Onset of association behavior in striped jack, *Pseudocaranx dentex,* in relation to floating objects

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Many marine and freshwater species associate with floating objects (flotsam) during some period of their life history (Senta, 1965; Hunter and Mitchell, 1967; Kingsford, 1993). This association behavior is well known among fishermen, who often choose flotsam-associated schools (Yabe and Mori, 1950; Greenblatt, 1979). Among a wide range of taxa collected in association with flotsam, the Carangidae is one of the most frequently observed groups (Hunter and Mitchell, 1967; Kingsford, 1993; Clarke and Aeby, 1998). The association behavior of carangid fishes has been used by fishermen in Asia. "Payaw" in the Philippines is a flotsam made of bamboo and attracts many species of Carangidae (Ibrahim et al., 1990). Juvenile yellowtail, *Seriola quinqueradiata,* are collected by Japanese fishermen by surrounding drift algae with a small scoop net. These fish are then raised in cages as a net-pen culture (Senta, 1965; Sakakura and Tsukamoto, 1997). Presently, a new sea ranching project is being developed, in which artificially reared juvenile striped jack, *Pseudocaranx dentex*, are released at a floating platform where they naturally aggregate. There they are fed and harvested after growth (Masuda and Tsukamoto, 1998a).

The importance of this association behavior from the perspective of fishery ecology has generated a great deal of field research and experimental work. Hunter and Mitchell (1967) showed that large flotsam attracts more fish than smaller flotsam, and fish associating with flotsam tend to have darker body color, compared with the silvery color of those that are not attracted (Hunter and Mitchell, 1968). Using tag and release techniques, Ibrahim et al. (1990) demonstrated that fish released as far as 180 m from flotsam will swim back to their place of capture, suggesting that these fish can learn the topography of the region surrounding the float. Much ecological research has been conducted with the assumption that floating objects, especially drift algae, are an important habitat for juveniles (reviewed by Kingsford, 1993). Although a considerable amount of field-based work exists, little research has been conducted on the developmental aspects of association behavior in the laboratory.

The ontogenetic changes in association behavior in striped jack, *Pseudocaranx dentex,* were therefore studied with hatchery-raised larvae and juveniles. Possible sensory mechanisms underlying association behavior were examined by comparing four different types of flotsam conditions (transparent flotsam, gray flotsam, shadow flotsam, and no flotsam [control]).

Materials and methods

Two batches of fish were used in our experiments: one hatched on 22 February 1994, the other on 28 March 1994, both at the Komame Branch of the Japan Sea-Farming Association (JASFA). These batches of fish were transferred to the Kamiura Branch of JASFA on the next day. Fish were reared in 150-m^3 concrete tanks on a routine diet of rotifers and *Artemia* nauplii, and formula diet (Masuda and Tsukamoto, 1996). Eight different stages of fish were used in the experiments ranging from 5.5 mm (20 days) to 28 mm (56 days) in mean total length (Table 1). Because large variations in growth occurred in the hatchery, the medium-size fish were selected for each age group, except for the 21-mm fish. The 21-mm fish (54 days) were the smallest group of those hatched on 22 February.

Four different types of flotsam were created in 30-liter polycarbonate tanks with water depths of 25 cm (ca. 26 liters). These were

1. Transparent flotsam: a transparent acrylic pipe (60 mm in outer diameter, 5 mm thickness) cut to 250 mm in length and covered by a transparent circular plate (5 mm thickness) on the bottom. This was filled with water and suspended from the ceiling by fishing line, the height adjusted so that 150 mm of the pipe was in the water (Fig. 1A). The experimental tank was marked into four sections, and the flotsam was located at the center of one randomly chosen section.
2. Gray flotsam: an opaque gray PVC pipe and plate of identical size to that used in type 1 and suspended in the same way (Fig. 1B). This arrangement provided stronger visual stimulus than that provided in type 1.
3. Shadow flotsam: a gray circular opaque PVC plate (60 mm in diameter, 5 mm thickness) was suspended from the ceiling, so that the bottom of the plate was about 5 mm above the water surface. This created a shadow on the water surface, but not on the bottom of the tank (Fig. 1C).
4. No flotsam (control) (Fig. 1D).

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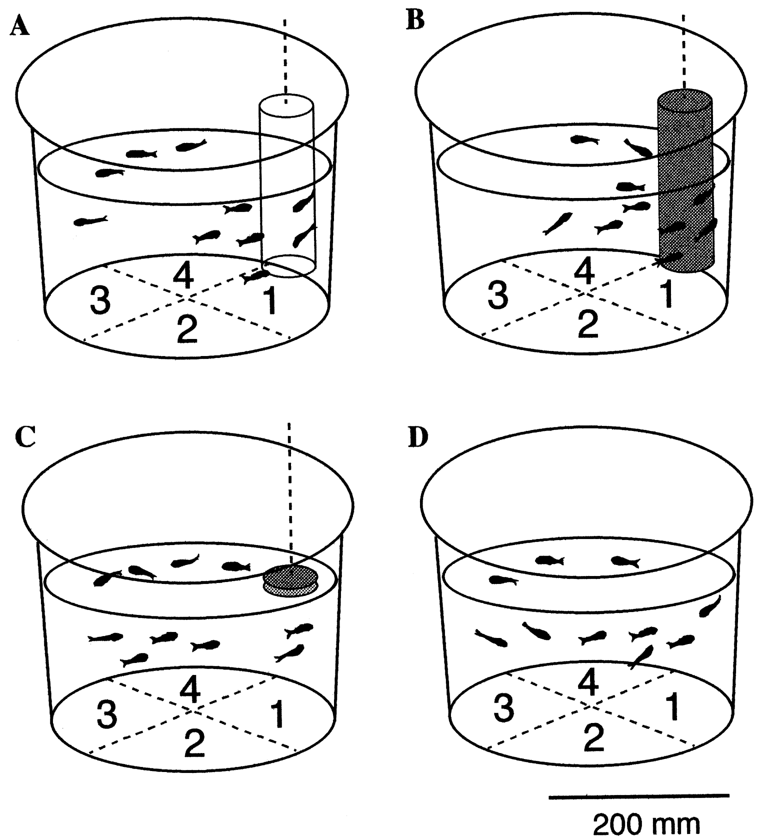

Figure 1

Schematic drawings of experimental tanks with each type of flotsam. (**A**) transparent flotsam, (**B**) gray flotsam, (**C**) shadow, and (**D**) control.

Carangid fish juveniles are commonly seen associated with floating and underwater objects, such as air tubes and vinyl bags, both in hatchery tanks and natural waters (Tachihara et al. 1993). Therefore acrylic and PVC pipes were suitable representative materials for use in examining the developmental changes of association behavior. We observed only horizontal distributions as an index of association behavior because in hatchery tanks, larvae and early juveniles of striped jack usually occur in the upper 30 cm of the water column.

All treatments were triplicated (twelve 30-liter tanks were used in total) and the location of the same type of flotsam was changed among triplicates. Experiments were conducted in an indoor facility and all tanks were placed in a water bath that was strongly aerated. Water temperature in each tank was maintained at hatchery levels (22.5°C). A photoperiod of 8 h light and 16 h dark was provided with 12 halogen illumination lights set above the tanks (light: 08:30–16:30 h). With this lighting, the light intensity at the surface of tanks was 0.01–0.05 lux at 20:00 h, lower than 0.01 lux between 00:00 and 04:00 h, 260–1000 lux at 08:00 h, and 17,000–24,000 lux at 12:00 and 16:00 h.

Table 1

Age, total length (mean ±SD), and hatching batch (+) of *Pseudocaranx dentex* used in the experiment.

		Batch	
Age (days)	TL (mm)	22 Feb	28 Mar 1994
20	5.5 ±0.5		+
27	8.8 ±0.9		+
30	10.3 ±1.1		+
31	11.9 ±2.4	+	
35	14.9 ±1.5		+
36	19.7 ±1.9	+	
54	21.0 ±1.8	+	
56	28.4 ±2.7	+	

At 20:00 h, fish were transferred from the hatchery tank to the 12 experimental tanks and ten fish were introduced into each tank (120 fish in total). Observations were con-

ducted immediately after introduction and once every 4 h over the following 24 h. For 10 mm, 15 mm, 21 mm, and 28 mm fish, observations were also made 36 h after introduction. During each observation period, the number of fish in each section of the tank was counted. At night time (20:00, 00:00 and 04:00 h), infrared illumination aided observation. At each observation, counts were repeated five times for each tank at approximately 5-min intervals. The average number of fish in each section with a flotsam was calculated and then divided by the total number of fish (n=10). This value, defined as the association ratio, would be 1.0 if fish associated strongly to the object and would be 0.25 with random movement or distribution. In the control treatment, the number of fish in the southeast, southwest, or northwest quadrants was counted from the triplicated tanks, respectively. The average value of these three tanks was used as a control. Total lengths of all the fish were measured after the experiment.

Association ratios were compared for each type of flotsam for each time of observation. Because association ratios deviated from normal distribution, we applied arcsine transformation ($p'=\arcsin\sqrt{p}$; Zar, 1996). The resultant data showed nearly normal distribution. One-way ANOVA was then applied followed by Scheffé's test as a *post hoc* test (Zar, 1996; Abacus Concepts, Inc., 1992). We considered an association ratio higher than the control ($P<0.05$, Scheffé's test) to be evidence of association behavior with that flotsam.

Results

In 5.5-mm, 8.8-mm, and 10-mm fish, no association behavior was observed with any types of flotsam, and the average association ratios were always near 0.25 (Fig. 2, A–C). At 12 mm, the first significant association behavior was observed both with transparent and gray objects (Fig. 2D; $P<0.05$). Association ratios did not differ significantly between these two object types at this stage ($P>0.2$). At 15 mm, association behavior was not obvious, perhaps because the fish swam around in the tank restlessly in this particular trial, both in test and control groups. At 20 mm, association was again obvious and the association ratio to the gray pipe tended to be higher than that to the transparent pipe (P=0.013 at 20:00 h on the second day, Fig. 2F). Association behavior was especially strong at night, and some individuals almost touched the transparent and gray pipes (Fig. 3). In most cases it took at least 12 h for fish to show an association behavior in the experimental tank, but 21-mm fish showed an association with gray objects immediately after they were introduced to the tank. At 28 mm, an association with transparent and gray pipes was positive, but the association ratio tended to be slightly less than fish at 20 mm and 21 mm. No association behavior with shadows was observed at any life-history stage of the fish.

Association ratios after 12 h and 24 h in the experiment (12:00 h and 20:00 h on the second day) were plotted against the total length of each fish (Fig. 4), showing that striped jack begin association behavior at 12 mm in TL with both transparent and gray objects.

Discussion

Accurate observation of association behavior can suffer from biases attributed to other behavior and taxis. For example, striped jack show strong phototaxis from 3.5 mm TL and rheotaxis from 4.5 mm TL (Masuda and Tsukamoto, 1996). In the present study these potential confounding factors were prevented by illuminating the tanks strongly from above and by using tanks without currents. This procedure was apparently successful because most fish smaller than 10 mm distributed themselves about equally in the experimental tanks (Fig. 2, A–C). Striped jack also exhibit schooling behavior from about 16 mm (Masuda and Tsukamoto, 1998b) which may have contributed to the fluctuating association ratio values with 15-mm or larger fish in the control tanks (Fig. 2, E and F).

Small tank size (30 liters) used in this experiment may have affected the results because the fish may have considered a tank wall as a structure with which to associate. However, fish apparently preferred the pipe to the tank wall and associated closely with it (Fig. 3). Strong aeration outside tanks in the water bath might have minimized their association to the tank wall. The limited swimming ability and shortsightedness of the larvae and juveniles also helped to reduce the effect of the tank wall.

Our results indicate that striped jack first started to show association behavior at 12 mm TL. Hunter and Mitchell (1967) reported six species of carangid fish juveniles associated with flotsam offshore Costa Rica, and their smallest sizes (given as standard lengths) were as follows: *Caranx caballus*: 9 mm; *C. hippos*: 16 mm; *Decapterus sp.*: 17 mm; *Elagatis bipinnulatus*: 11 mm; *Selar crumenophthalmus*: 15 mm; and *Seriola sp.*: 10 mm. From observation of hatchery tanks, Tachihara et al. (1993) reported that artificially reared greater amberjack, *Seriola dumerili,* larger than 11 mm standard length associate with objects. The smallest size of an flotsam-associating individual in natural waters may differ depending on species, area, season, and sampling methods. The smallest size (12 mm in TL) to associate with flotsam in our study was therefore consistent with field and hatchery observations of other carangid species.

We hypothesized that mechanical and visual stimuli may be cues for association behavior. No association with shadow flotsam was observed at any fish stages in our study, suggesting that shade is too weak a stimulus to evoke association behavior. At 12 mm, association behavior was observed to both transparent and gray flotsam, and in fish larger than 20 mm, association to gray flotsam was stronger. This finding suggests that in early juvenile stages, a mechanosensory system, as well as vision, may be involved in association behavior. Striped jack showed stronger association behavior in darkness than in light—a finding that seems to conflict with Gooding and Magnuson (1967) who found that residents of an experimental floating raft accumulate more rapidly by day than by night. In nature striped jack may find flotsam by vision during the daytime and maintain an association with it by a mechanosensory system during night. Floating structures may serve as feeding places, shelters from predation, and

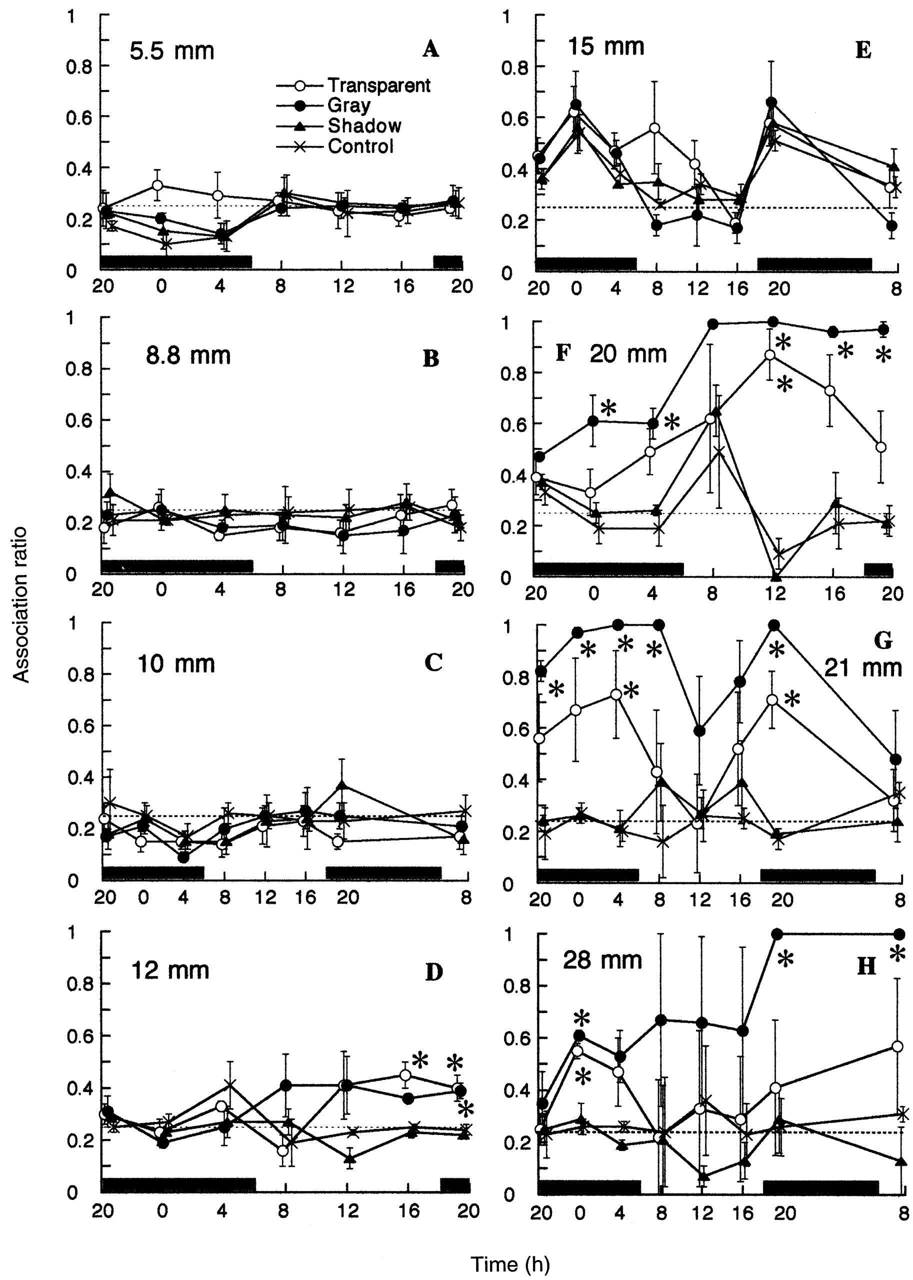

Figure 2

Association ratios for each type of flotsam in each stage. Each plot represents an average (±SE) of three tanks with the same type of flotsam. * shows significant difference between tests and controls ($P<0.05$; Scheffé's test). Expected value of random distribution (=0.25) is represented as a dotted line in each graph. Shaded bar corresponds with dark hours.

cues to migratory orientation (Hunter and Mitchell, 1967; Gooding and Magnuson, 1967; Kingsford, 1993). Flotsam may provide the first cue to finding conspecifics and to forming a school because association behavior may also be related to school formation and maintenance (Masuda and Tsukamoto, 1998b).

In conclusion, the association behavior of striped jack appeared at 12 mm and is probably dependent on a mechanosensory system, as well as vision. Association behavior may also help the development of schools and may provide transportation for migration. Environmental modifications that reduce flotsam, such as the removal of drift

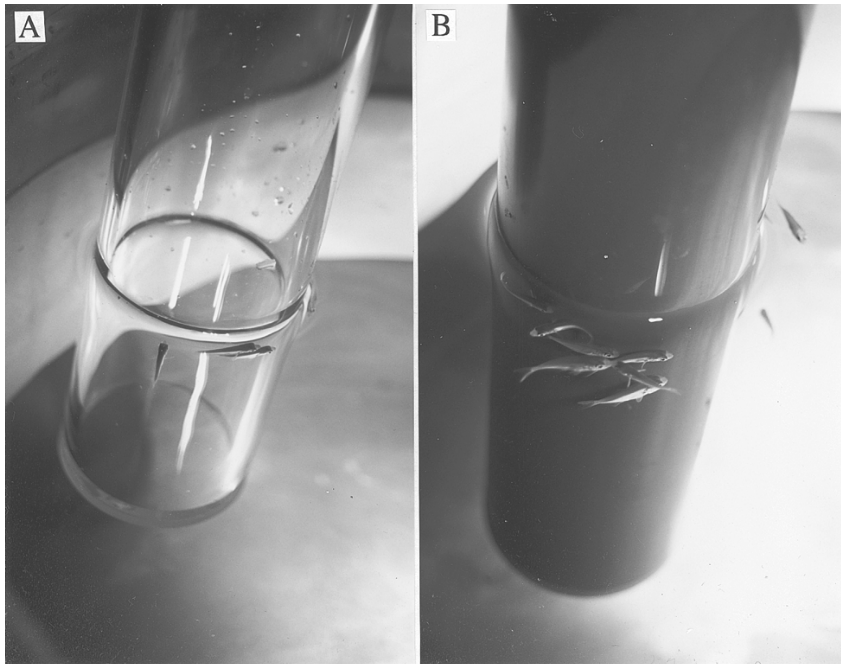

Figure 3

Typical association behavior of striped jack at night observed in 20-mm-TL juveniles: (**A**) transparent flotsam, (**B**) gray flotsam.

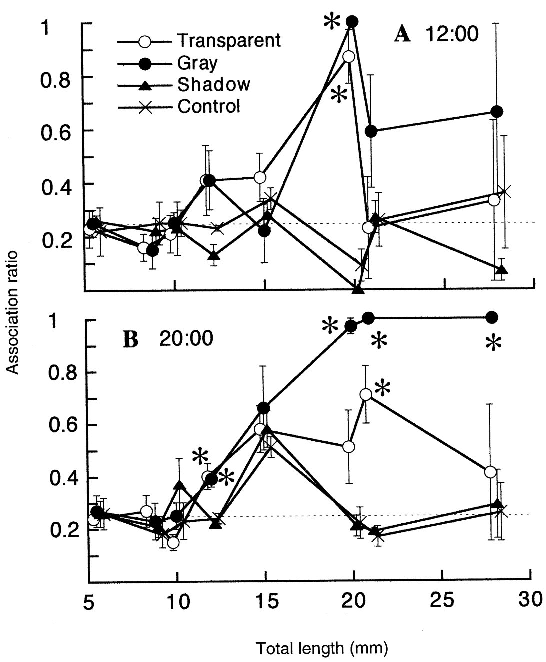

Figure 4

Onset of association behavior in the striped jack. Association ratios at 16 h (**A**) and 24 h (**B**) after starting experiments (12:00 and 20:00) were plotted against total length at each stage. * shows significant difference between tests and controls ($P<0.05$; Scheffé's test).

algae, may influence the recruitment of flotsam-associating species.

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