumination levels in larvae of three marine teleost species: cod, *Gadus morhua,* plaice, *Pleuronectes platessa,* and turbot, *Scophthalmus maximus.*Aquaculture Fisheries Management 25: 687-695.

Landeau, L. and Terborgh, J. 1986. Oddity and the 'Confusion effect' in predation. Animal Behaviour 34: 1372-1380.

Laurel, B.J., Brown, J.A. and Anderson, R. 2001. Behaviour, growth and survival of redfish larvae in relation to prey availability. Journal of Fish Biology 59: 884 – 901

Mangor-Jensen, A. and Waiwood, K.G. 1995. The effect of light exposure on buoyancy of halibut eggs. Journal of Fish Biology 47: 18-25.

Martin-Robichaud, D.J. and Peterson, R.H. 1998. Effects of light intensity, tank colour and photoperiod on swimbladder inflation successin larval striped bass, *Morone saxatilis* (Walbaum). Aquaculture Research 29: 539-547.

Mills, E.I., Confer, J.L. and Ready, R.C. 1984. Prey selection by young yellow perch: the influence of capture success, visual acuity, and prey choice. Transactions of the American Fisheries Society 113: 579-587.

Munk, P. 1995. Foraging behaviour of larval cod, *Gadus morhua,* influenced by prey density and hunger. Marine Biology 122: 205-212.

Naas, K., Huse, I. and Iglesias, J. 1996. Illumination in first feeding tanks for marine fish larvae. Aquacultural Engineering 15: 291-300.

O'Brien, W.J.,. Browman, H.I. and Evans, B.I. 1990. Search Strategies in Foraging Animals. American Scientist 78: 152-160.

O'Brien, W.J.,. Evans, B.I and Browman, H.I. 1989. Flexible search tactics and efficient foraging in saltatory searching animals. Oecologia 80: 100-110.

O'Brien, W.J.,. Evans, B.I. and Howick, G. 1986. A new view of the predation cycle in a planktivorous fish. Canadian Journal of Fisheries and Aquatic Sciences 43: 1894-1899.

Ostrowski, A.C.1989. Effect of rearing tank background color on early survival of dolphin larvae. Progressive Fish Culturist. 51:161-163.

Pankhurst, P.M. and Eager, R. 1996. Changes in visual morphology through life history stages of the New Zealand snapper, *Pagrus auratus,*. New Zealand Journal of Marine and Freshwater Research 30: 79-90.

Pankhurst, P.M. and Hilder, P.E. 1998. Effect of light intensity on feeding of striped trumpter, *Latris lineata*, larvae. Marine and Freshwater Research 49: 363-368.

Planas, M. and Cunha, I. 1999. Larviculture of marine fish: problems and perspectives. Aquaculture 177: 171-190.

Papoutsoglou, S.E., Mylonakis, H., Miliou, H., Karakatsouli, N.P. and Chadio, S. 2000. Effects of background color on growth performances and physiological responses of scaled carp (*Cyprinus carpio* L.) reared in a closed circulated system. Aquacultural Engineering 22: 309-318.

Puvanendran, V. and Brown, J. A. 1998. Effects of light on the foraging and growth of Atlantic cod, *Gadus morhua,* larvae: interpopulation differences? Marine Ecology Progress Series 167:207-214.

Puvanendran, V. and Brown, J.A. 1999. Foraging, growth and survival of Atlantic cod, *Gadus morhua,* larvae reared in different prey conditions. Aquaculture 175: 77-92.

Puvanendran, V. and Brown, J.A. 2002. Foraging, growth and survival of Atlantic cod, *Gadus morhua,* larvae reared in different light intensities and photoperiods. Aquaculture 214: 131-151.

Puvanedran, V., Salies, K., Laurel, B. and Brown, J.A. 2004. Size-dependent foraging of larval Atlantic cod (*Gadus morhua*). Canadian Journal of Zoology 82:1380 -1389.

Rabe, J. and Brown, J.A. 2001. The behaviour, growth and survival of witch flounder (*Glyptocephalus cynoglossus*) larvae in relation to prey availability: adaptations to an extended larval period. Fishery Bulletin 99: 465 - 474.

Rotllant, J., Tort, L., Montero, D., Pavlidis, M., Martinez, M., Wendelaar Bongae, S.E. and Balme, P.H.M. 2003. Background colour influence on the stress response in cultured red porgy, *Pagrus pagrus*. Aquaculture 223: 129-139.

Saka, S., Firat, K. and Suzer, C. 2001. Effects of light intensity on early life development of gilthead sea bream, *Sparus aurata,* larvae. Israeli Journal of Aquaculture 53(3-4): 139-146.

Shand, J. 1993. Changes in the spectral absorption of cone visual pigments during the settlement of the goatfish *Upeneus tragula*: the loss of red sensitivity as a benthic existence begins. Journal of Comparative Physiology 173: 155-177.

Shand, J. 1997. Ontogenetic changes in retinal structure and visual acuity: a comparative study of coral-reef teleosts with differing post-settlement lifestyles. Environmental Biology of Fishes 49: 307-322.

Shand, J. 2000. Variability in the location of the retinal ganglion cell area centralis is correlated with ontogenetic changes in feeding behavior in the black bream, *Sparidae teleostei*. Brain Behaviour and Evolution 55: 176-190.

Skiftesvik, A. 1992. Changes in behaviour at onset of exogenous feeding in marine fish larvae. Canadian Journal of Aquatic Science 49: 1570-1572.

Skiftesvik, A.B. 1994. Impact of physical environment on the behaviour of cod larvae. ICES Marine Science Symposium 198: 646-653.

Solberg, T.S. and Tilseth, S. 1987. Variations in growth pattern among yolk-sac larvae of cod, *Gadus morhua,* due to differences in rearing temperature and light regime. Sarsia 72: 347-349.

Tamazouzt, L., Chatain, B and Fontaine, P. 2000. Tank wall colour and light level affect growth and survival of Eurasian perch, *Perca fluviatilis,* larvae. Aquaculture 182: 85-90.

Tilseth, S., Blom, G., and Naas, K. 1992. Recent progress in research and development of marine cold water species for aquaculture production in Norway. Journal of the World Aquaculture Society 23(4): 277-285 .

Utne-Palm, A.C. 1999. The effect of prey mobility, prey contrast, turbidity and spectral composition on the reaction distance of *Gobiusculus flavescens* to its planktonic prey. Journal of Fish Biology 54: 1244-1258.

Wanzenbock, J. and Schiemer, F. 1989. Prey detection in cyprinids during early development. Canadian Journal of Fisheries and Aquatic Sciences 46: 995-1001.

Yin, M. and Blaxter, J.H.S. 1987. Feeding ability and survival during starvation of marine fish larvae reared in the laboratory. Journal of Experimental Marine Biology and Ecology 105: 73-83.