**Spectral Sensitivity in Juvenile Striped Jack** 
*(Pseudocaranx dentex)*

Taro MATSUMOTO¹, Hiroshi IHARA¹, Shinji YAMAMOTO², Osamu MURATA² and Yasunori ISHIBASHI¹,*

**Abstract:** Striped jack (*Pseudocaranx dentex*) live in dense populations along tropical and subtropical coasts worldwide. Currently, however, there is insufficient knowledge regarding the visual sensitivity of this species in relation to its ecology. The spectral sensitivity of juvenile striped jack was measured using electroretinograms obtained with light-emitting diodes that emitted light with wavelengths ranging from 369 to 652 nm (ultraviolet-visible light). Sensitivity peaked at wavelengths between approximately 513 nm in dark-adapted fish and light-adapted fish. The green-sensitive eyes of juvenile striped jack are adapted for the light conditions in the coastal shallow waters of its natural habitats.

**Key words:** Striped jack; Electroretinogram (ERG); Light emitting diode (LED); Visual spectral sensitivity

The striped jack (*Pseudocaranx dentex*) is a cosmopolitan coastal species inhabiting tropical and subtropical regions of the Indian Ocean, Western and Central Pacific Ocean, Atlantic Ocean, and adjacent seas (Honebrink 2000). This species is considered as the best fish for sashimi and is a much sought-after delicacy in Japan, making it the most expensive fish among the Carangids (Watanabe and Vassallo-Agius 2003). For this reason, this species is an important target in aquaculture and the effective management of its natural resources is necessary.

Long-term research of striped jack is difficult in its natural habitats, however, because as they grow, fish of this species migrate from shallow coastal waters or estuaries to offshore reefs (Masuda and Tsukamoto 1999). Several studies have investigated the natural environment of the striped jack (Masuda and Tsukamoto 1999; Masuda et al. 1993), but ecological and behavioral information for juvenile and adult fish is insufficient.

Striped jack is a strongly associating and schooling fish (Masuda et al. 1995; Kogane et al. 1996; Masuda and Tsukamoto 2000), and vision is the most important sensory input for schooling and association behavior (Masuda et al. 1995). Light avoiding behavior of juvenile striped jack was observed when the illuminance of natural sunlight was more than 10,000 lx in an outdoor tank (Kogane et al. 1996). Thus, the behaviors of juvenile striped jack appear to be related to the light conditions of its habitat.

The light intensity threshold for school formation in juvenile striped jack has been reported to decrease with growth (5 × 10² to 5 × 10⁴ lx; Miyazaki et al. 2000). However, the spectral sensitivity of striped jack vision has not been reported. Generally, the spectral sensitivity of an organism is thought to be related to the light environment of its habitat and to its behavior (Kobayashi 1962; Munz and McFarland...
For example, oceanic or deep-water fishes tend to be sensitive to blue light, whereas freshwater or shallow marine fishes tend to be sensitive to green light (Munz and McFarland 1977). Therefore, the spectral sensitivity of striped jack will provide an inference on its behavior and ecology.

In this study, we investigated the spectral sensitivity of light- and dark-adapted striped jack by using an electroretinogram (ERG) technique and we discuss our findings in relation to the behavior and ecology of the striped jack. Light-emitting diodes (LEDs) were used as narrow band light sources. The experimental recording apparatus and stimulus light sources have been described previously (Matsumoto et al. in press). When compared with conventional lamps with tungsten or xenon bulbs, LEDs have many advantages such as small size, better durability and energy efficiency, low-voltage operation, and superior safety. The emitted light is in the UV-visible light wavelength range and is narrow band stimuli without using color filters. Therefore, this is an inexpensive, easy to construct, and portable apparatus for obtaining ERGs. This compact system can be operated with batteries and hence could be used to obtain ERGs of fish on a boat or for field sampling.

### Materials and Methods

#### Experimental fish

The juvenile striped jack specimens, which were hatched artificially, were supplied by the Fisheries Laboratory of Kinki University, Shirahama Station in November and December 2007. Six juveniles of 223–246 mm standard length [SL] were used for the dark-adaptation experiment and five juveniles of 223–237 mm SL were used for the light-adaptation experiment. Prior to experimentation, the fish were maintained in a circular tank (1000 l) with filtered seawater (temperature, 19–21°C) under the natural photoperiod.

#### Procedures

Before one hour or more of the experiment, the fish were placed in 500 l circular tank with light from a fluorescent bulb and subsequently used for the determination of spectral sensitivity in light-adaptation. Dark-adapted fish which were stocked in 500 l circular tank in a dark room for at least one hour measured of spectral sensitivity. Each fish was then anesthetized in a solution of 2-phenoxyethanol (0.4 ml/l) and immobilized with an intramuscular injection of 6–9 ml of gallamine triethiodide solution (50 mg gallamine triethiodide per kg of Ringer’s solution). The immobilized fish was then taken out of the anesthesia and placed in a light-tight metal

---

**Fig. 1.** Relative spectral intensities of the LEDs for different stimuli (thin lines). Spectral energy distribution (thick line) of adapting backgrounds emitted from tungsten bulb used in the light-adapted spectral sensitivity experiments; the measurements plotted are in terms of \( \log_{10} \) quanta intensity (quanta \( \text{cm}^{-2} \text{s}^{-1} \text{nm}^{-1} \)).
box (length, 370 mm; width, 510 mm; height, 410 mm). The body of the fish remained out of the water. During the ERG recording, the fish respired artificially using oxygen from aerated seawater that was pumped over the gills.

**Electrophysiological apparatus**

The stimulation light source was comprised of 12 LEDs, each of which had a different peak emission wavelength, ranging from 369 to 652 nm (Fig. 1 and Table 1). The stimulation wavelength was controlled by selecting the appropriate LED with a rotary switch. Stimulus irradiance was controlled by placing neutral-density filters in the light path. The attenuated light was projected onto the entire pupil of the experimental fish. The stimulus light system was itself placed outside the box. For light adaptation experiments, a tungsten bulb powered with 12-V DC was set inside the box above the eye. The irradiances of the stimulus and adaptation lights were measured at the same position by using a radiometer (USB-4000, Ocean Optics, Dunedin, Florida, USA) that was sensitive to light in the UV-visible spectrum. The irradiances were converted to quanta/s/cm² and integrated from 300 to 750 nm. The irradiance of the background light from the tungsten bulb was 1.8 × 10¹⁰ quanta/s/cm² (Fig. 1).

An ERG was recorded using two silver wire electrodes (diameter, 0.3 mm) in the box. The recording electrode was placed on the retina through a small hole in the cornea. The end 3 mm of the recording electrode was bent manually into a ‘U’ shape in order to avoid any damage the retina. The reference electrode was a silver wire that was sharpened to hold its position and then placed on the cranium. The positions of the electrodes were maintained using a manipulator (MN-153, Narishige, Tokyo, Japan). The electrical signals were amplified by a differential amplifier (MEG-5100, Nihon Kohden, Tokyo, Japan) with a bandpass filter of 0.5 – 100 Hz with a hum filter (60 Hz). These signals were simultaneously transmitted to a digital oscilloscope (DS1M12, USB Instruments, Glasgow, U.K.) and the laboratory computer. The data acquisition rate of the computer was 100 Hz.

**Spectral sensitivity**

We conducted ERG recordings by using light stimuli of equal quanta at each wavelength. The stimuli were 500-ms narrow band flashes. The relative spectral sensitivity was calculated as the ratio of the b-wave amplitude at a particular wavelength to the maximum amplitude at the wavelength of peak sensitivity.

Dark-adapted fish (n = 6) in the circular tank were acclimatized for 15 min after being anesthetized before conducting the recording in the box. The intensity of the stimulus for each wavelength was 1.1 × 10¹¹ quanta/s/cm². To maintain the dark-adapted state, the stimuli were presented at intervals of at least 20 s.

For light-adapted fish, the recording session comprised two periods: (1) a light period that lasted for 1 – 5 min during which the tungsten

---

Table 1. Light-emitting diodes (LEDs) used as light sources for the electroretinogram recordings

<table>
<thead>
<tr>
<th>Peak (nm)</th>
<th>FWHM* (nm)</th>
<th>LED model number</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>369</td>
<td>10.7</td>
<td>NSHU590B</td>
<td>Nichia, Tokushima, Japan</td>
</tr>
<tr>
<td>382</td>
<td>15.6</td>
<td>E1L5M-4P0A2</td>
<td>Toyoda Gosei, Aichi, Japan</td>
</tr>
<tr>
<td>401</td>
<td>13.3</td>
<td>OSSV531</td>
<td>OptoSupply, Hong Kong, China</td>
</tr>
<tr>
<td>432</td>
<td>58.7</td>
<td>MV8B01</td>
<td>Fairchild Semiconductor, South Portland, ME, USA</td>
</tr>
<tr>
<td>449</td>
<td>22.2</td>
<td>L450-03U</td>
<td>Epitex, Kyoto, Japan</td>
</tr>
<tr>
<td>468</td>
<td>24.7</td>
<td>OSUB5111A</td>
<td>OptoSupply, Hong Kong, China</td>
</tr>
<tr>
<td>503</td>
<td>31.7</td>
<td>OSBG5111A</td>
<td>OptoSupply, Hong Kong, China</td>
</tr>
<tr>
<td>515</td>
<td>36.1</td>
<td>OSP511</td>
<td>OptoSupply, Hong Kong, China</td>
</tr>
<tr>
<td>573</td>
<td>13.4</td>
<td>L-7113MGCC</td>
<td>Kingbright, Taipei, Taiwan</td>
</tr>
<tr>
<td>597</td>
<td>12.9</td>
<td>OSYL5111A-TU</td>
<td>OptoSupply, Hong Kong, China</td>
</tr>
<tr>
<td>634</td>
<td>13.6</td>
<td>OSHR5111A-TU</td>
<td>OptoSupply, Hong Kong, China</td>
</tr>
<tr>
<td>652</td>
<td>20.5</td>
<td>L-1503SRC-F</td>
<td>Kingbright, Taipei, Taiwan</td>
</tr>
</tbody>
</table>

*FWHM: full width at half maximum
bulb was switched on; and (2) a dark period that lasted for less than 20 s during which the tungsten bulb was switched off. The stimuli were presented in the dark period. Alternating light and dark periods were repeated. The intensities of the stimuli for each wavelength were \(3.1 \times 10^{13}\) quanta/s/cm\(^2\) \((n = 4)\) and \(2.4 \times 10^{13}\) quanta/s/cm\(^2\) \((n = 1)\). Optimum stimulation intensities were selected for each fish.

Changes in sensitivity with time were corrected for by returning to the standard stimulation of 503 nm wavelength lights between each session. The temperature of the water used for respiration during the experiments was 19–21°C.

**Curve-fitting procedure**

To estimate the wavelength of the peak spectral sensitivity, we used a fitting template for visual pigments (Stavenga et al. 1993) for our averaged relative sensitivity data of dark-adapted fish. The parameter values were determined by least-squares fit. The fitting template was not applied for light adapted fish because the fish may possess more than one visual pigment / cone type.

**Results**

We conducted ERG recordings by using light stimuli of equal quanta at each wavelength tested. Spectral sensitivity curves of dark- and light-adapted striped jack are shown in Figs. 2 and 3, respectively.

In the dark-adapted striped jack \((n = 6)\), spectral sensitivity peaks were at approximately 513 nm using the Stavenga template. In the light-adapted striped jack \((n = 5)\), spectral sensitivity peaks were at approximately 513 nm, similar to the dark-adapted fish. It is comparable to our previous data at approximately 512 nm obtained from a spectral sensitivity curve calculated by response versus light intensity curves in each wavelengths (Ishibashi et al., 2008).

The shapes of spectral sensitivity curves were similar to other coastal marine fishes associated with estuary and reef (Blaxter 1970). However, a shoulder was observed at 432 nm-light in the spectral sensitivity curves.

**Discussion**

In this investigation, we used LEDs as light stimulators for recording ERG although LEDs have not been generally used for calculating spectral sensitivity (Ishibashi et al. 2008; Matsumoto et al. in press). The spectral sensitivity peak wavelengths of striped jack were approximately 513 nm in both dark-adapted and light-adapted fish. In general, coastal fishes possess green sensitive eyes and pelagic and deep-water fishes possess blue sensitive eyes. The observation of green sensitive eyes in this species is comparable to other coastal marine fishes associated with estuary and reef (Blaxter 1970; Munz and McFarland 1977). In contrast, pelagic species, such as Pacific bluefin tuna and chub mackerel investigated by using LEDs as well as present study (Ishibashi et al 2008; Matsumoto et al in press) possess blue sensitive eyes in dark adaptation; these observations are comparable to other pelagic fishes (Loew et al. 2002; Munz and McFarland 1977). Thus, our ERG recording system using LEDs showed

![Fig. 2. Relative spectral sensitivity of dark-adapted eyes in striped jack \((n = 6)\). Sensitivity was calculated by the electroretinogram response to equal quanta stimuli \((1.1 \times 10^{11}\) quanta/s/cm\(^2\)\) at each wavelength. Solid lines show the curve fitted to the template of Stavenga et al. (1993).](image-url)
reasonable results for seeking the wavelength of spectral sensitivity peak. However, a shoulder was observed at 432 nm-light in the spectral sensitivity curve. This shoulder is probably attributed to wide bandwidth of emitting light of the 432 nm-LED (Fig. 1 and Table 1). This LED slightly emits blue and green light that is sensitive to striped jack. Therefore, our ERG recording system using LEDs is useful because of the convenient feature (such as small size, better durability and energy efficiency, low-voltage operation, and superior safety); but bandwidths of LEDs should be controlled constantly to avoid the shoulders.

In previous studies, juvenile striped jack were observed in coastal areas near estuaries in Okinawa (Kanashiro and Ebisawa 1993) and Ogasawara (Masuda et al. 1993), Japan. According to field observations, wild striped jack shift their habitat from shallow waters to offshore reefs when they reach a total length (TL) of about 150–200 mm or larger (Masuda et al. 1993). In Okinawa, juvenile striped jack of 50–160 mm fork length [FL] appear in the inner bay area in spring and these juveniles can be captured by set net or gillnet until the following spring at 200–300 mm FL, whereas larger striped jack of 350–600 mm FL are captured by deep-water gillnets (30–100 m or deeper; Kanashiro and Ebisawa 1993). Therefore, the habitats of juvenile striped jack of smaller than 300 mm FL appear to be shallow coastal areas around the Okinawasima Islands. Coastal water transmits wavelengths primarily in the range of 500–600 nm (Jerlov 1976). Therefore, the green-sensitive eyes of juvenile striped jack are adapted to the light environment of shallow coastal or brackish waters.

According to a report concerning gillnet fishing (2 to 4 m water depth) at a reef surrounded by a sandy area, striped jack were captured mainly in the open sandy area at dusk and dawn, only in the reef area at midnight, and in both areas at midday (Howard 1989). Therefore, striped jack may stay around reefs at night, swim back and forth between reefs and sandy areas during the day, and aggregate in sandy area at dawn and dusk. In the daytime, striped jack feed on benthos and detritus on the sandy bottom (Masuda et al. 1993) or consume suspending plankton (Sazima 1998). Upwelling and downwelling light is mainly in the green region of the spectrum in shallow coastal waters during the daytime, (Munz and McFarland 1977). Therefore, the green-sensitive eyes of light-adapted striped jack may be an adaptation for bottom feeding. The visual axis of striped jack is directed frontally (Takei and Somiya 2002), which is well suited for bottom feeding, feeding on plankton, and for maintaining schools. In the nighttime, juvenile striped jack of 220 mm TL formed tighter schools at night than during the day near the sea surface (<3 m) around a moored vessel (Masuda et al. 1993). The range of vision during the nighttime is narrower and shorter than during the day due to low light conditions. Therefore, striped jack may form relatively tight schools and may associate with reefs or moored vessels at night. Light from both moonless and moonlit night skies mainly consists of green light, and the spectral irradiance tends to shift to blue light with increasing water depth (Munz and McFarland 1977). In this study, we observed the peak spectral sensitivity of striped jack in

![Fig. 3. Relative spectral sensitivity of light-adapted eyes in striped jack (n = 5). Sensitivity was calculated by the electroretinogram response to equal quanta stimuli (3.1 × 10^{13} quanta/s/cm^2, n = 4; 2.4 × 10^{13} quanta/s/cm^2, n = 1) at each wavelength.](image-url)
the green light region of the spectrum. Unlike a related carangid, the kingfish (Kaiwarinus equula), striped jack do not possess reflecting tapeta in the eyes (Takei and Somiya 2002). Therefore, the green sensitivity of the dark-adapted eyes of striped jack would be suitable for shallow water depths at night.

Our findings indicate that the spectral sensitivity of juvenile striped jack of around 230-mm SL is adapted for the light environment of shallow coastal areas, which agrees with findings of previous ecological and behavioral studies. Shifts with growth in the wavelengths of peak absorption have been observed for the visual pigments of yellowfin tuna (Thunnus albacares, Loew et al. 2002) and pink salmon (Oncorhynchus gorbuscha, Cheng and Novales Flamarique 2004), and these shifts appear to be adaptations to habitat changes. As striped jack mature, they migrate from shallow reefs to offshore reefs, and therefore their spectral sensitivity may change with growth as well. Further investigation is needed for all parts of the life cycle of this species.

Acknowledgements

We are grateful to Dr. Hiroshi Kobayashi for his advice regarding the ERG recording. The authors also thank the staff of the Shirahama Experiment Station of the Fisheries Laboratory of Kinki University for providing experimental fish. This research was supported by the 21st Century and Global Center of Excellence Program of the Ministry of Education, Science, Sports and Culture of Japan.

References


Honebrink, R. R. (2000) In “Division of Aquatic Resources


Munz, F. W., and W. N. McFarland (1973) The significance


シマアジ稚魚の分光感度特性

松本太朗・伊原大志・山本真司・村田 修・石橋泰典

シマアジは，熱帯・亜熱帯の沿岸に広く分布する高級魚であるが，その視感度特性と生態との関係については不明な点が多い。そこで本研究は，紫外線から可視光まで（369－652 nm）の12種類の発光ダイオードを刺激光源として用い，シマアジ稚魚の分光感度を網膜電図により測定した。その結果，シマアジ稚魚の感度ピークは明順応，暗順応ともに513 nm 付近であることがわかった。これより，シマアジ稚魚は，緑色に感度の高い分光感度特性を有して主な生息域である沿岸表層域に適応していることが示唆された。