

# Light intensity effects on early life stages of black sea bass, *Centropristis striata* (Linnaeus 1758)

Kimberly A Copeland & Wade O Watanabe

Center for Marine Science, University of North Carolina Wilmington, Wilmington, NC, USA

**Correspondence:** W O Watanabe, Center for Marine Science, University of North Carolina Wilmington, 7205 Wrightsville Avenue, Wilmington, NC 28403, USA. E-mail: watanabew@uncw.edu

## Abstract

The effects of four light intensities on growth and survival of first-feeding stage black sea bass larvae *Centropristis striata* were investigated in a controlled-environment laboratory. Fertilized eggs, obtained from LHRHa-induced spawning of captive broodstock, were stocked ( $72 \text{ eggs L}^{-1}$ ) into twenty 15 L black tanks under light intensities of 100, 500, 1000 and 1500 lx, with five replicate tanks per treatment. The photoperiod was 12L:12D, the temperature was  $20^\circ\text{C}$  and the salinity was  $35 \text{ g L}^{-1}$ . Larvae were fed rotifers *Brachionus rotundiformis* from day 2 post-hatching (d 2ph) at  $5\text{--}10 \text{ rotifers mL}^{-1}$ . Microalgae *Nannochloropsis oculata* and *Isochrysis* sp. were added (1:1) daily to maintain a density of  $300\,000 \text{ cells mL}^{-1}$ . Hatching success and larval growth and survival from d 2ph through d 15ph were monitored. Hatching success was 28–38% under all light intensities, and notochord length at hatching ranged from 2.8 to 3.0 mm, with no significant differences among treatments. By d 15ph, growth (mg wet weight) was significantly higher in the 1000 lx (0.914) and 1500 lx treatments (0.892) than in 100 lx (0.483), and a highly significant trend ( $P < 0.01$ ) towards increased survival with increasing light intensities was observed, from 1.3% at 100 lx to 13.9% at 1500 lx. Higher light intensities within the range of 100–1500 lx improved growth and survival of early larval black sea bass, suggesting that even higher light intensities may improve culture performance. This is consistent with conditions in shallow, near-shore locations where eggs and larvae are distributed in nature.

**Keywords:** black sea bass, *Centropristis striata*, light intensity, larviculture

## Introduction

The black sea bass, *Centropristis striata* (Linnaeus 1758) (family Serranidae), is a commercially and recreationally important finfish with a natural distribution extending from Northern Massachusetts to central Florida. Based on the South Atlantic Fishery Management Council's stock assessment, the black sea bass stock is heavily exploited south of Cape Hatteras, NC, and a 62% reduction in harvest is needed [North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries (NCDENR DMF) 2006]. Owing to its high value and declining natural populations, black sea bass is a prime candidate for commercial cultivation.

A number of studies of black sea bass larvae and juveniles have examined the effects of temperature (Berlinsky, Watson, Nardi & Bradley 2000; Berlinsky, Taylor, Howell, Bradley & Smith 2004) and salinity (Atwood, Young, Tomasso & Smith 2001; Atwood, Young, Tomasso & Smith 2003) and dominant factors affecting growth and survival of marine finfish. Marine fish larvae are visual feeders and are highly dependent on light (Blaxter 1968) for prey capture and feeding success. Although light can have important effects on growth and survival of the early life stages of marine finfish (Watanabe, Feeley, Ellis & Ellis 1998; Henne & Watanabe 2003), these effects vary significantly among species (Boeuf & LeBail 1999). In a number of species, such as Nassau grouper, *Epinephelus striatus* (Bloch) (Ellis, Watanabe, Ellis, Ginoza & Moriwake 1997), striped bass, *Morone saxatilis* (Walbaum) (Chesney 1989), and Atlantic cod, *Gadus morhua* (Linnaeus) (Puvanendran & Brown 2002), increased light intensities (1636–2400 lx) produced positive phototaxis, and increased feeding, survival and

growth of larvae. On the other hand, in summer flounder, *Paralichthys dentatus* (Linnaeus) (Watanabe *et al.* 1998), and in southern flounder, *P. lethostigma* (Jordan & Gilbert) (Henne & Watanabe 2003), maximum larval growth was observed at relatively low light intensities (50–500 lx).

Little or no experimental data are available on the effects of illumination on early life stages of black sea bass. The objectives of this study were to determine the effects of light intensity on growth and survival of black sea bass reared from the yolk-sac through the first feeding stages as a basis for establishing practical hatchery protocols.

## Methods

### Experimental animals

This study was conducted in July 2001 at the University of North Carolina Wilmington, Center for Marine Science Aquaculture Facility (Wrightsville Beach, NC, USA). Fertilized eggs were obtained following volitional spawning of captive broodstock induced with pelleted LHRHa at 19 °C and 35 g L<sup>-1</sup> salinity (Watanabe, Smith, Berlinsky, Woolridge, Stuart, Copeland & Denson 2003). Eggs were placed in a 150 L incubator where they were counted, and their embryonic development was monitored under 560 lx and a 12 L:12 D photoperiod. Approximately 1 day before hatching, embryos that were developing normally were stocked into rearing aquaria.

### Experimental design

To study the effects of light intensity on growth and survival of larval black sea bass, embryos were stocked into 20 aquaria at a density of 72 L<sup>-1</sup> under four light intensities of 100, 500, 1000 and 1500 lx. Five replicate tanks were maintained per treatment. The temperature was 20 °C and salinity was 35 g L<sup>-1</sup>. Seawater was pumped from the Atlantic Intracoastal Waterway adjacent to the laboratory and was filtered (1 µm, UV treated) before use. Aeration to each aquarium was provided at approximately 50 mL min<sup>-1</sup> through a diffuser placed at the bottom and centre of each tank.

### Experimental system

The experimental system consisted of four temperature-regulated water baths (152 × 61 × 23 cm), each

covered by a light hood (152 × 65 × 19 cm) suspended from the ceiling and isolated with an opaque black curtain to eliminate extraneous light. Each water bath housed four cylindrical black plastic aquaria (15 L working volume) where the larvae were reared. To maintain a constant temperature, fresh-water in the baths was continuously re-circulated through a heater/chiller, and room temperature was controlled by an air conditioner.

Illumination to the aquaria in each water bath was provided by two 40 W fluorescent bulbs supplying full-spectrum lighting (Vita-Lite, Duro-Test, Philadelphia, PA, USA), simulating natural sunlight. Light intensity was controlled by adjusting the height of each hood and using of shade cloth. Photoperiod was maintained at 12 L:12 D in each water bath by timers.

### Feeding

Larvae were fed rotifers (*Brachionus rotundiformis*) that were cultured in 150 L tanks under continuous illumination and at a temperature of 22–25 °C and salinity of 35 g L<sup>-1</sup>. Rotifers were enriched with Culture Selco<sup>®</sup> (INVE Aquaculture, Ogden, UT, USA) to enhance their nutritional value, especially ω-3 fatty acids (Sargent, McEvoy & Bell 1997).

Each morning, rotifers were harvested and then acclimated to the larval rearing temperature over a period of several hours. Rotifers were added to the rearing aquaria beginning on day 2 post-hatching (d 2ph), approximately 48 h before the first feeding stage, at a density of 5–10 individuals mL<sup>-1</sup>. This density was maintained by counting the rotifers in each culture vessel using volumetric methods and adding the appropriate number of enriched rotifers to make up the difference on a daily basis. Growth and survival of black sea bass are significantly improved when microalgae are added to the seawater culture medium (greenwater; Berlinsky *et al.* 2000). Hence, preserved *Nannochloropsis oculata* and *Isochrysis* sp. were each added at a rate of 150 000 cells mL<sup>-1</sup> daily to maintain a total concentration of approximately 300 000 cells mL<sup>-1</sup> throughout the experiment.

### Growth and survival

To monitor larval growth, larvae were sampled from each replicate tank on d 0 (hatching), 2, 5 (first-feeding), 8, 11 and 15ph. Sampling began at 08:00 hours before rotifers were added to minimize the amount of newly ingested rotifers in the larval gut. Larvae

were collected by vigorously aerating the culture water for a short period to ensure uniform distribution and then sampling at least 10 larvae. Notochord length was recorded from anaesthetized (0.3–0.5 mg L<sup>-1</sup> 2 phenoxyethanol) larvae using a microscope fitted with an ocular micrometer. Length was measured to the nearest 0.1 mm. Wet and dry weights were measured on d 2, 5, 11 and 15ph. To determine wet weights, 10 larvae aquaria<sup>-1</sup> were rinsed with deionized water on a Nitex screen, blotted dry and then weighed on a Sartorius (Goettingen, Germany) electrobalance to the nearest 10 µg. To determine dry weights, 10 larvae were dried to a constant weight at 60 °C ( ~ 72 h) and then weighed.

On d 2 and 15ph, larval density (number of larvae L<sup>-1</sup>) was calculated as the quotient of the number of larvae sampled and total volume sampled. Larval survival was calculated as a percentage of yolk sac larvae present at hatching and was adjusted for sampling.

### Water quality

Temperature (YSI, Yellow Springs, OH, USA, ± 0.1 °C) and salinity (refractometer, ± 1 g L<sup>-1</sup>) were measured in each replicate tank daily. Light intensity, also recorded daily, was measured at the water surface of each tank with a light meter (Extech Instruments, Waltham, MA, USA). Dissolved oxygen (YSI 555, ± 0.01 mg L<sup>-1</sup>) and pH (± 0.1) were measured daily from one replicate tank per treatment, and total ammonia nitrogen was measured on alternate days (HACH DR 850, Loveland, CO, USA, ± 0.01 mg L<sup>-1</sup>). Airflow (40–60 mL min<sup>-1</sup>) to each aquarium was monitored daily with a flow meter (Cole-Parmer Instrument, Vernor Hills, IL, USA, ± 1 mL min<sup>-1</sup>) and adjusted as needed. Tank surfaces were skimmed daily to remove surface oil films. During the experimen-

tal period, the mean (range) daily water quality conditions were as follows: temperature (°C), 19.6 (19–21); dissolved oxygen (mg L<sup>-1</sup>), 6.8 (6.4–7.2); salinity (g L<sup>-1</sup>), 35 (33–35); and pH 8.3 (8.2–8.3). The mean (range) light intensity (lx) was 118 (111–126), 444 (421–470), 984 (924–1052) and 1410 (1282–1529) at treatment levels of 100, 500, 1000 and 1500 respectively.

### Statistical methods

Quantitative values were expressed as treatment means ± standard errors, with mean values from each tank considered to be units of observation. The effects of light intensity were tested using a one-way ANOVA (Sokal & Rohlf 1995). Linear regression analysis was used to determine the relationship between light intensity and survival. Significant treatment effects were detected by the Tukey–Kramer honestly significant difference test for multiple comparisons among means. Analysis was performed using JMP (SAS Institute, Cary, NC, USA) statistical software.

## Results

### Survival

Hatching success was moderate (28.2–37.6%) under all light intensities, with no significant differences ( $P > 0.05$ ) among treatments (Table 1). On d 2ph, survival ranged from 17.3% to 30.1%, with no significant ( $P > 0.05$ ) differences among treatments. Under all light intensities, larvae reached the first feeding stage by d 4ph. On d 15ph, survival was significantly higher ( $P < 0.05$ ) in the 1500 lx treatment (17.4%) than in the 100 lx treatment (1.7%). Survival on d 15ph declined to 0% in two replicate tanks in the 100 lx treatment. A highly significant ( $P < 0.01$ ) linear relationship

**Table 1** Hatching success and survival (%) of black sea bass larvae through day 15 post-hatching (dph) under different light intensities

	Illumination (lx)				P value
	100	500	1000	1500	
Hatching success (%)	37.0 ± 7.9	28.2 ± 6.7	37.6 ± 7.2	33.8 ± 8.9	NS
Survival (%)*					
d 2ph	20.1 ± 3.5	30.1 ± 7.6	17.3 ± 4.6	21.4 ± 6.9	NS
d 15ph	1.7 ± 1.1a	4.2 ± 2.6ab	9.0 ± 3.5ab	17.4 ± 4.1b	<0.05

\*Percentage of yolk sac stage larvae present at hatching (d 0ph).

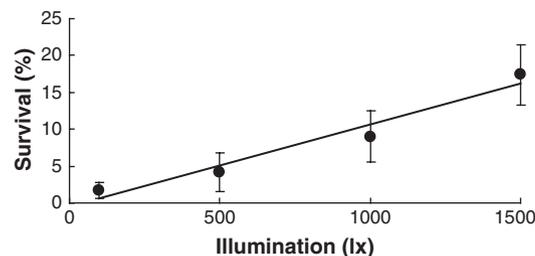
Values represent means ± SE,  $n = 4-5$ .

a,b,  $P \leq 0.05$ .

between light intensity and survival was observed (Fig. 1).

### Growth

Notochord length at hatching ranged from 2.83 to 3.00 mm, with no significant differences ( $P > 0.05$ ) among treatments (Table 2). Notochord lengths (mm) on d 2, 5, 8, 11 and 15ph ranged from 2.43 to 2.70, 2.44 to 2.71, 3.15 to 3.75, 3.50 to 4.18 and 3.84 to 4.42, respectively, with no significant differences ( $P > 0.05$ ) among treatments (Table 2).



**Figure 1** Relationship between survival (%),  $x$  and light intensity (lx),  $y$  in black sea bass on d 15ph. Linear regression defined this relationship as follows:  $y = 0.0111x - 0.5585$ ,  $r^2 = 0.958$ ,  $n = 17$ ,  $P < 0.01$ .

On d 0, 2 and 11ph, wet weights (mg) ranged from 0.199 to 0.244, 0.068 to 0.102 and 0.495 to 0.644, respectively, with no significant differences ( $P > 0.05$ ) among treatments (Table 3). On d 15ph, a significant trend ( $P < 0.05$ ) towards higher wet weight with increasing light intensity was observed from 0.483 at 100 lx to 0.914 at 1000 lx. Wet weights were significantly ( $P < 0.05$ ) higher in the 1000 lx (0.914) and 1500 lx (0.892) treatments than in the 100 lx (0.483) treatments (Fig. 2, Table 3).

On d 0ph, dry weights (mg) ranged from 0.035 to 0.055, with no significant differences ( $P > 0.05$ ) among treatments (Table 4). On d 2ph, dry weights were significantly higher ( $P < 0.05$ ) in the 1000 lx (0.056) treatments than in the 100 lx (0.037) treatments and 500 lx (0.040) treatments (Table 4). On d 11 and 15ph, dry weights ranged from 0.113 to 0.133 and 0.122 to 0.197, respectively, with no significant differences ( $P > 0.05$ ) among treatments (Table 4).

### Discussion

Under all light intensity treatments, hatching rates (28.2–37.6%) of black sea bass embryos in this study were moderate. This is similar to results of an earlier

**Table 2** Notochord length (mm) of black sea bass larvae on days 0, 2, 5, 8, 11 and 15 post-hatching (dph) under different light intensities

Age (dph)	Illumination (lx)			
	100	500	1000	1500
0	2.83 ± 2.09	2.91 ± 0.74	2.90 ± 1.15	3.00 ± 0.48
2	2.70 ± 0.61	2.43 ± 2.93	2.51 ± 2.08	2.46 ± 2.50
5	2.71 ± 0.58	2.50 ± 2.41	2.46 ± 2.37	2.44 ± 1.45
8	3.15 (3.10–3.20)	3.50 ± 5.27	3.62 ± 2.80	3.75 ± 1.03
11	3.50 (3.45–3.55)	3.99 ± 4.00	4.18 ± 0.68	3.94 ± 4.09
15	3.84 (3.82–3.85)	4.24 ± 3.32	4.42 ± 1.95	4.32 ± 4.88

Values represent means ± SE,  $n = 3–5$ , except for the 100 lx treatment on d 8, 11 and 15ph, where  $n = 2$  (range shown in parentheses).

**Table 3** Wet weights (mg) of black sea bass larvae on days 0, 2, 11 and 15 post-hatching (dph) under different light intensities

Age (dph)	Illumination (lx)				P value
	100	500	1000	1500	
0	0.206 ± 0.021	0.206 ± 0.01	0.199 ± 0.013	0.244 ± 0.049	NS
2	0.086 ± 0.004	0.102 ± 0.012	0.068 ± 0.005	0.073 ± 0.009	NS
11	0.495 (0.380–0.610)	0.520 ± 0.111	0.644 ± 0.094	0.565 ± 0.054	NS
15	0.483 (0.493–0.472)a	0.655 ± 0.086ab	0.914 ± 0.051b	0.892 ± 0.114b	<0.05

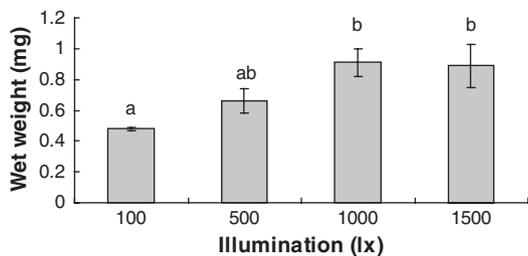
Values represent means ± SE,  $n = 3–4$ , except for the 100 lx treatment on d 11ph and d 15ph, where  $n = 2$  (range shown in parentheses).

a,b,  $P \leq 0.05$ .

study (Watanabe *et al.* 2003), where the hatching success of black sea bass eggs produced in 19 induced spawning trials averaged 24.3–27.2%, but with high variability (range = 0.5–83.0%) among trials.

Survival of yolk sac (i.e. pre-feeding) stage larvae in this study declined markedly in all treatments to 16.1–24.1% by d 2ph, with no significant effects of illumination. This marked decrease in the survival of pre-feeding stage larvae may be attributed in part to temperature, which averaged 19.6 °C, probably sub-optimal for black sea bass early larval growth and survival. Other workers have also reported that survival of embryos and early black sea bass larvae to d 3ph is optimized at 22–25 °C (Berlinsky *et al.* 2004).

While no significant effects of light intensity on survival or growth of early yolk sac stage larvae were evident, there was a clear trend towards higher survival and growth (wet wt) with increasing light intensity in feeding stage larvae by d 15ph, suggesting that feeding success was improved at higher light intensities. This is consistent with what was observed in larval striped bass, which showed increased growth and survival with increasing light intensities ranging from 300 to 2000 lx under a 12 L:12 D photo-



**Figure 2** Wet weights (mg) ( $\bar{x} \pm$  SE,  $n = 3-4$ , except for the 100 lx treatment where  $n = 2$ , and range values are shown) of black sea bass larvae reared under different light intensities on d 15ph. Means with the same letters are not significantly different ( $P > 0.05$ ).

period (Chesney 1989). Growth, gut fullness and survival of Atlantic cod *G. morhua* larvae also increased with increasing light intensities ranging from 300 to 2400 lx under a continuous photoperiod (Puvanendran & Brown 2002). In Nassau grouper, *E. striatus*, survival was significantly higher for larvae reared at 1636 lx (vs. 714 and 0 lx) under a 11 L:13 D photoperiod (Ellis *et al.* 1997). In sea bass, *Dicentrarchus labrax*, larvae grew faster, but with lower survival, at high light intensities of 1400–3500 lx (vs. 300–700 lx), under a continuous photoperiod (Barahona-Fernandes 1979).

In contrast to early larval summer flounder *P. dentatus* (Watanabe *et al.* 1998) and southern flounder *P. lethostigma* (Henne & Watanabe 2003), which showed optimal growth under low light levels (500 and 50–100 lx respectively), early larval black sea bass showed higher growth and survival at 1000–1500 lx than at 100–500 lx. Summer flounder spawn on or near the bottom in shelf waters ranging from 30 to 200 m depth (Rogers & Van Den Avyle 1983), and southern flounder also spawn in relatively deep offshore locations (Stokes 1977). As light intensity attenuates rapidly with depth, from 10 000 lx at the surface to 0.5 lx at 200 m in the clearest ocean water (Helvik & Walther 1992), eggs and early larvae of summer flounder are exposed to very low levels of illumination in deeper shelf waters (Smith 1973). In contrast, black sea bass spawn at depths of 18–45 m in continental shelf waters (Musick & Mercer 1977; Able, Fahay & Shepherd 1995) where light intensities are much higher. For example, the maximum ocean surface light intensity on a clear day at 30°N latitude at solar noon is 93 513  $\mu\text{W cm}^{-2}$  (343 193 lx) (Wurts & Stickney 1984). In clear coastal waters, light intensity is attenuated to 23 064 and 402 lx at 18 and 45 m depth respectively. Hence, improved feeding and growth at relatively high light intensities is consistent with shallow, near-shore locations where eggs and larvae of black sea bass are distributed in nature.

**Table 4** Dry weights (mg) of black sea bass larvae on days 0, 2, 11 and 15 post-hatching (dph) under different light intensities

Age (dph)	Illumination (lx)				P value
	100	500	1000	1500	
0	0.035 $\pm$ 0.009	0.044 $\pm$ 0.004	0.034 $\pm$ 0.002	0.055 $\pm$ 0.011	NS
2	0.037 $\pm$ 0.005a	0.040 $\pm$ 0.003a	0.056 $\pm$ 0.002b	0.048 $\pm$ 0.001ab	<0.05
11	0.125 (0.120–0.130)	0.113 $\pm$ 0.015	0.129 $\pm$ 0.016	0.133 $\pm$ 0.016	NS
15	0.122 (0.136–0.108)	0.151 $\pm$ 0.015	0.197 $\pm$ 0.019	0.164 $\pm$ 0.019	NS

Values represent means  $\pm$  SE,  $n = 3-5$ , except for the 100 lx treatment on d 11ph and d 15ph, where  $n = 2$  (range shown in parentheses).

a,b,  $P \leq 0.05$ .

To summarize, higher light intensities within the range of 100–1500 lx improved growth and survival of early larval black sea bass in greenwater culture, suggesting that growth and survival may be improved at even higher light intensities. To improve embryonic and early larval survival, studies are needed to determine the interactive effects of environmental factors (e.g. temperature, salinity and light) on early life stages of black sea bass.

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