La mer 42 : 67–72, 2004
Société franco-japonaise d'océanographie, Tokyo

Diet shift with settlement in the yellowfin goby *Acanthogobius flavimanus* on a tidal mudflat

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Abstract : To ascertain the diet shift from pelagic larval to benthic juvenile phases in the yellowfin goby, *Acanthogobius flavimanus*, the gut contents of 287 specimens (9.7–15.9 mm in standard length), collected on a tidal mudflat in the Tama River estuary, central Japan, were examined. Major food components changed rapidly from planktonic animals (e.g., polyphemoids, and calanoid and cyclopoid copepods) to benthic or epiphytic crustaceans (e.g., harpacticoid copepods), with a decrease in prey size, as juveniles settled to their benthic habitat. Settled juveniles had lower gut fullness index values than recorded for small pelagic larvae and juveniles.

Keywords : *Acanthogobius flavimanus, settlement, diet shift, tidal mudflat*

1. Introduction

The yellowfin goby, *Acanthogobius flavimanus*, is one of the most common fishes in Japanese estuarine and coastal waters and has enjoyed some popularity as a game fish (SHIMIZU, 1984). The early life history has been studied comprehensively (e.g., DOTSU and MITO, 1955; SUZUKI *et al.*, 1989; KANOU, 2003), the habitat shift being summarized as follows; spawning occurs mainly at a depth of 5–10 m in sheltered bay waters, newly-hatched and early pelagic larvae being distributed around the spawning ground (Tokyo Metropolitan Fisheries Experimental Station, 1985); late pelagic larvae and juveniles migrate to shallow water, such as estuarine tidal mudflats, subsequently settling to a demersal habitat (KANOU *et al.*, 2000, 2004a).

Although the feeding ecology of benthic juvenile yellowfin goby has been reported by many authors (e.g., KIKUCHI and YAMASHITA, 1992; TAKIZAWA *et al.*, 1994; SAKAI *et al.*, 2000), that of the transitional phase from late pelagic larvae to newly-settled juveniles, which may play an important role in the survival of marine fishes under natural conditions (THORISSON, 1994; MINAMI, 1995), has not been studied well. The present study describes ontogenetic changes in the food habit of yellowfin goby during the transitional phase, on the basis of specimens collected on a tidal mudflat.

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2. Materials and Methods

Sampling was conducted on a tidal mudflat in the Tama River estuary (35° 32′ N, 139° 46′ E), central Japan, on 12 April 2001. To collect larval and juvenile *Acanthogobius flavimanus*, a small seine net (1×1 mm square mesh, 10 m wide and 1 m deep) was towed at a depth of 1 m three hours after low tide in daytime, following the methods described in KANOU *et al.* (2004b). During the sampling period, the water was turbid, the salinity and temperature in surface water being 21.0‰ and 18.4℃, respectively. All samples were fixed in 5% formalin in the field and later preserved in 70% ethanol in the laboratory.

Based on morphological changes, the yellowfin goby postflexion larvae and juveniles

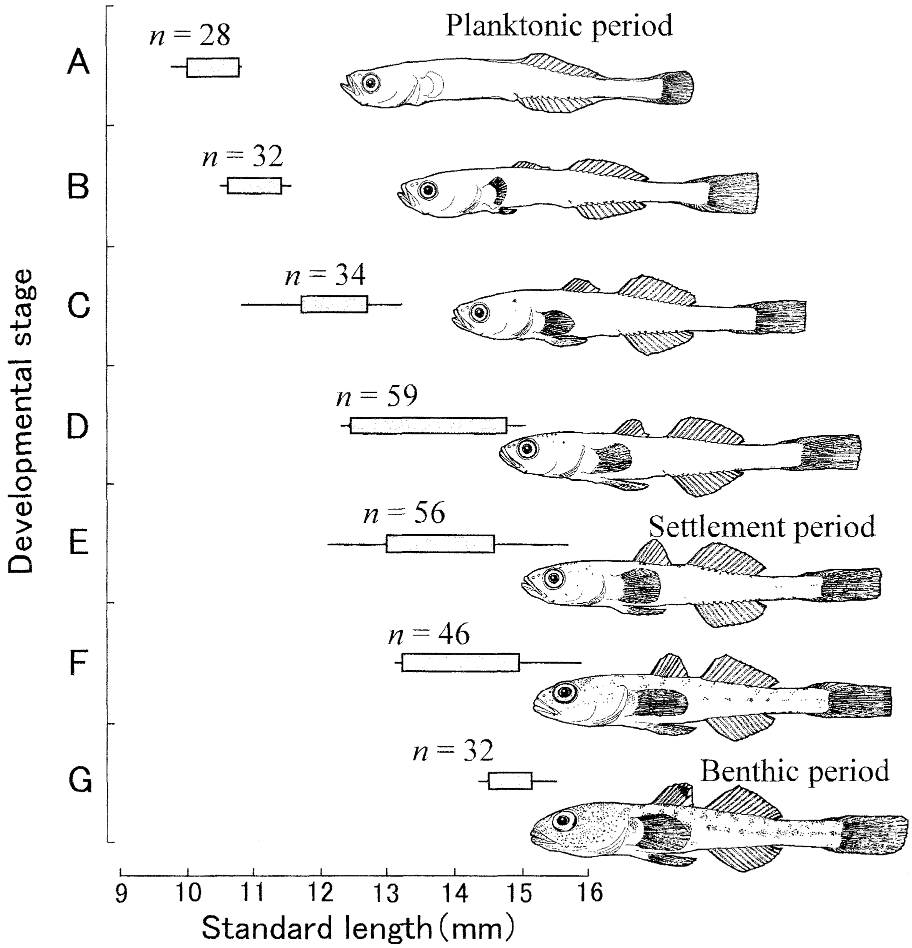

Fig. 1. Number of specimens and standard length in each developmental stage (A–G) of *Acanthogobius flavimanus* examined in this study. Narrow and broad horizontal bars indicate range and standard deviation of standard length, respectively. A–D, planktonic period ; E and F, settlement period ; G, benthic period.

were divided into seven stages (A–G) (KANOU *et al.*, 2004c). In addition, following observations of swimming behavior under rearing conditions, the life mode of each stage was categorized into planktonic (stages A–D), settlement (stages E and F) and benthic periods (stage G) (KANOU *et al.*, 2004c). For gut content analyses, 287 specimens representing all seven stages [9.7–15.9 mm in standard length (SL)] were selected from the above samples, the number of specimens and body size of each stage examined being shown in Fig. 1.

Mouth width and SL of each specimen were measured to the nearest 0.01 mm with a micrometer attached to a binocular microscope, following YOUNG and DAVIS (1990). The entire alimentary canal (from mouth to anus) then was removed. The gut was straight at stage A, folding beginning in stages B and C. A deep "N" shape gut (adult condition) was evident by stage F (KANOU *et al.*, 2004c). Because of the differences in gut shape, we examined the contents in the anterior part of the gut in specimens with a straight gut and up to the first bend of the gut in larger specimens. Food items in the gut contents of each fish were sorted in major taxonomic categories. The number and body width of items in each gut were counted and measured, respectively. Carapace width in crustaceans and the deepest width against the longest axis in the other organisms were measured. The percentage volume of each food item in the diet was visually determined as follows: gut contents were squashed on a 1×1 mm grid slide to a uniform depth of 0.2 to 1.0 mm and the volume occupied by each item measured. The latter was then divided by the total volume of the gut contents to calculate the percentage volume of that item in the diet. Food resource use was expressed as mean percentage composition of each item by volume (%V), which was calculated by dividing the sum total of the individual volumetric percentage for the item by the number of specimens examined (SANO *et al.,* 1984; HORINOUCHI and SANO , 2000). Specimens with empty guts were excluded from the analysis.

The gut fullness index (GFI) was used to measure the degree of feeding intensity of each fish as follows:

$$GFI = (GCV / SL^3) \times 1000$$

where GCV is the volume of the contents in the anterior part of the gut in specimens with a straight gut and up to the first bend of the gut in larger specimens. Specimens with empty guts were included in the comparison of mean GFI among the different developmental stages. In addition, the vacuity index (VI) was calculated as follows:

$$VI = (\text{number of specimens with empty guts} / \text{the total number of specimens}) \times 100.$$

Non-parametric Kruskal-Wallis analysis was employed to test if %V, GFI, mouth width of fish, and number and body width of prey differed among fish developmental stages. If the differences were significant ($P < 0.05$), they were compared between all possible pairs of developmental stages using Tukey's Q test.

3. Results

Of the 287 specimens examined, 224 individuals contained food items and 63 were empty (VI = 22.0). VI values for each developmental stage were low, ranging from 12.5 to 26.1 (Table 1), with mean overall GFI being 0.41. The GFI values differed significantly among the developmental stages (Fig. 2, Kruskal-Wallis test, $H = 49.5$, $P < 0.001$), with higher values in stages B and C than in the subsequent stages (Tukey's Q test, $P < 0.05$).

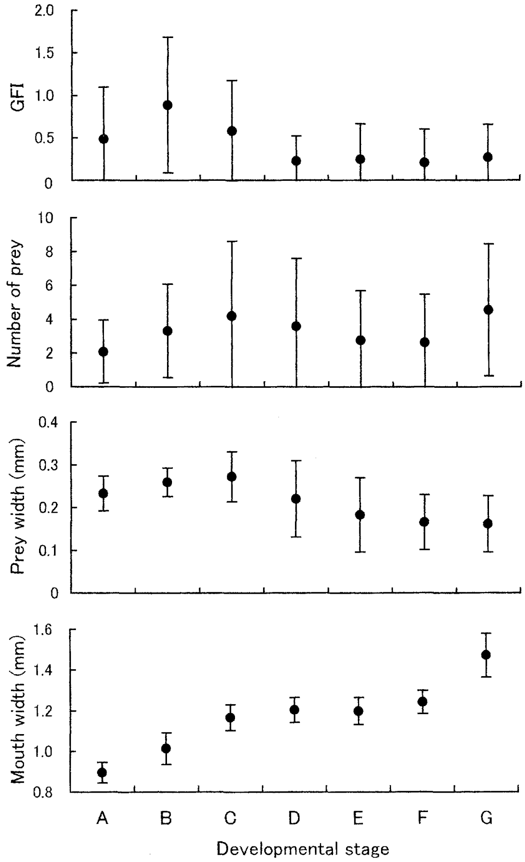

Fig. 2. Ontogenetic changes in mean gut fullness index (GFI), number and width of prey, and mouth width in *Acanthogobius flavimanus*. Bars indicate standard deviation.

The major food items overall were planktonic animals, including polyphemoids, and calanoid and cyclopoid copepods, and small benthic or epiphytic crustaceans, such as harpacticoid copepods, these categories accounting for 89.5% of the gut contents by volume. The %V of major food items (planktonic animals and small benthic or epiphytic crustaceans) differed significantly among the developmental stages

Table 1 Percentage volume of food items in the diet of each developmental stage of *Acanthogobius flavimanus*

Food item	Developmental stage							Total
	A	B	C	D	E	F	G	
Planktonic animals								
Calanoid and cyclopoid copepods	54.7	46.6	42.8	55.6	33.6	7.9	9.5	36.0
Polyphemoids	29.0	45.1	34.1	15.1	9.9	2.5	0	17.3
Barnacle larvae	13.6	2.8	8.9	5.7	4.8	0	0	4.8
Shrimp larvae	0	0	0	0	0.2	0	0	+
Crab zoeae	0	0	0	0	1.7	0	0	0.3
Small benthic or epiphytic crustaceans								
Harpacticoid copepods	0	3.4	5.7	11.6	38.2	51.0	43.4	23.9
Poechilostomid copepods	0	0	0	0.4	0.7	4.5	1.9	1.1
Podocopid ostracods	0	0	0.8	2.9	4.3	0	0.5	1.6
Gammaridean amphipods	0	0	7.6	3.4	0.9	5.6	0	2.7
Cumaceans	0	0	0	1.2	0	7.1	4.0	1.8
Polychaetes								
Errant polychaetes	0	0	0	3.6	2.9	10.5	21.7	5.6
Sedentary polychaetes	0	0	0	0	0	6.8	4.8	1.6
Molluscs								
Gastropods	0	0	0	0	0.4	0	0	0.1
Bivalves	0	0	0	0	0	0.4	0	0.1
Nematodes	0	0	0	0	0.2	0.4	1.7	0.3
Invertebrate eggs	2.7	2.1	0	0	0	0	0	0.5
Detritus	0	0	0	0.4	2.0	3.4	12.7	2.6
Number of fish with food examined	21	25	27	47	42	34	28	224
Vacuity index	25.0	21.9	20.6	20.3	25.0	26.1	12.5	22.0

+<0.1.

(Table 1, Kruskal-Wallis test, planktonic animals, $H = 122.3$, $P < 0.001$; small benthic or epiphytic crustaceans, $H = 90.5$, $P < 0.001$). The %V of planktonic animals was greater in stages A–D than in stages E–G (Tukey's Q test, $P < 0.05$), the opposite being found for small benthic or epiphytic crustaceans (Tukey's Q test, $P < 0.05$).

Prey numbers per gut ranged from 0 to 17 individuals, although the Kruskal-Wallis test revealed that the number did not differ significantly among the developmental stages (Fig. 2, $H = 10.6$, $P = 0.10$). Body width of prey in the gut contents ranged from 0.08 to 0.41 mm. The differences in prey width among fish developmental stages were statistically significant (Fig. 2, Kruskal-Wallis test, $H = 168.4$, $P < 0.001$), with greater widths in stages B and C than in stages E to G (Turkey's Q test, $P < 0.05$). Mouth width of fish increased during stages A to C, thereafter stabilizing at about 1.2 mm until stage F and increasing rapidly in stage G (Fig. 2, Tukey's Q test, $P < 0.05$).

4. Discussion

The major food items of yellowfin goby changed rapidly from planktonic animals to benthic or epiphytic crustaceans, with fish settlement. Similar switching in food items coupled with settlement are known for various demersal fishes (see MINAMI, 1984; TANAKA *et al.*, 1996; MCCORMICK and MAKEY, 1997).

In general, marine fish larvae and juveniles select larger prey items with growth (e.g., LAST, 1978; PETERSON and AUSUBEL, 1984; YOUNG and DAVIS, 1990), which may be partly the result of morphological changes in feeding-related characters as follows: increasing mouth width (LAST, 1978; HUNTER, 1981), improvement of jaw structure (GOSLINE, 1971; KOHNO *et al.*, 1997), and development of teeth and gill rakers (GOSLINE, 1971; WRIGHT *et al.*, 1983). On the other hand, decreasing prey size from late larvae to juveniles has been reported for several fishes (THORISSON, 1994), although the reason remains unclear. In the present study, such a decrease in prey size was observed in the yellowfin goby, with a change in food items at settlement. Because significant changes in feeding-related characters (e.g., mouth width, jaw structure and number of teeth) of the fish were not found at the same time (KANOU *et al.*, 2004c, present study), the decreased prey size may be related to differences in prey composition between the pelagic and benthic habitats in the study area.

Cessation or difficulty in feeding from late larvae to juveniles, indicated by high VI values (VI > 50 in most cases), have been reported in a number of coastal fishes under natural conditions (e.g., THORISSON, 1994; TANAKA *et al.*, 1996; KANOU and KOHNO, 2001). Such may be partly linked to starvation or vulnerability to predation (THORISSON, 1994; MINAMI, 1995; GWAK *et al.*, 1999). In some flatfishes, the non-feeding span coincides with the settlement period (KEEFE and ABLE, 1993; TANAKA *et al.*, 1996), which may be a result of the structural and functional reorganization of the digestive system during metamorphosis, delayed behavioral adaptation to the benthic habitat and a shortage of suitably-sized prey for newly-settled individuals (TANAKA *et al.*, 1996; NOICHI, 2001). Although yellowfin goby did not have a non-feeding period as shown by low VI values from 13 to 26, GFI values decreased around settlement. These results suggest that the settlement period for this goby is characterized by poor nutritional condition, even though feeding was not ceased entirely. Because of a lack of data for prey abundance on the mudflat, however, we could not determine whether or not the poor nutritional condition is related to exogenous factors. Further experimental studies under field condition, including information for prey availability around settlement, will be required.

Acknowledgements

We thank G. Hardy, Ngungura, New Zealand, for critical comments on the manuscript. We also thank K. Fujita, M. Moteki, K. Arayama and H. Imai, Tokyo University of Marine Science and Technology, K. Shibukawa, National Science Museum of Tokyo, H. Kurokura, The University of Tokyo and T. Noichi, Natural History Museum and Institute of Chiba, for their support during this investigation.

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Received August 30, 2004
Accepted November 25, 2004