FISHERIES SCIENCE 2007; **73**: 38–45

Relationships between short-term variations in density of juvenile yellowfin goby *Acanthogobius flavimanus* and environmental variables on an estuarine mudflat

Kouki KANOU,[1]* Mitsuhiko SANO[2] AND Hiroshi KOHNO[3]

[1]*Japan Wildlife Research Center, Taito, Tokyo 110-8676,* [2]*Department of Global Agricultural Sciences, Graduate School of Agricultural and Life Sciences, University of Tokyo, Bunkyo, Tokyo 113-8657, and* [3]*Laboratory of Ichthyology, Tokyo University of Marine Science and Technology, Minato, Tokyo 108-8477, Japan*

ABSTRACT: Weekly variations in density of juvenile yellowfin goby *Acanthogobius flavimanus* with a variety of environmental variables (e.g. water temperature, salinity and transparency, and prey density) were investigated on a tidal mudflat within the Tama River estuary, central Japan, from March to July 2001. Metamorphosing newly settled juveniles occurred from mid-March to late May. Metamorphosed benthic juveniles first appeared in late March, the density sharply increasing to a peak (67.0 ind./m^2) in early May but rapidly decreasing to less than 10% of that two weeks later. No consistent relationships were apparent between short-term variations in fish density by developmental stages and water temperature, or salinity. In contrast, a weak negative relation was found between juvenile density and water transparency. Further, benthic juvenile density was positively related to short-term fluctuations of errant polychaetes, which is one of the main prey items.

KEY WORDS: ***Acanthogobius flavimanus*****, juveniles, nursery, prey density, settlement, tidal mudflat.**

INTRODUCTION

Many coastal fishes use shallow estuarine habitats as nurseries.[1–4] Estuarine nurseries are widely believed to offer juvenile fishes a measure of protection from predators, plus plentiful food.[5–9] In contrast, estuaries are also highly variable environments, strongly influenced by coastal conditions and upland freshwater drainage. Such variations in abiotic factors may lead to changes in predation pressure on juvenile fishes,[10–12] or can restrict food availability, even in a highly productive estuarine habitat.[13] The environment experienced by juveniles will likely differ according to the timing of recruitment to the estuarine nursery; growth and survival consequently vary among juveniles using the same nursery.[13] Accordingly, to understand variations in nursery functions of shallow estuarine habitats for each fish species, the relationships between juvenile abundance and environmental variables need to be investigated throughout the recruitment and postrecruitment periods.

The yellowfin goby *Acanthogobius flavimanus* is a common benthic inhabitant of sandy mud areas in estuarine and sheltered bay waters along the main islands of Japan, the Korean Peninsula, China Sea, and Amur basins.[14] This goby has acquired popularity as a game fish in Japan.[15] Spawning occurs from early January to late May[16–20] when males construct burrows 1.3–3 m long, with 3–5 entrances, mainly in sandy muddy bottoms at depths of 2–10 m in sheltered bay waters.[21] Females lay demersal adhesive eggs that attach to the inner wall of the burrow. Hatching begins approximately 16–28 days after insemination,[17,22] and newly hatched larvae, which range from 4–5 mm total length,[22] inhabit the middle and bottom layers around the spawning ground.[17,23,24] At the end of the pelagic period (~1 month), late postflexion larvae and juveniles appear abundantly in shallow estuarine habitats such as tidal

*Corresponding author: Tel: 81-3-5824-0969. Fax: 81-3-5824-0970. Email: kkano@jwrc.or.jp
Received 21 November 2005. Accepted 28 July 2006.

mudflats with flood tides,[25] subsequently settling to benthic habitats with marked morphological changes when they reach 13–15 mm standard length (SL),[26,27] and growing rapidly thereafter within these habitats.[18,20,28,29] Several studies have indicated that yellowfin goby use shallow estuarine habitats as nurseries.[30–32] However, short-term variations (e.g. weekly occurrence) in abundance of the goby during the arrival of larvae and shortly after settlement, a period in which many fishes suffer a higher mortality rate,[33–36] have not been investigated to date. If shallow estuarine habitats function as a nursery for the goby during this critical period, advantageous environmental conditions for their survival and growth may exist within those habitats.

This article describes the results of a field survey in which we examined short-term variations in density of juvenile yellowfin goby on an estuarine mudflat during spring and summer. We also investigated whether such variations were associated with environmental parameters (e.g. water temperature, salinity and transparency, and prey density). In this study, the term recruitment refers to the arrival of postlarval and juvenile stages of fishes to an estuarine mudflat.

MATERIALS AND METHODS

Study site

The study was carried out in the Tama River estuary (35°32′N, 139°46′E) located on the western shore of Tokyo Bay, central Japan. The estuary is subjected to semidiurnal tides with a tidal range of 0–2 m. The tidal current from the bay flows along the estuary at flood tide, but the effect of freshwater inflows is significant at low tide. The study site was located on a tidal mudflat approximately 3 km from the river mouth. A map of the study site is given by Kanou *et al.*[25] Sediment of the surface layer in the subtidal zone consisted of approximately 20% silty clay and 80% sand. There was no rooted macrophyte vegetation in the site during the study period.

Sampling of fish

Fish sampling was conducted weekly from early March to mid-July 2001. A small seine (1 mm × 1 mm square mesh, 10 m wide, 1 m deep with a 4-m-long purse-bag at its center) was hauled along the shoreline for 25 m at a depth of 1 m, following methods described in Kanou *et al.*[37] Four hauls were taken 1 h after low tide in the daytime on each day. The deployment of each haul required approximately 1 min, and the estimated area covered by each was approximately 100 m^2. All samples were fixed in 5% formalin in the field and later preserved in 70% ethanol in the laboratory.

Fishes were removed from the samples using a dissecting microscope and identified to the lowest possible taxon, following Okiyama,[38] Kanou *et al.*,[39] and Nakabo.[40] The number of individuals of each species was counted, and SL measured to the nearest 0.1 mm with either digital calipers or a micrometer attached to a microscope. Further, yellowfin goby specimens were sorted into the following developmental stages: (i) postflexion larvae (stages A and B in Kanou *et al.*[27]); (ii) pelagic juveniles (stages C and D); (iii) settling juveniles (stages E and F); and (iv) benthic juveniles (stage G). The number of goby in each stage was counted.

Sampling of primary prey

As yellowfin goby juveniles settle to their benthic habitat, their main food components change rapidly from planktonic (cladocerans, and calanoid and cyclopoid copepods) to benthic animals (harpacticoid copepods and polychaetes).[41] The contribution of polychaetes to the diets of benthic juveniles increases with growth.[42] To ascertain whether short-term variations in abundance of the goby were associated with primary prey density, such prey animals were collected immediately after fish sampling each day.

Planktonic prey animals, including cladocerans, and calanoid and cyclopoid copepods, were collected using a 0.3 mm-mesh conical net (45 cm mouth diameter and 180 cm long) with a flow meter. The net was towed just below the surface in 1-m deep water along the shoreline. Four tows were taken each day. The volume of water filtered was 2.9–4.6 m^3 per tow. The sample was fixed in 5% buffered formalin. Cladocerans, and calanoid and cyclopoid copepods in each sample were sorted and counted under a binocular microscope in the laboratory.

Benthic prey animals, such as harpacticoid copepods and polychaetes, were collected with a cylindrical core sampler (11 cm diameter) that was used to extract a 300-cm^3 volume (3.2 cm depth) of sediment from four points located randomly (at least 5 m apart) in the subtidal zone. Immediately after collection, each sample was fixed in 5% buffered formalin. Errant and sedentary polychaetes were removed by initial sorting using a 0.5 mm-mesh sieve, and harpacticoid copepods were extracted subsequently by decantation using a 0.1 mm-mesh conical net.[43] Prey animals in each core were sorted and counted under a binocular microscope in the laboratory.

Physical environmental variables

Immediately after fish sampling each day, surface water temperature, salinity, and transparency were surveyed at a depth of 1 m. Salinity was measured by a salinity refractometer (S/Mill-E, Atago, Tokyo, Japan). Transparency was evaluated by observing the visibility of objects with clear patterns through a layer of water. The column of water above the patterns in a long plastic transparent tube (4 cm diameter, 50 cm high) was altered gradually and the depth of disappearance of the object recorded as transparency in centimeters.[44]

Data analysis

The density of each developmental stage of yellowfin goby was expressed as the number of individuals per 1 m^2. According to Kanou *et al.* [37] the catch efficiency of the small seine for benthic juvenile yellowfin goby was estimated as 23–71%. A negative relationship between efficiency (E) and fish length (SL) was found as:

$$E\,(\%) = 104.4 - 2.14 \times SL\,(\text{mm})\,(r^2 = 0.969, P = 0.01)$$

Therefore, the absolute abundance of this stage was calculated by using the catch efficiency data and mean SL for each day. The densities of planktonic prey animals (cladocerans, and calanoid and cyclopoid copepods) were expressed as the number of individuals per 1 m^3, and those of benthic prey animals (harpacticoid copepods, and errant and sedentary polychaetes) as the number of individuals per 300 cm^3 of sediment.

A one-way analysis of variance (ANOVA) was used to test whether the density of each developmental stage of juvenile yellowfin goby differed among sampling dates during the period when each developmental stage of juvenile yellowfin goby occurred. The Bonferroni test was used for a *posteriori* multiple comparison procedure. Before analysis, the homogeneity of variances was improved by transformation of data to $\log_{10}(x + 1)$.[45] The density of each prey animal (cladocerans, calanoid and cyclopoid copepods, harpacticoid copepods, and errant and sedentary polychaetes) was also compared among sampling dates using one-way ANOVA and a *post hoc* Bonferroni test. Simple linear regression was performed to test the null hypothesis that no relationship existed between environmental conditions (water temperature, salinity and transparency, and prey density) and the mean density of each developmental stage of goby during the occurrence season.

RESULTS

Physical variables

Water temperature remained constant at 13°C until mid-March, but increased gradually thereafter, reaching 20°C in early May and 27°C in late June (Fig. 1a). Salinity and water transparency ranged from 4.1–18.2 and 17–45 cm, respectively (Fig. 1a). No clear seasonal trend in either variable was found.

Primary prey density

The density of each prey category in the study site differed significantly among sampling dates (one-way ANOVA, cladocerans $F_{14,45} = 20.1$, $P < 0.001$; calanoid and cyclopoid copepods $F_{17,54} = 57.3$, $P < 0.001$; harpacticoid copepods $F_{17,54} = 23.9$, $P < 0.001$; errant polychaetes $F_{17,54} = 29.3$, $P < 0.001$; sedentary polychaetes $F_{17,54} = 41.0$, $P < 0.001$). Cladocerans, calanoid and cyclopoid copepods, and harpacticoid copepods were much more abundant from early March to mid-April than in other periods (Bonferroni test, all $P < 0.05$; Fig. 1b,c). A much higher density of sedentary polychaetes was found from early March to early May (Bonferroni test, $P < 0.05$; Fig. 1c). In contrast, the density of errant polychaetes was very low during much of March, starting to increase from late March and peaking in early May (Bonferroni test, $P < 0.05$; Fig. 1c). The rapid decline in errant polychaetes after early May was similar to that of sedentary polychaetes.

Density and body size of yellowfin goby

A total of 108 941 individuals, representing 12 families and 27 species, were collected using the seine net during the study period. Of these species, yellowfin goby was the most abundant, comprising 56.9% of the total number of fishes. Yellowfin goby collected mainly comprised benthic and settling juveniles (75.3 and 19.3%, respectively, of the total number for the species), and partly pelagic juveniles (5.3%). The abundance of each stage is shown in Figure 1d. Postflexion larvae were rarely collected (~0.1%).

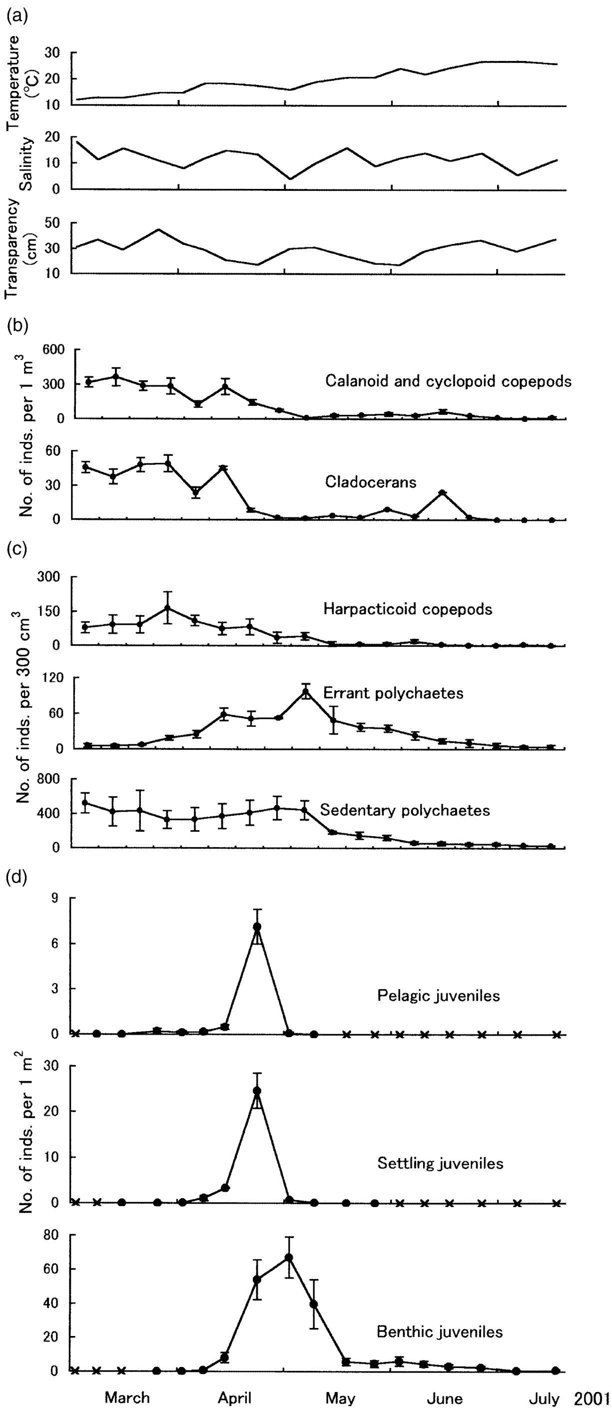

Fig. 1 Weekly changes in (a) physical variables, (b) mean number of individuals per 1 m^3 of each planktonic prey category, (c) mean number of individuals per 1 m^2 of each benthic prey category, and (d) mean number of individuals per 1 m^2 of each developmental stage of juvenile yellowfin goby, during the study period. Vertical bars indicate standard deviation. ×, not caught.

Pelagic and settling juveniles occurred from mid-March to early May and mid-March to late May, respectively (Fig. 1d). Short-term variations in the density of each stage were statistically significant (one-way ANOVA, pelagic juveniles $F_{8,27} = 228.5$, $P < 0.001$; settling juveniles $F_{9,30} = 443.5$, $P < 0.001$). Much higher densities of both stages were found in late April, coinciding with a spring tide.

The density of benthic juveniles also differed significantly among dates (one-way ANOVA, $F_{14,45} = 108.1$, $P < 0.001$). Benthic juveniles occurred abundantly from late April to early May, with a peak density of 67.0 ind./m^2 in early May (Bonferroni test, $P < 0.05$, Fig. 1d), but the density decreased rapidly to 5.7 ind./m^2 two weeks after the peak. Thereafter, the density remained constant until beginning to decrease gradually from early June (Bonferroni test, $P < 0.05$).

The mode of size-frequency distribution of benthic juveniles remained constant at 15.0–19.9 mm SL in early May, when the peak abundance was found, but increased thereafter, finally stabilizing at 40.0–49.9 mm SL in late June (Fig. 2).

Relationships between yellowfin goby density and environmental variables

There were no consistent relationships between short-term fluctuations in density of each developmental stage of yellowfin goby and either water temperature or salinity (Table 1). In contrast, a weak negative relationship was found between juvenile density and water transparency.

The arrival of pelagic juveniles to the present site coincided with the end of the period of higher densities of major prey items (cladocerans, and calanoid and cyclopoid copepods) (Fig. 1b,d). Therefore, the short-term variation in density of pelagic juveniles was unrelated to prey density (Table 1). A similar tendency was found between settling juveniles and prey density (Table 1). The mean density of benthic juveniles was positively related to those of errant polychaetes, but not to harpacticoid copepods or sedentary polychaetes (Table 1).

DISCUSSION

Metamorphosing newly settled juvenile yellowfin goby occurred from mid-March to late May, with the peak density in late April 2001. In a survey on the present mudflat in 1998, a similar duration of the settlement period of the goby, but with earlier peak density, was observed,[46] indicating only

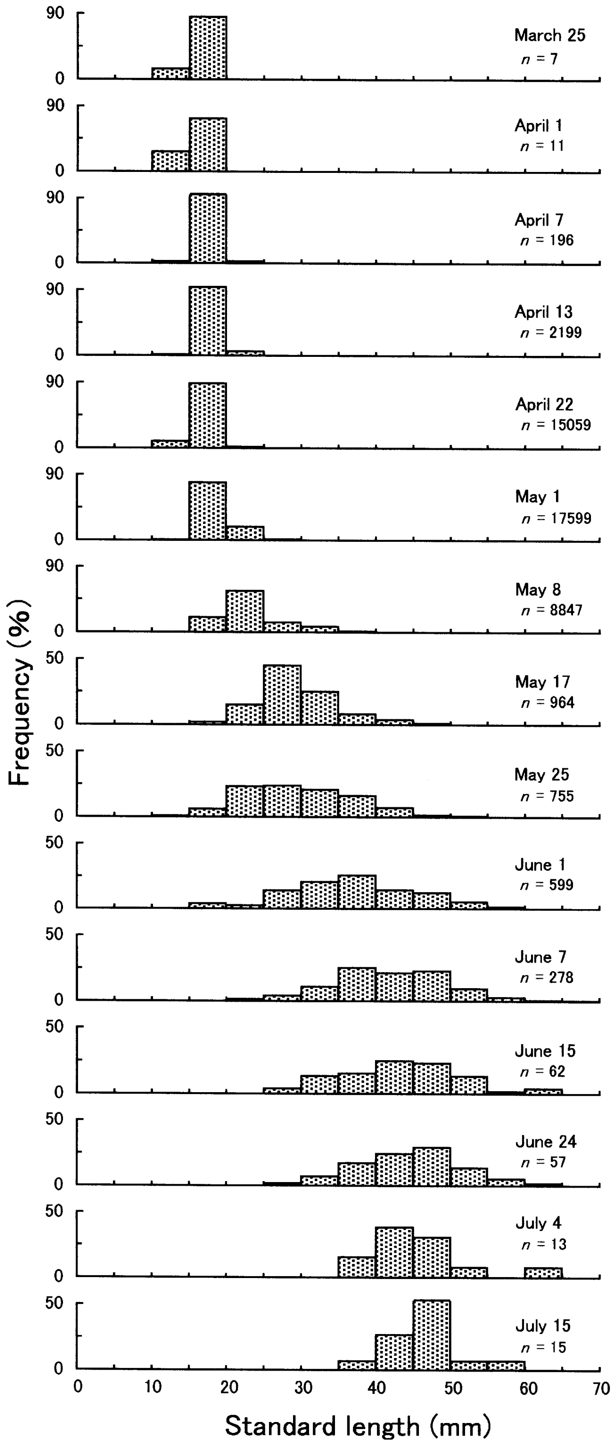

Fig. 2 Weekly changes in size-frequency distribution of benthic juvenile yellowfin goby during the study period.

minor interannual variations in the duration of recruitment, despite different abundance patterns among years. Based on bi-weekly collections of dominant fish species in estuarine epibenthic habitats over 4 years, Allen and Barker[47] also demonstrated that the duration of larval fish recruitment was similar among years but that the patterns of abundance were not consistent from year to year.

Table 1 Coefficients of determination (r^2) in the relationships between mean density of each developmental stage of juvenile *Acanthogobius flavimanus* and environmental variables (water temperature, salinity, transparency, and prey organisms), along with *F*- and *P*-values for the significance test in linear regression

	r^2	F	P
Pelagic juveniles			
Water temperature	0.10	0.75	0.41
Salinity	0.08	0.64	0.45
Transparency	0.43	5.26	0.06
Calanoid and cyclopoid copepods	<0.01	0.02	0.89
Cladocerans	0.22	1.93	0.21
Settling juveniles			
Water temperature	0.01	0.05	0.83
Salinity	0.05	0.45	0.52
Transparency	0.30	3.45	0.10
Harpacticoid copepods	0.01	0.08	0.78
Errant polychaetes	0.17	1.59	0.24
Sedentary polychaetes	0.27	2.96	0.12
Benthic juveniles			
Water temperature	0.06	0.78	0.39
Salinity	<0.01	0.01	0.91
Transparency	0.24	4.21	0.06
Harpacticoid copepods	<0.01	<0.01	0.96
Errant polychaetes	0.37	7.80	0.02
Sedentary polychaetes	0.14	2.04	0.18

Short-term variations in density of juvenile yellowfin goby within the study period were typically large and did not appear to be related to differences in either water temperature or salinity among dates. Several studies have shown that water temperature and salinity have little effect on short-term fluctuations in fish species abundance in temperate estuaries,[48–50] although such may be primary factors affecting long-term changes (i.e. interannual and seasonal variations) in estuarine fish assemblages.[47,51–54]

In various coastal fishes, the timing of arrival at nearshore nursery areas has been partly linked to specific hydrographic events such as a strong tidal current during spring tide.[47–49,55] In addition, Kanou *et al.*[25] showed that pelagic juvenile yellowfin goby may be effectively transported onto an estuarine mudflat by tidal currents during night-flood tides. If the present mudflat functions as a nursery for the goby during the arrival of larvae and shortly after settling, advantageous environmental conditions for their survival and growth must exist in the habitat. In this study, a weak negative relationship was found between juvenile goby density and water transparency. Turbid waters are considered to benefit larval and juvenile fishes by reducing predation pressure and favoring the development of suitable food associated with shallow water,[10–12] which is a possibility for yellowfin goby at the present site.

The concentration of suitable prey items may also act as an aggregating factor for fishes in a specific space.[56,57] In the Ythan estuary, Scotland, Healey[58] reported that the sand goby *Gobius minutus* occurred abundantly with an increase in the primary prey item (gammaridean amphipod *Corophium volutator*). Similarly, in the Tama River estuary, the seasonal pattern of recruitment of benthic juvenile yellowfin goby was directly related to that of errant polychaetes, one of most important food items for the goby.[42,59] Such sympathized patterns in juvenile recruitment and prey abundance may be the adaptive mechanism that enables the goby to use more efficiently the benthic food resources on the mudflat.

In contrast, Kanou *et al.*[42] showed that significant foraging impacts of juvenile yellowfin goby on polychaetes existed on the mudflat during spring, when the goby reached maximum population density. Such effects of foraging may partly account for the rapid decline in densities of errant and sedentary polychaetes in early May. Similarly, some European gobiids occurring abundantly in littoral zones greatly influence the prey population structures.[60–62]

The population size of yellowfin goby on the present mudflat declined rapidly to approximately 10% two weeks after peak abundance in early May, when body lengths ranged from 15–20 mm. Thereafter, densities remained constant until early July, with commencement of emigration of larger individuals to other habitats such as deeper water.[16,18,20] These results suggested that heavy mortality of yellowfin goby may occur shortly after settlement, although during this period, significant physical disturbances, such as strong fresh water discharge by heavy rain, were not apparent.

In various coastal fishes, vulnerability to predation is often high during and shortly after settlement, causing a proportionally higher mortality among newly settled individuals.[34–36,63–66] Previous examinations of the gut contents of several fish species occurring on estuarine mudflats in Tokyo Bay have indicated their potential as predators of small benthic yellowfin goby individuals (<20 mm SL). These predators are adults of three gobiids (*Acanthogobius lactipes* > 38 mm SL, *Gymnogobius macrognathos* > 34 mm SL, and *Gymnogobius breunigii* > 45 mm SL), juveniles of flathead (*Platycephalus* sp. > 55 mm), flatfish (*Kareius bicoloratus* > 50 mm SL), and sea bass (*Lateolabrax japonicus* > 32 mm SL).[46,47] Although the seine used in this study was unsuitable for collection of larger individuals,[37] juvenile sea bass and adult *A. lactipes* and *G. macrognathos* were frequently collected throughout the study period.[46] Therefore, the vulnerability to such predators may lead to a high mortality of juvenile yellowfin goby on the mudflat, although higher water turbidity may partly reduce predation pressure.

Results from this study suggest that juvenile yellowfin goby settled on the mudflat during the period enabling more efficient use of nursery functions (i.e. abundant primary food or turbid waters reducing predation pressure), but the population size appeared to decrease shortly after settlement. To ascertain the complex mechanisms that determine high mortality of benthic juveniles in a nursery, further experimental studies, including information on the influence of potential predators, will be required.

ACKNOWLEDGMENTS

We thank G. Hardy, Ngunguru, New Zealand for critical comments on the manuscript. Thanks to T. Watanabe, Marine Biological Research Institute of Japan Co., Ltd, M. Moteki, Tokyo University of Marine Science and Technology, and H. Kurokura and T. Inoue, University of Tokyo, for support during this investigation.

REFERENCES

1. Weinstein MP. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. *Fish. Bull. (Wash. D.C.)* 1979; **77**: 339–357.
2. Heck KL Jr, Thoman TA. The nursery role of seagrass meadows in the upper and lower reaches of the Chesapeake Bay. *Estuaries* 1984; **7**: 70–92.
3. Beck MW, Heck KL, Able KW, Childers DL, Eggleston DB, Gillanders BM, Halpern B, Hays CG, Hoshino K, Minello TJ, Orth RJ, Sheridan PF, Weinstein MP. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. *Bioscience* 2001; **51**: 633–641.
4. Gillanders BM, Able KW, Brown JA, Eggleston DB, Sheridan PF. Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: an important component of nurseries. *Mar. Ecol. Prog. Ser.* 2003; **247**: 281–295.
5. Ruiz GM, Hines AH, Posey MH. Shallow water as a refuge habitat for fish and crustaceans in non-vegetated estuaries:

an example from Chesapeake Bay. *Mar. Ecol. Prog. Ser.* 1993; **99**: 1–16.
6. Kneib RT. The role of tidal marshes in the ecology of estuarine nekton. *Oceanogr. Mar. Biol. Annu. Rev.* 1997; **35**: 163–220.
7. Paterson AW, Whitfield AK. Do shallow-water habitats function as refugia for juvenile fish? *Estuar. Coast. Shelf Sci.* 2000; **51**: 359–364.
8. Laegdsgaard P, Johnson C. Why do juvenile fish utilise mangrove habitats? *J. Exp. Mar. Biol. Ecol.* 2001; **257**: 229–253.
9. Clark KL, Ruiz GM, Hines AH. Diel variation in predator abundance, predation risk and prey distribution in shallow-water estuarine habitats. *J. Exp. Mar. Biol. Ecol.* 2003; **287**: 37–55.
10. Blaber SJM, Blaber TG. Factors affecting the distribution of juvenile estuarine and inshore fish. *J. Fish Biol.* 1980; **17**: 143–162.
11. Cyrus DP, Blaber SJM. The influence of turbidity on juvenile marine fishes in estuaries. Part 1. Field studies at St. Lucia on the southeastern coast of Africa. *J. Exp. Mar. Biol. Ecol.* 1987; **109**: 53–70.
12. Cyrus DP, Blaber SJM. The influence of turbidity on juvenile marine fishes in estuaries. Part 2. Laboratory studies, comparisons with field data and conclusions. *J. Exp. Mar. Biol. Ecol.* 1987; **109**: 71–91.
13. Kneib RT. Growth and mortality in successive cohorts of fish larvae within an estuarine nursery. *Mar. Ecol. Prog. Ser.* 1993; **94**: 115–127.
14. Shibukawa K. Systematic revision of the East Asian gobiid genus *Acanthogobius* and its relatives. PhD Thesis, Tokyo University of Fisheries, Tokyo. 1997.
15. Shimizu M. Fishes and shellfishes in Tokyo Bay (1). *Aquabiology* 1984; **30**: 9–13 (in Japanese with English abstract).
16. Miyazaki I. Studies on the Japanese common goby, *Acanthogobius flavimanus* (Temminck et Schlegel). *Nippon Suisan Gakkaishi* 1940; **9**: 159–180 (in Japanese with English abstract).
17. Dotsu Y, Mito S. On the breeding-habits, larvae and young of a goby, *Acanthogobius flavimanus* (Temminck et Schlegel). *Jpn. J. Ichthyol.* 1955; **4**: 153–161 (in Japanese with English abstract).
18. Zama A. Ecological study on the fishes found in Mangokuura, Miyagi Prefecture (in Japanese with English abstract). PhD Thesis, Tokyo University of Fisheries, Tokyo. 1999.
19. Katayama S, Sakai K, Iwata T, Honda H. Life history of Japanese common goby *Acanthogobius flavimanus* in Hiroura Lagoon of Natori River mouth. *Bull. Miyagi Pref. Fish. Res. Dev. Center* 2000; **16**: 93–97.
20. Sakai K, Katayama S, Iwata T. Life history of the Japanese common goby, *Acanthogobius flavimanus* in the Matsushima Bay. *Bull. Miyagi Pref. Fish. Res. Dev. Center* 2000; **16**: 85–92.
21. Tokyo Metropolitan Fisheries Experimental Station. On the spawning ecology of *Acanthogobius flavimanus* at the inner part of Tokyo Bay. *Mem. Tokyo Metropolitan Fish. Exp. Stn.* 1985; **182**: 1–65.
22. Suzuki N, Sakurai N, Sugihara T. Development of eggs, larvae and juveniles of the oriental goby *Acanthogobius flavimanus* reared in the laboratory. *Suisanzoshoku* 1989; **36**: 277–289.
23. Takeuchi H, Yasuda S. Seasonal and vertical distribution patterns of fish eggs, larvae and juveniles. *Research report on biology of Shinhama Bird Sanctuary, Chiba Prefecture. Publication 5.* Society of the Study of Shinhama, Ichikawa. 1980;5: 57–90 (in Japanese).
24. Andrew EJ, Robert JL. Fine-scale distribution of nearshore, suprabenthic fish larvae. *Mar. Ecol. Prog. Ser.* 1986; **31**: 223–231.
25. Kanou K, Sano M, Kohno H. Larval and juvenile fishes occurring with flood tides on an intertidal mudflat in the Tama River estuary, central Japan. *Ichthyol. Res.* 2005; **52**: 158–164.
26. Kanou K, Sano M, Kohno H. A net design for estimating the vertical distribution of larval and juvenile fishes on a tidal mudflat. *Fish. Sci.* 2004; **70**: 713–715.
27. Kanou K, Kohno H, Sano M. Morphological and functional development of characters associated with settlement in the yellowfin goby *Acanthogobius flavimanus*. *Ichthyol. Res.* 2004; **51**: 213–221.
28. Kikuchi T, Yamashita Y. Seasonal occurrence of gobiid fish and their food habits in a small mud flat in Amakusa. *Publ. Amakusa. Mal. Biol. Lab.* 1992; **11**: 73–93.
29. Honda H, Katayama S, Ito K, Chida Y, Omori M, Okata A. Structure and function of the production system in an estuarine fish assemblage. *Bull. Coast. Oceanogr.* 1997; **35**: 57–68 (in Japanese with English abstract).
30. Kanou K, Koike T, Kohno H. Ichthyofauna of tidelands in the inner Tokyo Bay, and its diversity. *Jpn. J. Ichthyol.* 2000; **47**: 115–129 (in Japanese with English abstract).
31. Fujita S, Kinoshita I, Takahashi I, Azuma K. Species composition and seasonal occurrence of fish larvae and juveniles in the Shimanto Estuary, Japan. *Fish. Sci.* 2002; **68**: 364–370.
32. Hibino M, Ohta T, Kinoshita I, Tanaka M. Fish larvae and juveniles occurring in the littoral zone of a tidal mudflat, in the bottom of Ariake Bay. *Jpn. J. Ichthyol.* 2002; **49**: 109–120.
33. van der Veer HW. Immigration, settlement, and density-dependent mortality of a larval and early postlarval 0-group plaice (*Pleuronectes platessa*) population in the western Wadden Sea. *Mar. Ecol. Prog. Ser.* 1985; **29**: 223–236.
34. van der Veer HW, Bergman MJH. Predation by crustaceans on a newly settled 0-group plaice *Pleuronectes platessa* population in the western Wadden Sea. *Mar. Ecol. Prog. Ser.* 1987; **35**: 203–215.
35. Tanaka M, Goto T, Tomiyama M, Sudo H. Immigration, settlement and mortality of flounder (*Paralichthys olivaceus*) larvae and juveniles in a nursery ground, Shijiki Bay, Japan. *Neth. J. Sea Res.* 1989; **24**: 57–67.
36. Wennhage H. Vulnerability of newly settled plaice (*Pleuronectes platessa* L.) to predation: effects of habitat structure and predator functional response. *J. Exp. Mar. Biol. Ecol.* 2002; **269**: 129–145.
37. Kanou K, Sano M, Kohno H. Catch efficiency of a small seine for benthic juveniles of the yellowfin goby *Acanthogobius flavimanus* on a tidal mudflat. *Ichthyol. Res.* 2004; **51**: 374–376.
38. Okiyama M. *An Atlas of the Early Stage Fishes in Japan*. Tokai University Press, Tokyo. 1988.
39. Kanou K, Koike T, Shibukawa K, Kohno H. Larvae and juveniles of two gobiids, *Chaenogobius uchidai* and *C. macrognathos*, collected from tidelands in the inner bay of Tokyo Bay. *La Mer* 1999; **37**: 59–68.
40. Nakabo T. *Fishes of Japan with Pictorial Key to the Species*, English edn. Tokai University Press, Tokyo. 2001.

41. Kanou K, Sano M, Kohno H. Diet shift with settlement in the yellowfin goby *Acanthogobius flavimanus* at a tidal mudflat. *La Mer* 2004; **41**: 67–72.
42. Kanou K, Sano M, Kohno H. Ontogenetic diet shift, feeding rhythm and daily ration in juvenile goby, *Acanthogobius flavimanus,* at a tidal mudflat in the Tama River estuary, central Japan. *Ichthyol. Res.* 2005; **52**: 319–324.
43. Yamanishi R. Efficiency of decantation method to extract meiobenthos from sediment samples. *Benth. Res.* 1979; **17/18**: 52–58.
44. Nasu T. Turbidity, clarity, and transparency. In: The Japan Society for Analytical Chemistry, Hokkaido Branch (ed.). *Analysis of Water*, 5th edn. Kagakudojin, Kyoto. 2005; 176–181 (in Japanese).
45. Zar JH. *Biostatistical Analysis*, 4th edn. Prentice Hall, New Jersey, NJ. 1999.
46. Kanou K. Ecology of larvae and juveniles of the oriental goby *Acanthogobius flavimanus* at the tidal flat area in Tokyo Bay, central Japan. PhD Thesis, The University of Tokyo, Tokyo. 2003.
47. Allen DM, Barker DL. Interannual variations in larval fish recruitment to estuarine epibenthic habitats. *Mar. Ecol. Prog. Ser.* 1990; **63**: 113–125.
48. Potter IC, Claridge PN, Warwick RM. Consistency of seasonal changes in an estuarine fish assemblage. *Mar. Ecol. Prog. Ser.* 1986; **32**: 217–228.
49. Drake P, Arias AM. Composition and seasonal fluctuations of the ichthyoplankton community in a shallow tidal channel of Cadiz Bay (S. W. Spain). *J. Fish Biol.* 1991; **39**: 245–263.
50. Cattrijsse A, Makwaia ES, Dankwa HR, Hamerlynck O, Hemminga MA. Nekton communities of an intertidal creek of a European estuarine brackish marsh. *Mar. Ecol. Prog. Ser.* 1994; **109**: 195–208.
51. Hoff JG, Ibara RM. Factors affecting the seasonal abundance, composition and diversity of fishes in a southeastern New England estuary. *Estuar. Coast. Mar. Sci.* 1977; **5**: 665–678.
52. Weinstein MP, Weiss SL, Walters MF. Multiple determinants of community structure in shallow marsh habitats, Cape Fear River estuary, North Carolina, USA. *Mar. Biol.* 1980; **58**: 227–234.
53. Rogers SG, Targett TE, Van Sant SB. Fish-nursery use in Georgia salt-marsh estuaries: the influence of spring-time freshwater conditions. *Trans. Am. Fish. Soc.* 1986; **113**: 595–606.
54. Rozas LP, Hackney CT. Use of oligohaline marshes by fishes and macrofaunal crustaceans in North Carolina. *Estuaries* 1984; **7**: 213–224.
55. Norcross BL, Shaw RF. Oceanic and estuarine transport of fish eggs and larvae: a review. *Trans. Am. Fish. Soc.* 1984; **113**: 153–165.
56. Keefe M, Able KW. Contributions of abiotic and biotic factors to settlement in summer flounder, *Paralichthys dentatus*. *Copeia* 1994; **1994**: 458–465.
57. Levin PS. Fine-scale recruitment variation in a temperate fish: the role of macrophytes and food supply. *Environ. Biol. Fish* 1994; **40**: 271–281.
58. Healey MC. The distribution and abundance of sand gobies, *Gobius minutus*, in the Ythan estuary. *J. Zool.* 1971; **163**: 177–229.
59. Kanou K, Sano M, Kohno H. Food habits of fishes on unvegetated tidal mudflats in Tokyo Bay, central Honshu, Japan. *Fish. Sci.* 2004; **70**: 978–987.
60. Kuipers BR, Dapper R. Nursery function of Wadden Sea tidal flats for the brown shrimp *Crangon crangon*. *Mar. Ecol. Prog. Ser.* 1984; **17**: 171–181.
61. Reise K. *Tidal Flat Ecology: An Experimental Approach*. Springer-Verlag, Heidelberg. 1985.
62. del Norte-Campos AGC, Temming A. Daily activity, feeding and rations in gobies and brown shrimp in the northern Wadden Sea. *Mar. Ecol. Prog. Ser.* 1994; **115**: 41–53.
63. Caley MJ. Predation, recruitment and the dynamics of communities of coral-reef fishes. *Mar. Biol.* 1993; **117**: 33–43.
64. Caley MJ, Carr MH, Hixon MA, Hughes TP, Jones GP, Menge BA. Recruitment and the local dynamics of open marine populations. *Annu. Rev. Ecol. Syst.* 1996; **27**: 477–500.
65. Carr MH, Hixon MA. Predation effects on early post-settlement survivorship of coral-reef fishes. *Mar. Ecol. Prog. Ser.* 1995; **124**: 31–42.
66. Sogard SM. Size-selective mortality in the juvenile stage of teleost fishes: a review. *Bull. Mar. Sci.* 1997; **60**: 1129–1157.