AACL BIOFLUX

Aquaculture, Aquarium, Conservation & Legislation
International Journal of the Bioflux Society

Distribution and community structure of fish in Obitsu-gawa River Estuary of inner Tokyo Bay, central Japan

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Abstract. The distribution and community structure of fish in Obitsu-gawa River Estuary of inner Tokyo Bay, central Japan was studied from May to December 2005 and March to April 2006. A total of 19,006 individuals, represented by 25 species and some unidentified species under family Clupeidae, Cyprinidae, Gobiidae, Hemiramphidae, Mugilidae, Platycephidae, Pleuronectidae and Triglidae were collected. Family Gobiidae had the most number of taxa with 13 genera and 10 species. Greatest fish abundance happened in August and secondarily in April and May. Species richness was evident in the warmer months particularly in May (17 taxa), August (21 taxa), September (15 taxa) and October (17 taxa). Marine teleosts significantly contributed to the species richness and abundance of fish, which corresponded to 52.9% (10,046 individuals) of the total catch while the estuarine fishes were the second most abundant group with 33.5% (6,372 individuals) of the total catch. Species dominance was a coherent feature of this community. The proportional contribution of marine teleosts to the fish community decreased with increase distance upstream while that of estuarine fishes increased with increase distance upstream. The developmental stages of gobies range from larvae to adult but juveniles constitute 77.06% of the total sample. The distribution of developmental stage of estuarine gobies was influenced to a greater extent by variation in monthly water temperature and station or the interaction of both. Adult estuarine gobies had the tendency to aggregate in the middle estuary reflecting their high tolerance to a wide range of water salinity inherent in this station but avoided the lower estuary most likely due to the predominance of high salinity waters.
Key Words: Tokyo Bay, estuary, gobies.

Introduction. Understanding the distribution and community structure of fish in its natural habitat will delineate the importance of the habitat to the local ichthyofauna and reduces the uncertainty in restoring this lost habitat if the cost of rehabilitating a natural system can be large while the benefits are uncertain because of limited experience in ecosystem management practices (Holl et al 2003). The tidelands of inner Tokyo Bay has been known to support a number of teleosts species (Kanou et al 2004a, 2005a, 2007) and considered as nursery grounds for some local species (Kanou et al 2000, 2005b; Okazaki et al 2011). However, decades of intensive dredging and landfill activities reduced this natural system to a mere 7.3% because of increased exigency for industrial sites. The estuarine tideland of Obitsu-gawa Estuary contribute a significant portion of what is still considered as a natural system. Motivated by the idea that habitat degradation through changes in land use have resulted to reduced biodiversity (Kanou et al 2000) perhaps due to displacement or even loss of some local species, further study is needed to understand the contribution of the different species of fish to the ichthyofauna in a natural system such as that in Obitsu-gawa River estuary in an effort to develop strategies for fisheries management design for this system. Habitat variation is often a factor that is frequently overlooked in the assessment of ichthyofaunal diversity in estuaries (Whitfield 1999). The estuarine tideland of inner Tokyo Bay is in fact a complex system that is composed of several biological niches that can function as potential habitats for fish in various stages of its development. A number of studies have been published on the tideland ichthyofauna of inner Tokyo Bay in recent years (Kanou et al

2000, 2004a, 2004b, 2005a, 2005b, 2007; Okazaki et al 2011) that generated a considerable amount of knowledge on the lifecycle patterns as well the developmental stages of some of the common fish taxa present in the estuarine tidelands of inner Tokyo Bay. These data were used in the current study to further understand the distribution and community structure of fish in Obitsu-gawa River Estuary and provided some pertinent details regarding the relevance of water temperature and site in predicting the dynamics in the distribution of the developmental stages of selected estuarine species.

Material and Method. Sampling was performed from May to December 2005 and March to April 2006 along Obitsu-gawa River situated at the Boso Peninsula near Egawa, Kisarazu City, Chiba Prefecture northeast of Tokyo Bay, Japan. There were 3 designated stations along the saline reaches of the river. The lower estuary (Longitude: 139°53'50"; Latitude: 35°24'33") was the station situated adjacent to the river mouth along the coast fronting Tokyo Bay while the middle estuary (Longitude: 139°54'10"; Latitude: 35°24'39") was situated inner to the previous station at a distance of 0.5 km. The upper estuary on the other hand was situated further upstream at a distance of 2 km from the middle estuary (Figure 1). Sampling was not made possible in January and February in the 3 stations as well as in the lower estuary station in March and April.

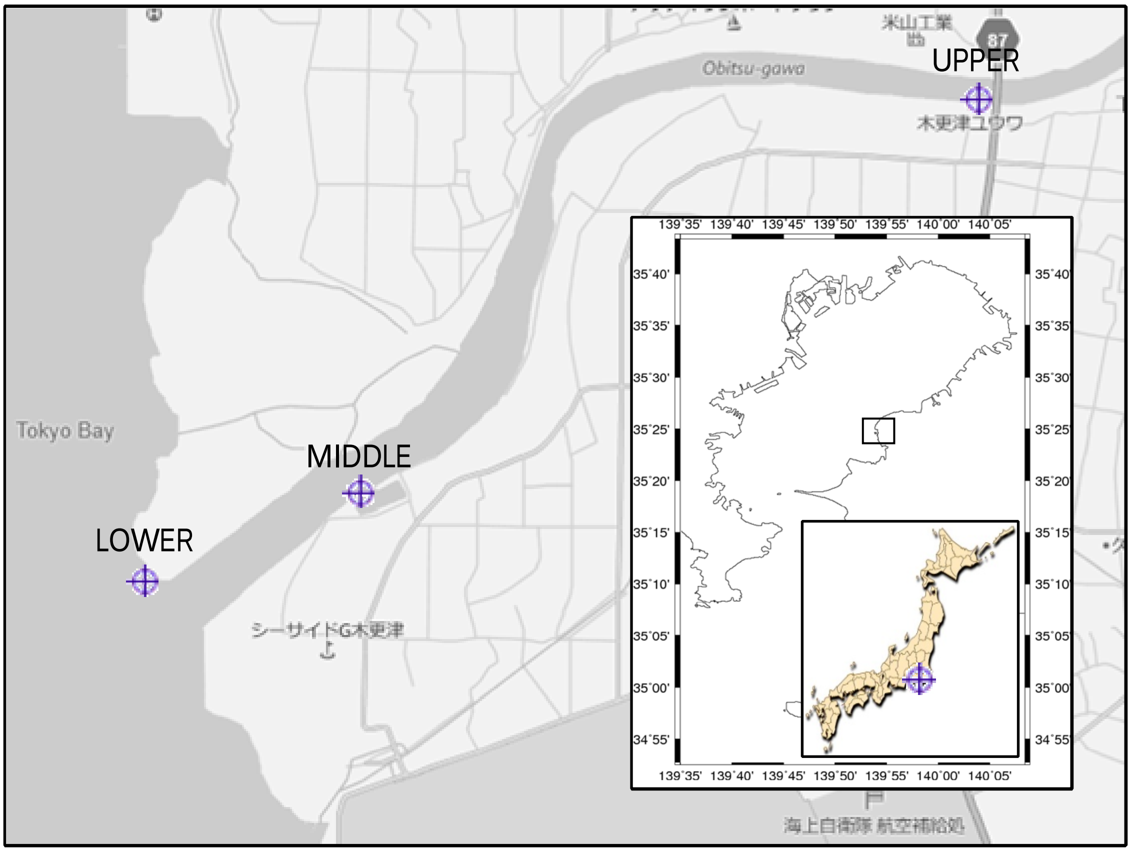

Figure 1. Map of Tokyo Bay and the location of the sampling stations along the Obitsu-gawa River estuary [Maps courtesy of the National Geophysical Data Center (http://www.ngdc.noaa.gov/mgg/coast/) and Environmental Sciences Research Institute (http://www.esri.com/)].

Fish was sampled using a seine net that was towed parallel to the river bank at day time over a distance of 20 m and depths between 0.5-1 m. Each side of the nylon mesh extends 2 m laterally with a mesh size of 2 mm. At its center was a rectangular mouth that was 2 m in width and 1 m in height. It extends into a conical net with a length of 4.5 m and a mesh size 0.8 mm. Fish were placed in pre-labeled plastic bottles with the addition of 10% formalin as initial fixative. Water temperature and salinity were also taken from each station. In the laboratory, fish was identified to species level as possible. Standard length (SL) was measured to the nearest 0.1 mm. Developmental stages were determined for gobies according to the descriptions made by Kendall Jr et al (1984) while juveniles were further divided into 3 groups on the basis of its body pigmentation (Kanou et al 1999, 2005b). Juvenile 1 (J1) had pigmentation similar to postflexion larvae while juvenile 2 (J2) was the transition period between J1 and J3. Juvenile 3 (J3) had the same pigmentation pattern as adults. Additionally, species were grouped based on lifecycle category in accordance with the work of Kanou et al (2000). Samples were then fixed in 70% ethanol and kept for further analysis.

Rényi diversity profile was used to describe the species richness and species evenness properties of the fish community in the 3 stations. Rényi diversity offers a more complete summarization of community diversity that uses a parametric family of diversity indices (alpha "α" diversity) whose members have varying sensitivities to the presence of rare and abundant species in a community, which then becomes increasingly dominated by the commonest species for increasing values of the parameter α (Ricotta 2003). Tóthmérész (1995) recommended the use of Rényi diversity since it conveys the degree of dominance in the community such that a homogenous community has a perfect horizontal profile while a community with high degree of dominance has a steep profile. Diversity profile values were calculated at fixed scales (α = 0, 0.25, 0.5, 1, 2, 4, 8, ∞). The values of the Rényi diversity at scales 0, $\approx$1, 2 and ∞ (or infinity) reflect the logarithm of species richness, Shannon diversity index, and the logarithms of reciprocal Simpson and Berger-Parker diversity indices, respectively (Ricotta 2003). A fish community in a given station was more diverse if all the values of the diversity profile were higher. Rényi diversity curve for each station was calculated by randomized pooling of months that belong to a particular station and a diversity profile was calculated on these pooled months.

Abundance for each taxon was fitted into ordination space using a nonmetric multidimentional scaling (NMDS) in search for patterns in their distribution in relation with months and stations. Moreover, a statistical test was performed using the maximum likelihoood approach on the SL of selected estuarine species whose distribution were evident for a protracted period and covering at least 2 stations within this period to explore any variation in size in response to water temperature and stations. To do this, the SL for each species was initially fitted to 2 feasible statistical distribution families (e.g., Gaussian, Gamma) appropriate for size data (Crawley 2007) and was integrated into a Generalized Linear Model (GLM) framework. The Akaike`s Information Criteria or AIC (Akaike 1981; Burnham & Anderson 2004) was used to identify which of the 2 distribution families best explained the variation in the SL of a given species. Model with the lowest AIC score was selected as the “best” approximating model (Burnham & Anderson 2004; Ellison 2004). Station and water temperature were considered as the explanatory variables in the model-fitting process with 4 covariates (e.g., water temperature only, station only, water temperature and station as well as water temperature and station interaction). These covariates were fitted to the SL data for each species with the appropriate distribution family. The AIC was used to determine which model best explained the variation in size of a particular species. The best model was then plotted. A plot containing the SL distribution for each species against the water temperature gradients for each station was created and a line was drawn that corresponded to the predicted response of SL to gradients in water temperature observed for each station.

Statistical tests were carried out under the statistical computing language R (version 2.12.0). NMDS was performed using the “vegan” package (Dixon 2003; Oksanen et al 2007) while the Rényi diversity was performed using the “BiodiversityR” package (Kindt & Coe 2005). The model fitting of SL to the best distribution family and subsequently, to the most appropriate combination of explanatory variables were performed using the “MASS” package (Venables & Ripley 2002).

Results and Discussion. Station and month best explained the variation in water temperature in Obitsu-gawa River Estuary while station best described the variation in water salinity in the said estuary (Table 1). As for water temperature, however, month (p=0.001) was more important than station (p=0.05). Figure 2 showed the monthly variation in water temperature as well as variation in water salinity observed in the 3 stations. High water temperature was observed from June to August (26±2.3 – 26.7±1.2°C), which decreased gradually from September (19.4±0.6°C) to December (6.1±0.6°C). Water temperature was increasing from March (11.4±3.5°C) to May (18.2±0.2°C). Highest salinity was observed in the lower estuary (24.1±6.7 psu), which begun to decrease upstream (middle estuary = 13.1±7.1 psu; upper estuary = 3.1±3.4 psu).

Table 1

AIC scores for different combination of covariates for water temperature and salinity. The covariate or covariate combination with the lowest AIC score (*) was considered the suitable approximating model that explained the variation in water temperature and salinity

Physical variable	*Model*	*Covariates*	*AIC Score*	*Distribution family*
Water temperature	1	Water temperature	185.3	Gaussian
	2	Station	188.8	
	3	Month	101.4	
	4	Station + Month	97.5*	
Water salinity	1	Water salinity	175.3	Gamma
	2	Station	160.1*	
	3	Month	186.2	
	4	Station + Month	172.4	

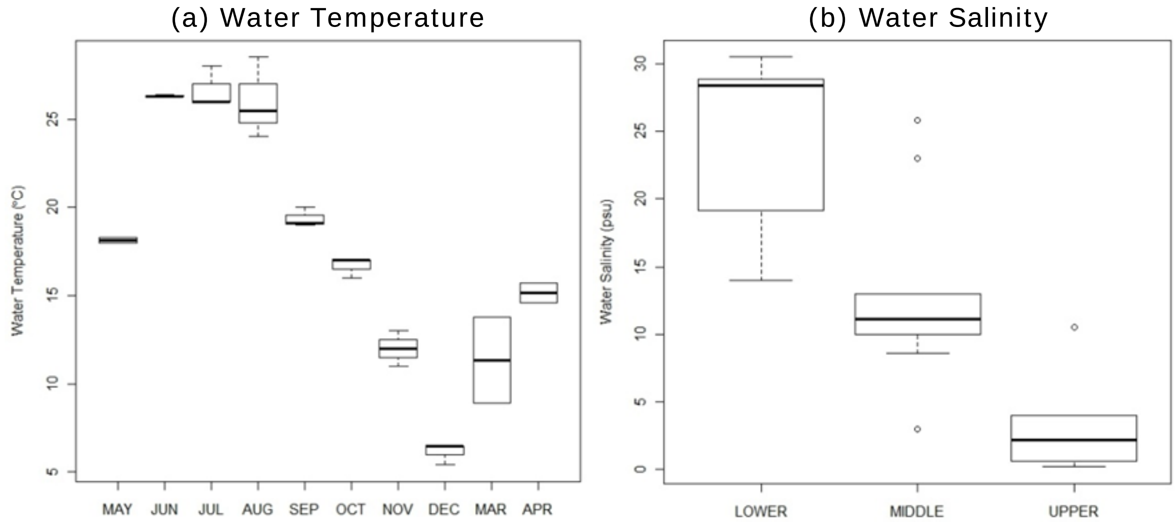

Figure 2. Average monthly variation in water temperature (a) and spatial variation in water salinity (b) in Obitsu-gawa River Estuary.

A total of 19,006 individuals, representing 25 species and some unidentified species under family Clupeidae, Cyprinidae, Gobiidae, Hemiramphidae, Mugilidae, Platycephidae, Pleuronectidae and Triglidae, were collected from Obitsu-gawa River estuary (Table 2). Family Gobiidae had the most number of taxa with 13 genera and 10 species. The diversity of gobies in this system was likely due to their ability to inhabit a wide range of environments because of their resilient physiological-adaptation ability (Fonds & Van Buurt 1974; Akihisa & Seiichi 2005; Taylor et al 2005; Eme & Bennett 2009) considering that estuaries are regions where marine and fresh waters meet resulting to highly fluctuating environmental gradients. The current study however slightly deviated from the general trend wherein greatest fish abundance happened in spring (March to May) in the tidelands of Tokyo Bay (Nasu et al 1996; Kanou et al 2000) considering that 59.1% (11,236 individuals) of the fish in the current study was caught in August (late summer).

Nevertheless, secondary peaks in fish abundance were realized in spring particularly in April (15%; 2,848 individuals) and May (13.3%; 2,534 individuals).

Species richness was evident in the warmer months particularly in May (17 taxa), August (21 taxa), September (15 taxa) and October (17 taxa), which was congruent with studies on the ichthyofauna in the tidelands (Kanou et al 2000) and euhaline systems (Kohara & Kohno 1999; Kanou et al 2002) of inner Tokyo Bay. NMDS based on actual count per taxon in Figure 3 showed that the occurrence as well as incidence of peak abundance of fish were prevalent in months when the water temperature was increasing with the exception of the amphidromous fish, *Plecoglossus altivelis altivelis* (Temminck & Schlegel, 1846), whose larvae (13.7±2.9 mm SL) were prevalent in November in the lower estuary (Table 2). The larvae of this species was known to occur in the estuarine and coastal systems following hatching period around October to December in the upstreams of the river (Hamada & Kinoshita 1988; Takahashi et al 2000; Kensaku et al 2003; Yo et al 2006) and the brackish waters were considered an important habitat for the larvae of this species (Saruwatari 1995; Yasuhiko 2002). Generally, the occurrence and abundance of fish in Obitsu-gawa River Estuary vary with changed in monthly water temperature and a substantial number of taxa had abundance peak in the warm months. Particularly, 7 out of the 12 marine species had their occurrence and abundance peak in summer (June to August) and 6 of which were prevalent in August (Table 2) suggesting that the connectivity between these two systems became more relevant around summer particularly in August when a considerable number of marine species had moved to the estuary. This study proposed that the Obitsu-gawa River Estuary served as a transient habitat for some marine species particularly during summer. Conversely, the low winter temperatures in combination with low salinities in estuaries can cause severe physiological stress for most fishes including the estuarine species (Whitfield et al 1981), which likely limits the fish colonization of these systems during the cold months (Whitfield 1999).

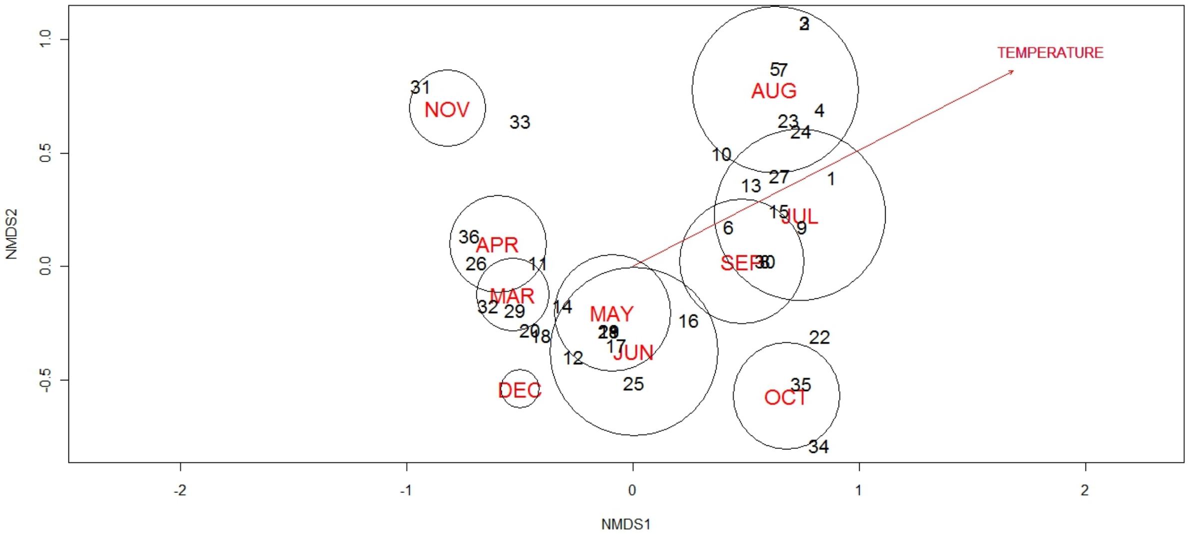

Figure 3. Nonmetric multidimensional scaling (NMDS) for the numerical abundance of the 36 taxa in relation to months. The Bray–Curtis was the dissimilarity index used to generate the NMS. The bubble plot was proportional to the average water temperature for each month while the vector (arrow) was directed towards the months with increasing gradient in water temperature. Each number in the plot corresponds to a code for a particular taxon given in Table 2.

Marine teleosts contributed significantly to the species richness and abundance of fish in Obitsu-gawa River Estuary, which was 52.9% (10,046 individuals) of the total catch (Table 2). There were 11 families and 12 species under this category and were prevalent in May, July, September but most importantly in August (Table 2). A more or less similar pattern was observed by Loneragan & Potter (1990) in the Swan Estuary of temperate southwestern Australia wherein species richness and abundance of marine species were relevant in the warm months reflecting its tendency to aggregate in the estuary during the warm months. *Gymnogobius heptacanthus* (Hilgendorf, 1879) was prominent in May while *Hypoatherina valenciennei* (Bleeker, 1854) in July. Although *Sardinella zunasi* (Bleeker, 1854) was the most dominant species in this group because of its remarkable abundance in August, other marine teleosts particularly *Konosirus punctatus* (Temminck & Schlegel, 1846) and *Salangichthys ishikawae* Wakiya & Takahashi, 1913 were also prevalent in this month. *Nuchequula nuchalis* (Temminck & Schlegel, 1845) was the second most abundant marine species that was prevalent in September. The remarkable number of *S. zunasi* can be attributed to the seasonal spawning period of this species that peak around August (Oda 2007). It was likely that a substantial number of larvae (11.2±1.4 mm SL) migrated to the estuary following hatching from the adjacent euhaline waters. All these species can be considered as estuarine opportunists since they were present in substantial number in this system but only for a short period while the remaining species were marine stragglers because they were very few and assumed to be stenohaline (Claridge et al 1986; Lenanton & Potter 1987; Loneragan et al 1989; Loneragan & Potter 1990; Whitfield 1999; Elliott et al 2007). Nevertheless, the latter contributed considerably to the species richness in this system.

Estuarine fishes were the second most abundant group that corresponded to 33.5% (6,372 individuals) of the total catch with 8 representative species exclusively under family Gobiidae (Table 2). They were particularly prominent from March to September but most importantly in April (35.9%; 2,288 individuals) and May (36.6%; 2,331 individuals). *Acanthogobius flavimanus* (Temminck and Schlegel, 1845) and *Gymnogobius breunigii* (Steindachner, 1879) were the most abundant species, which were responsible for the substantial number of individuals in April and May, respectively. However, the abundance of *Gymnogobius uchidai* (Takagi, 1957), *Gymnogobius macrognathos* (Bleeker, 1860) and *Favonigobius gymnauchen* (Bleeker, 1860) in May as well as *Eutaeniichthys gilli* Jordan & Snyder, 1901 in August were also important. *Acanthogobius lactipes* (Hilgendorf, 1879) and *Pseudogobius masago* (Tomiyama, 1936) were relatively few in this system. Generally, a substantial number of gobies in April were J1 (78.1%; 386 individuals) while J1 (31%; 728 individuals) and J2 (47%; 1,102 individuals) in May. A more or less similar result was observed in the temperate Swan Estuary of Australia wherein influx of 0+ recruits of estuarine gobies were relevant in the warm months (Gill & Potter 1993). One particular advantage in the timing of reproduction around late spring was the higher growth rate of the progeny resulting from rise in water temperature like in the case of the estuarine goby, *Pseudogobius olorum* (Sauvage, 1880), of Swan Estuary (Gill et al 1996). Significant recruitment of estuarine gobies around spring can also be attributed to the high primary productivity of the coastal system of the bay during this season (Ogawa & Ogura 1997; Nakane et al 2008; Bouman et al 2010) especially if the utilization of the intertidal habitat by epibenthic fishes were related to feeding (Cattrijsse et al 1994; Kneib & Wagner 1994; Kneib 1997; Laffaille et al 2000; Nemerson & Able 2003; Kanou et al 2004a) given the fact that the highly eutrophic estuaries located east of inner Tokyo Bay were generally described as areas with notable phytoplankton growth and high chlorophyll a concentration in the particulate organic matter during the warm months (Ogawa & Ogura 1997; Suzumura et al 2004). Moreover, the prevalent warm waters from late spring to early autumn can promote temperature-mediated growth for the young fish cohorts (Gill et al 1996; Krück et al 2009). Thus, the current study proposed that the abundance of early juveniles around spring was a strategy that increase the chances of survival and the subsequent recruitment of estuarine gobies into the system.

Amphidromous fish had 4 representative families each with a single representative species (Table 2). It corresponded to 3.9% (737 individuals) of the total catch and was prevalent from March to April particularly for the Japanese sea bass, *Lateolabrax japonicus* (Cuvier, 1828). Early life stages of this species were known to inhabit the estuaries (Matsumiya et al 1982; Fujita et al 1988) and their occurrence in the estuary of Obitsu-gawa River between March and April was in timing with the commencement of larval migration from the euhaline spawning ground towards the estuary. This pattern was observed in Chikugo River in Ariake Bay, Japan wherein larvae ascended the river in

March from their spawning ground in the waters off Kumamoto and inhabit the freshwater through spring (Shoji et al 2006). The 3 remaining species of amphidromous fish contributed only to the species richness of fish in Obitsu-gawa River Estuary.

Lepomis macrochirus Rafinesque, 1819 was the only freshwater representative identified in this system, which corresponded to 0.2% (47 individuals) of the total catch (Table 2). This species was prevalent in August. Considering that freshwater fish in general is a not capable of osmoregulation in high saline waters (Potter & Hyndes 1999), it was likely that the occasional presence of this species in the estuary was coherent with the incidence of low water salinity in the lower reaches of the river, which happened in August when the average water salinity was 8.4±11.9 psu.

Teleosts with unknown lifecycle corresponded to 9.5% (1,804 individuals) of the total catch with 8 families and 8 genera (Table 2). Abundance of this group was prominent in March and August but most importantly in August. *Kareius* spp. and some unidentified mugilids (Mugilidae spp.) were prevalent in March. On the other hand, the goby, *Tridentiger* spp., together with some unidentified clupeids (Clupeidae spp.) were prominent in August. *Tribolodon* spp., *Gymnogobius* spp., *Rhinogobius* spp. *Hemiramphu*s spp., *Platycephalus* spp., *Chelidonichthys* spp. and some unidentified gobies (Gobiidae spp.) were important contributions to the richness of ichthyofauna in Obitsu-gawa River estuary.

At least 6 distributional patterns were identified by NMDS based on actual count of the 36 taxa (Figure 4). Prevalent in the lower estuary were one amphidromous (*P. altivelis altivelis*), 2 estuarine (*E. gilli* and *G. macrognathos*), 2 marine (*G. heptacanthus* and *S. zunasi*) and 4 taxa with unknown lifecycle (Clupeidae spp., Gobiidae spp., *Rhinogobius* spp. and *Tridentiger* spp.). Prevalent in the middle estuary were 2 marine (*Liza haematocheilus* (Temminck & Schlegel, 1845), and *S. ishikawae*) and 3 genera with unknown lifecycle (*Hemiramphus* spp., *Kareius* spp. and *Chelidonichthys* spp.). A conspicuous component of the upper estuary were 2 amphidromous (*Gymnogobius urotaenia* (Hilgendorf, 1879) and *Sicyopterus japonicus* (Tanaka, 1909), 3 estuarine (*A. flavimanus*, *A. lactipes* and *P. masago*), 4 marine (*Caranx sexfasciatus* Quoy & Gaimard, 1825, *H. valenciennei*, *Takifugu niphobles* (Jordan & Snyder, 1901) and *Terapon jarbua* (Forsskål, 1775)) and 4 taxa with unknown lifecycle (*Gymnogobius* spp., Mugilidae spp., *Platycephalus* spp. and *Tribolodon* spp.). Prevalent in both lower and middle estuaries were one estuarine (*G. uchidai*) and 3 marine (*K. punctatus*, *Omobranchus elegans* (Steindachner, 1876) and *N. nuchalis*) species. Prevalent in both middle and upper estuaries were one amphidromous (*L. japonicus*) and one freshwater (*L. macrochirus*). Prevalent in both lower and upper estuaries but with considerable representative individuals in the middle estuary were 2 gobiid (*G. breunigii* and *F. gymnauchen*) and one marine species (*Engraulis japonicus* Temminck & Schlegel, 1846). Generally, a paucity in peak abundance of estuarine species was observed in the middle estuary that was likely attributed to a wider range of water salinity (3-25.8 psu) inherent in this station as compared to the lower estuary (14-30 psu) and upper estuary (0.2-10.5 psu). Nevertheless, about 63.4% (350 individuals) of the adult estuarine gobies were collected from the middle estuary suggesting the high tolerance of this particular developmental stage to a wide range of water salinity in this station.

Rényi's diversity in Figure 5 showed a sheer drop in diversity profile in the 3 stations suggesting that species dominance was a coherent feature of the fish community in these stations. However, the diversity profile further indicated that the abundance of fish in the middle estuary was relatively more homogenous as compared with the lower estuary as shown by the lack of overlap in the diversity profile between the lower estuary and middle estuary due to high diversity scores attained by the latter.

Table 2

Actual count of fish across the sampling months grouped according to lifecycle category. Minimum (Min) and maximum (Max) standard length (SL) as well as proportional abundance (%) of fish were also presented for each taxon (each taxon was assigned a specific numeric code that was used as a reference in Figures 3, 4 and 6)

Lifecycle	*Family*	*Taxon*	*Code*	*SL (mm)*		*Month*										*Count*	*%*
				Min	*Max*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Mar*	*Apr*		
Amphidromous						2				1		31		168	535	737	3.9
	Clupeidae																
		Sicyopterus japonicus	8	26.3	26.3					1						1	0.0
	Gobiidae																
		Gymnogobius urotaenia	21	22.1	24	2										2	0.0
	Lateolabracidae																
		Lateolabrax japonicus	26	13.5	33.5									167	530	697	3.7
	Plecoglossidae																
		Plecoglossus altivelis altivelis	31	5.7	17.4							31		1	5	37	0.2
Estuarine						2,331	607	332	157	226	140	15	63	213	2,288	6,372	33.5
	Gobiidae																
		Acanthogobius flavimanus	11	10.4	83.8	245	13	9	1	2	1				2,231	2,502	13.2
		Acanthogobius lactipes	12	15	49.2	1	1		3	29	4		9	9	16	72	0.4
		Eutaeniichthys gilli	13	2.8	35.1	2		1	96		1			1		101	0.5
		Favonigobius gymnauchen	14	6	61	137	1	1	4	41	6	8	14	21	2	235	1.2
		Gymnogobius breunigii	16	10.5	54	1,156	574	317	48	153	120	2	2	2		2,374	12.5
		Gymnogobius macrognathos	18	11	39.6	245			3				3	13	10	274	1.4
		Gymnogobius uchidai	20	12.9	31.7	545	18	1	2			5	35	167	29	802	4.2

		Pseudogobius masago	22	5.6	21.3			3		1	8					12	0.1
Freshwater								3	44							47	0.2
	Centrarchidae																
		Lepomis macrochirus	4	14.2	35.5			3	44							47	0.2
Marine						189	10	89	9,559	158	4	17	1	3	16	10,046	52.9
	Atherinidae																
		Hypoatherina valenciennei	1	6.4	104.7	0	0	78	16							94	0.5
	Blenniidae																
		Omobranchus elegans	2	9.3	10.8				2							2	0.0
	Carangidae																
		Carnx sexfasciatus	3	52.5	52.5				1							1	0.0
	Clupeidae																
		Konosirus punctatus	6	7.5	44.2	12	6	6	116							140	0.7
		Sardinella zunasi	7	8.2	16	85		2	9,210	1						9,298	48.9
	Engraulidae																
		Engraulis japonicus	10	15.6	39.8	8			31							39	0.2
	Gobiidae																
		Gymnogobius heptacanthus	17	14.5	25.5	83	4	1	3				1			92	0.5
	Leiognathidae																
		Nuchequula nuchalis	27	5.7	43.1				137	155						292	1.5
	Mugilidae																
		Liza haematocheilus	28	14.4	14.4	1										1	0.0
	Salangidae																
		Salangichthys ishikawae	33	13	83.1			2	43	1		17		3	16	82	0.4

	Terapontidae														
		Terapon jarbua	34	17.7	22.7						3			3	0.0
	Tetraodontidae														
		Takifugu niphobles	35	108.7	137.3					1	1			2	0.0
Unknown						12	4	3	1,476	55	4	241	9	1,804	9.5
	Clupeidae														
		Clupeidae spp.	5	4.6	12.5	5			342					347	1.8
	Cyprinidae														
		Tribolodon spp.	9	21.6	78.6			1		4				5	0.0
	Gobiidae														
		Gobiidae spp.	15	12.4	47.7	1			42	8	1			52	0.3
		Gymnogobius spp.	19	27.2	27.2	1								1	0.0
		Rhinogobius spp.	23	4	14				6	1				7	0.0
		Tridentiger spp.	24	5	14.4			2	1,086	39	3			1,130	5.9
	Hemiramphidae														
		Hemiramphus spp.	25	11.1	11.1		1							1	0.0
	Mugilidae														
		Mugilidae spp.	29	65	36.1	5	3					156	8	172	0.9
	Platycephidae														
		Platycephalus spp.	30	11.5	14.7					3				3	0.0
	Pleuronectidae														
		Kareius spp.	32	14.3	33.1							85		85	0.4
	Triglidae														
		Chelidonichthys spp.	36	20	20								1	1	0.0

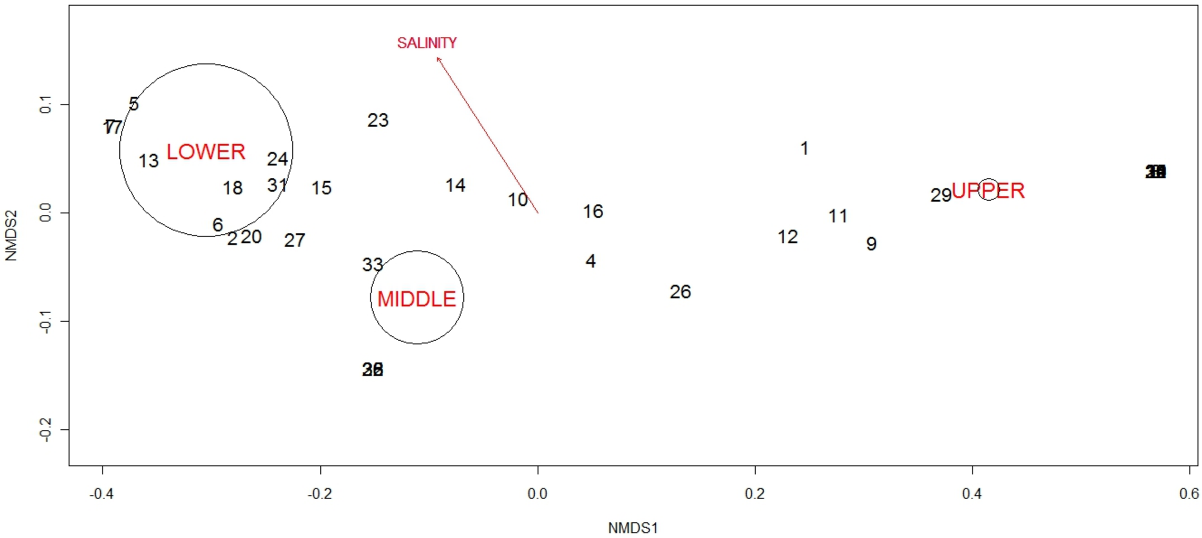

Figure 4. Nonmetric multidimensional scaling for the numerical abundance of the 36 fish taxa in relation to the 3 stations. The Bray–Curtis was the dissimilarity index used to generate the NMS. The bubble plot was proportional to the average water salinity recorded for each station while the vector (arrow) was directed towards the stations with increasing gradient in water salinity. Each number in the plot corresponds to a code for a particular taxon given in Table 2.

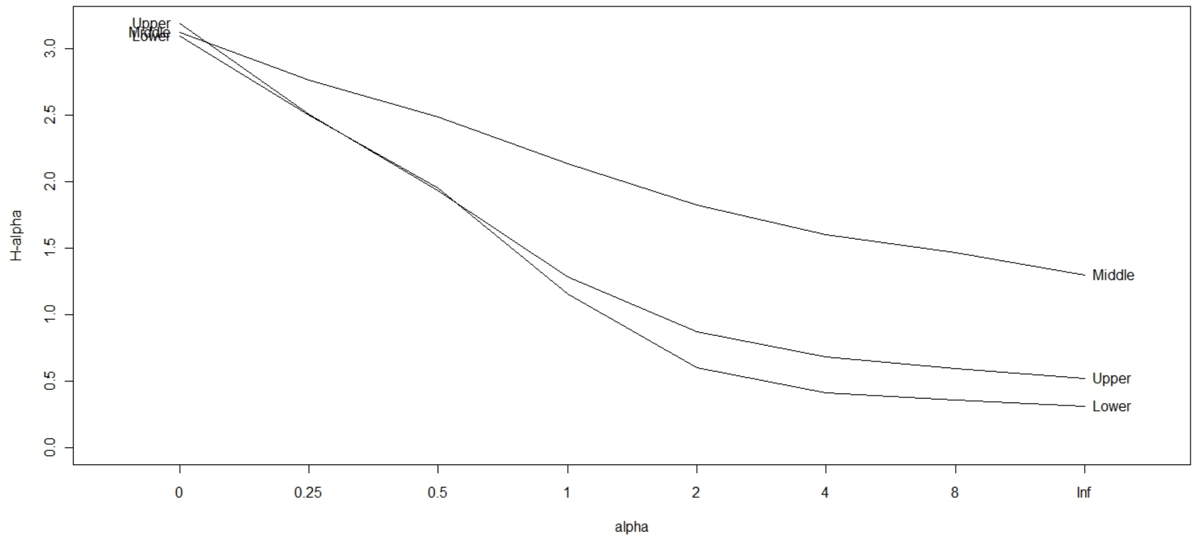

Figure 5. Rényi's diversity profile of the fish community in the lower, middle and upper estuaries of Obitsu-gawa River.

The upper estuary was more taxonomically diverse with 19 identified species and 8 unidentified species under family Clupeidae, Cyprinidae, Gobiidae, Mugilidae and Platycephalidae. It was followed by the middle estuary with 18 identified species and 7 unidentified species that belong to family Cyprinidae, Gobiidae, Hemiramphidae, Mugilidae, Pleuronectidae and Triglidae. About 17 identified species and 5 unidentified species that belong to family Clupeidae, Gobiidae and Mugilidae were collected from the lower estuary. Rank abundance curve in Figure 6 showed that the marine species *S. zunasi*, was no doubt the dominant species in the lower estuary. However, the dominance of this species was prominent only in August. On the other hand, the estuarine gobies such as *G. breunigii* and *G. uchidai* significantly contributed to the fish community in the lower estuary while the upper estuary was dominated *A. flavimanus*, and *G. breunigii*. In addition to *A. breunigii* and *A. flavimanus*, other species such as *G. uchidai* and *L. japonicus* were also prevalent in the middle estuary. This lend support to the previous contention that estuaries are dominated by ichthyofaunal species that demostrate a wide tolerance limits to the fluctuating conditions prevalent in this system (Whitfield 1999).

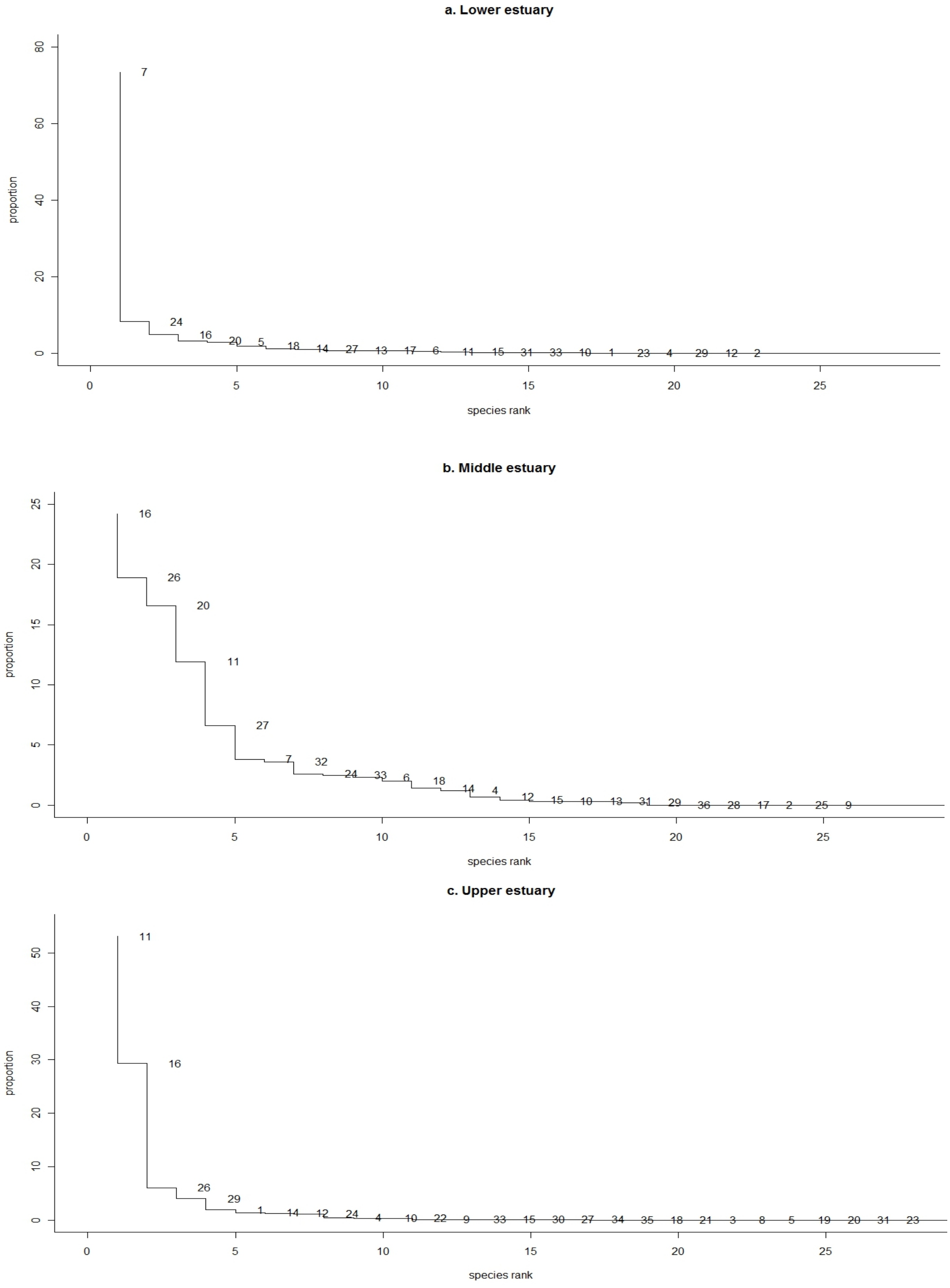

Figure 6. Rank abundance curve for the proportional abundance (%) of the fish taxa that were present in the lower (a), middle (b) and upper (c) estuaries. Each number in the plot corresponds to a code for a particular taxon given in Table 2.

The abundance of marine teleosts decreased with increase distance upstream. This group corresponded to 76.3% (9,566 individuals) of the total catch in the lower estuary, 15.7% (376 individuals) in the middle estuary and 2.6% (104 individuals) in the upper estuary (Table 3). This abundance pattern was similar to the large Swan Estuary of temperate southwestern Australia wherein density of marine fishes decreased with distance from the mouth of the estuary but contrasting to some degree because species richness in the said system also decreased with distance from the river mouth (Loneragan & Potter 1990). In the current study however, species richness of marine fish did not changed much in the lower estuary (7 families and 8 species), middle estuary (7 families and 8 species) and upper estuary (7 families and 7 species) despite the marked difference in water salinity particularly between the lower and upper estuaries. Except for *H. valenciennei*, count of marine species in the upper estuary were sparse and most likely were marine stragglers (Elliott et al 2007). On the other hand, a significant number of *H. valenciennei* larvae (7.5±0.7 mm SL) were sampled in the upper estuary in July when the water salinity was 0.2 psu while adults (69.1±16.4 mm SL) remained in the lower estuary. Jutagate et al (2009) described this species as an opportunistic marine species that sometimes entered the estuary for the purpose of feeding and breeding. It was likely that the larval stage of this species effectively penetrated the saline reaches of the estuary for the purpose of feeding and has a considerable tolerance to the oligohaline waters of the upper estuary.

Although actual count of estuarine gobies did not change much in the lower estuary (1,524 individuals) and middle estuary (1,362 individuals) as compared to the upper estuary (3,486 individuals) (Table 3), its proportional contribution to the fish community increased considerably from 12.2% in lower estuary to 57% in the middle estuary and 85.5% in the upper estuary. This observation closely paralleled with the results in Swan Estuary wherein the greatest densities of estuarine fish were recorded at sites in the middle and upper estuaries as compared to the lower estuary (Loneragan et al 1989). Generally, species richness of these estuarine gobies did not changed across the 3 stations with 7 species per station. However, the scarcity in the actual number of *P. masago* and *E. gilli* in this site can be attributed to habitat preference of these estuarine gobies. Okazaki et al (2011) collected a considerable number of *P. masago* from the tidepools on the mudflats in Tama River estuary of inner Tokyo Bay with developmental stages ranging from J1 to adult suggesting the importance of this habitat to the said species. The same can be said for *E. gilli* wherein a significant number of the catch in the lower estuary were predominantly planktonic larvae and there was paucity in the actual number of juvenile and adult. This species was in fact known to inhabit the estuarine tide pools under stones (Masuda et al 1987). Although not shown here, samples collected from the tidal creek and tidal pools of Obitsu-gawa River from July 2009 to June 2010 at low tide had found that *E. gilli* and *P. masago* belong to the 5 most abundant species in these habitats and that they form an important part the of the fish community in the tidal creek and soft sediment pools of Obitsu-gawa River Estuary.

Abundance of amphidromous fish was prevalent in the middle estuary (Table 3) but species richness of this group was evident in the upper estuary (4 species) as compared to the middle estuary (2 species) and lower estuary (one species). *L. japonicus* was the most abundant species in this group with 2 distinct size groups. Small individuals (18.3±1.3 mm SL) were prevalent in March particularly in the upper estuary while large individuals (22.5±2.7 mm SL) were evident in April in the middle estuary. Small individuals in the upper estuary most likely subsisted on oligohaline copepods in which according to Islam & Tanaka (2005), were suitable prey items and provide a better foraging environment in the upstream nursery. On the other hand, large individuals in the middle estuary most likely subsisted on mysids, cumaceans and gamaridean amphipods that were prominent prey items in the estuarine tidal mudflats (Kanou et al 2004a).

Table 3

Actual count of the 36 fish taxa in the 3 stations grouped according to lifecycle category

Lifecycle	*Family*	*Taxon*	*Lower Estuary*	*Middle Estuary*	*Upper Estuary*
Amphidromous			30	458	249
	Clupeidae				
		Sicyopterus japonicus			1
	Gobiidae				
		Gymnogobius urotaenia			2
	Lateolabracidae				
		Lateolabrax japonicus		452	245
	Plecoglossidae				
		Plecoglossus altivelis altivelis	30	6	1
Estuarine			1,524	1,362	3,486
	Gobiidae				
		Acanthogobius flavimanus	52	284	2,166
		Acanthogobius lactipes	1	17	54
		Eutaeniichthys gilli	94	7	
		Favonigobius gymnauchen	144	33	58
		Gymnogobius breunigii	602	577	1,193
		Gymnogobius macrognathos	224	48	2
		Gymnogobius uchidai	405	396	1
		Pseudogobius masago			12
Freshwater			3	28	16
	Centrarchidae				
		Lepomis macrochirus	3	28	16
Marine			9,566	376	104
	Atherinidae				
		Hypoatherina valenciennei	16		78
	Blenniidae				
		Omobranchus elegans	1	1	
	Carangidae				
		Carnx sexfasciatus			1
	Clupeidae				
		Konosirus punctatus	84	56	
		Sardinella zunasi	9,207	91	
	Engraulidae				
		Engraulis japonicus	17	8	14
	Gobiidae				
		Gymnogobius heptacanthus	91	1	
	Leiognathidae				
		Nuchequula nuchalis	131	158	3
	Mugilidae				
		Liza haematocheilus		1	
	Salangidae				
		Salangichthys ishikawae	19	60	3
	Terapontidae				
		Terapon jarbua			3
	Tetraodontidae				
		Takifugu niphobles			2
Unknown			1,417	165	222
	Clupeidae				
		Clupeidae spp.	346		1
	Cyprinidae				
		Tribolodon spp.		1	4
	Gobiidae				
		Gobiidae spp.	40	9	3
		Gymnogobius spp.			1
		Rhinogobius spp.	6		1
		Tridentiger spp.	1,023	63	44
	Hemiramphidae				
		Hemiramphus spp.		1	
	Mugilidae				
		Mugilidae spp.	2	5	165
	Platycephidae				
		Platycephalus spp.			3
	Pleuronectidae				
		Kareius spp.		85	
	Triglidae				
		Chelidonichthys spp.		1	

Count of freshwater species was evident in the middle estuary (Table 3). Generally, freshwater fish is not capable of osmoregulation in high saline waters and are only present in estuaries when salinities decline to very low levels during the periods of heavy freshwater discharge (Potter & Hyndes 1999). This was most likely the case for *L. macrochirus* whose abundance was conspicuous in the middle estuary in August when this station experienced low salinity of 3 psu. This species most likely belong to the freshwater straggler category because of its brief occurrence at certain period when the conditions in the estuary was favorable for the said species (Whitfield 1999).

The developmental stage of gobies ranges from larvae to adult but the juvenile contributed a substantial portion (77.06%) of the sample. J2 corresponded to 29.86% while J1 and J3 represent 26.18% and 21.06% of the juveniles, respectively. Specifically, the juveniles of estuarine gobies were abundant from April to July with abundance from 201 to 1,995 individuals and were coherent with increasing water temperature that would likely prompted the enhance productivity of the estuary as well as growth of the young fish (Whitfield 1999). The presence of large number of juveniles lend support to the previous studies that the estuarine fish assemblage was essentially high in abundance particularly for juvenile fishes (Whitfield 1999; Ramos et al 2006) and the estuarine tidelands of inner Tokyo Bay function as an important nursery habitat for some of the local fishes (Kanou et al 2000, 2005b; Okazaki et al 2011). *F. gymnauchen, G. breunigii* and *G. macrognathos* can be further categorized as estuarine residents because of their ability to complete their lifecycle within the estuary (Whitfield 1999). On the other hand, larvae were not found for *A. flavimanus*, *A. lactipes* and *G. uchidai* as well as J1 for *A. lactipes* and were likely estuarine migrants because the marine larval stage and to a certain extent, the J1 stage of these species were likely found in the adjacent aquatic habitats (Whitfield 1999).

The size of *A. flavimanus* increased with increase water temperature (Table 4; Figure 7). A substantial number of J1 was evident in April while J2 and J3 in May. Adult on the other hand was prominent from May to July (Table 5). Size was also found to vary with the stations and while small individuals (e.g., J1) were prevalent in the upper estuary, the large individuals (e.g., J2, J3 and adult) were prominent in the middle estuary suggesting a shift from low saline waters to relatively high saline waters with growth (Table 6). The size distribution of this species can be related to the differential food preferences with growth (Kanou et al 2004a). Juveniles with mean SL of 13.5±1.87 mm were known to inhabit the upper Chikugo Estuary in Ariake Bay, Japan characterized by low salinity (0.37-3.1 psu) with strong dietary relationship on a oligohaline copepod, *Sinocalanus sinensis* (Poppe, 1889), which was an important diet responsible for it upstream distribution of this species in spring (Islam et al 2006). In the current study, a substantial number of settling J1 (14±1.4 mm SL) were conspicuous in the upper estuary in April and these individuals most likely subsisted on oligohaline copepods in this station while the larger J1 (14.5±0.7 mm SL) migrated downstream with shift in the diet for epiphytic crustaceans and polychaetes in which according to Kanou et al (2004a), were an important part of its diet present in the tidal mudflats.

Station-water temperature interaction best explained the observed variation in size of *A. lactipes* implying that there was a relevant changed in size with change in water temperature in a given station (Table 4). Generally, an increase in size was evident with increase in water temperature (Figure 7). J2 was evident in March while J3 in December and March. Adult on the other hand was prominent in April (Table 5). Moreover, J2 was prominent in the middle estuary while J3 and adult in the upper estuary indicating movement from relatively high salinity waters to low salinity waters with growth (Table 6). However, its size substantially increased with increase in water temperature in the upper estuary resulting to a huge disparity in size between the upper estuary and middle estuary in a given month when the water temperature was high particularly around April. Smaller fish (14-33 mm SL) preyed on harpacticoids, polychaetes and detritus that were found in the intertidal mudflats of the estuaries and the migration of J3 and adults in the upper estuary was likely attributed to shift in diet preference for the settling juveniles of *A. flavimanus* (Kanou et al 2004a), which were prevalent in the upper estuary in April.

Station-water temperature interaction best described the variation in size of *F. gymnauchen* (Table 4). While size decreased with increase water temperature in the upper estuary, there was an increase in size with increase in water temperature in the middle estuary (Figure 7). The upper estuary was in fact predominantly inhabited by both larvae and J1 in September with the occasional occurrence of J2 from October to November and J3 in November and March. This species most likely moved downstream when they reached J3 stage particularly around December and inhabit to the middle estuary when they reached the adult stage particularly around April and May (Tables 5 and 6) where they likely subsisted on mysids and detritus prevalent in the estuarine mudflats (Kanou et al 2004a). Moreover, Inui et al (2010) found that the abundance of *F. gymnauchen* in the surf zones of northwestern Kyushu Island, Japan responded negatively to current velocity and its abundance was shown to decrease with increase depth in the surf zone suggesting the preference of this species for shelving and calm water conditions.

Station and water temperature best explained the variation in the size of *G. breunigii* (Table 4). Generally, the size decreased with increase in water temperature (Figure 7). Stages from larvae to J2 were prevalent in May when the water temperature was increasing while J3 was present from June to August when high temperature waters were evident in this system. Adult on the other hand was prominent from September to October when the water temperature was decreasing (Table 5). Spatial variation in size was also evident with large individuals prevalent in the middle and upper estuaries while small individuals in the lower estuary suggesting habitat shift from high saline waters to low saline waters with growth. The larvae and J1 were in fact prevalent in the lower estuary while abundances of J2 to J3 increased from the middle estuary to upper estuary. Adults on the other hand were prevalent in the upper estuary (Table 6). The predominance of larvae and J1 stages in the lower estuary can be attributed to the abundance of cladocerans and planktonic copepods in the tidal mudflats in which this species fed (Kanou et al 2004a). On the other hand, the preference for the middle and upper estuaries by the later stages can be attributed to the preference of these stages to shelving and calm water conditions (Inui et al 2010).

Variation in the size of *G. macrognathos* was best explained by station-water temperature interaction (Table 4). Although small individuals were prominent in the lower estuary and large individuals in the middle estuary, the size decreased substantially with increase in water temperature (Figure 7). J1 and J2 were prevalent in the lower estuary in May with the occasional presence of J3 in December. Adult was prevalent in the middle estuary from March to May together with J3 in April as well as J1 and J2 in May (Tables 5 and 6). Nevertheless, this pattern in size distribution indicated an inward movement with growth but at a very narrow habitat range from the lower estuary to the middle estuary. According to Kanou et al (2004a), the J1 subsisted on calanoid and cyclopoid copepods while J2 to adults shifted their diet to errant polychaetes, podocopid ostracods and harpacticoid copepods, which were prey items commonly found in the estuarine mudflats.

Moreover, station-water temperature interaction also explained the size variation of *G. uchidai* (Table 4). A decrease in size was evident with increase in water temperature (Figure 7). Generally, J1 and J2 were prominent in the lower estuary in May together with the occasional presence of J3 and adult in December. A substantial number of J3 and adult were observed in the middle estuary from March to May but J2 was likely to occur in the same habitat around May to August (Tables 5 and 6). Generally, the pattern in the distribution of *G. uchidai* was also limited to the lower and middle estuaries with inward movement with growth. It was likely that the limited range in the distribution of this species was a reflection of the habitat preference of adults given the fact this species was known to inhabit the river mouths (Masuda et al 1987).

Table 4

AIC scores for different combination of covariates for the standard length of selected estuarine gobies. The covariate or covariate combination with the lowest AIC score (*) was considered the most appropriate model that explained the variation in size for a particular gobiid species

Species	*Model*	*Covariates*	*AIC Score*	*Distribution family*
Acanthogobius flavimanus	1	Temperature	3558.1	Gamma
	2	Station	3851.9	
	3	Temperature + Station	3351.3*	
Acanthogobius lactipes	1	Temperature	427.6	Gamma
	2	Station	435.3	
	3	Temperature + Station	428.6	
	4	Temperature:Station	426.1*	
Favonigobius gymnauchen	1	Temperature	657.1	Gamma
	2	Station	603.9	
	3	Temperature + Station	605.4	
	4	Temperature:Station	572.9*	
Gymnogobius breunigii	1	Temperature	9336.7	Gaussian
	2	Station	8413	
	3	Temperature + Station	8384.4*	
	4	Temperature:Station	8602	
Gymnogobius macrognathos	1	Temperature	3443.6	Gamma
	2	Station	3011.7	
	3	Temperature+Station	2956.6	
	4	Temperature:Station	2949.8*	
Gymnogobius uchidai	1	Temperature	5925.3	Gamma
	2	Station	4437.1	
	3	Temperature + Station	4127.8	
	4	Temperature:Station	3997.3*	

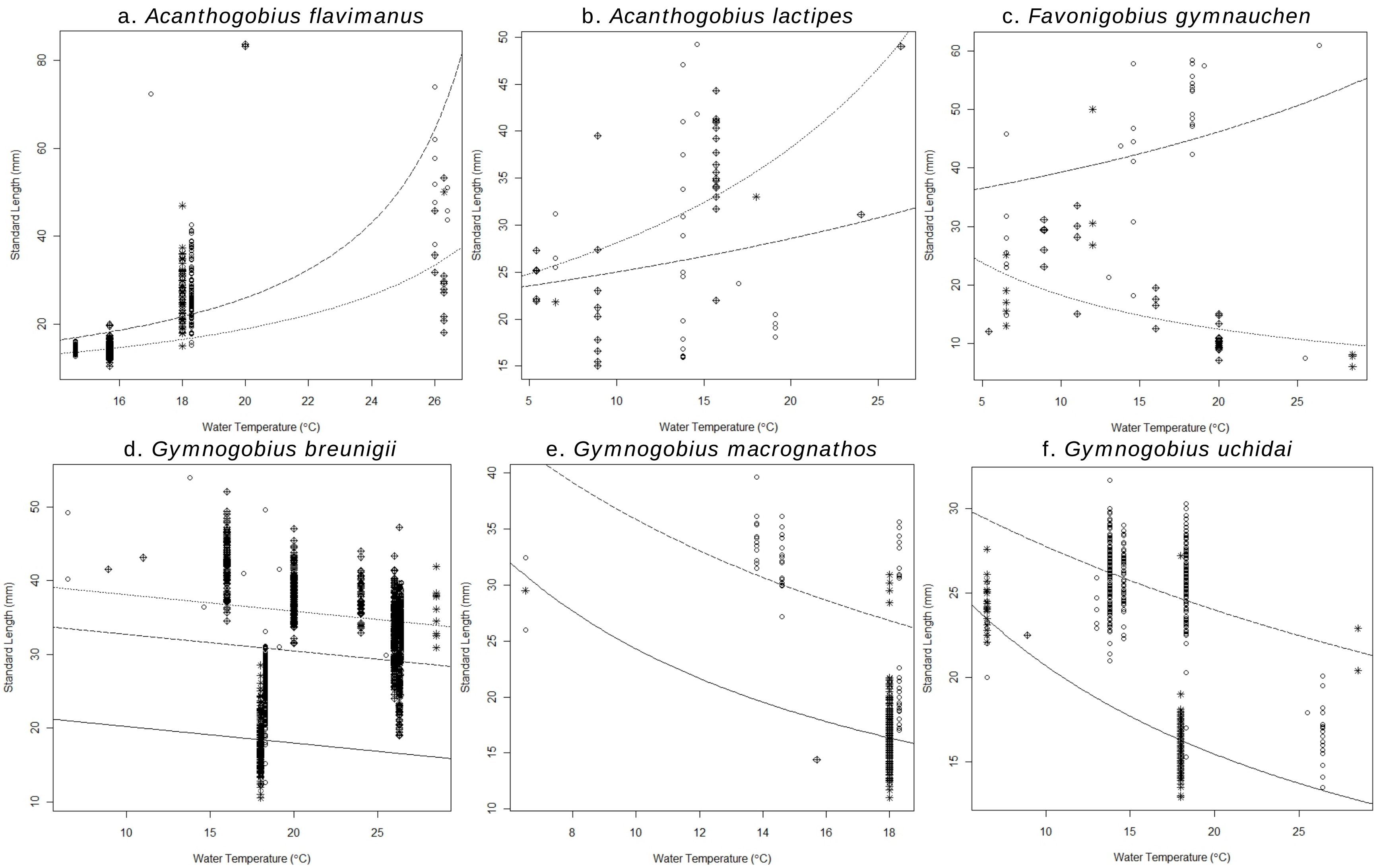

Figure 7. Standard length of estuarine gobies based on gradients in water temperature in the lower (*), middle (°) and upper (◇) estuaries. A line was drawn for the lower (solid line), middle (long dash) and upper (dotted line) estuaries that corresponded to the predicted response of SL to gradients in water temperature observed for each station in accordance with the result of the AIC for the best covariate combinations.

Table 5

Actual count and mean standard length (SL) for each developmental stage of goby in Obitsu-gawa River Estuary within the 10-month sampling period

Taxon	*Stage*	*Mar*		*Apr*		*May*		*Jun*		*Jul*		*Aug*		*Sep*		*Oct*		*Nov*		*Dec*	
		Count	*SL*	*Count*	*SL*	*Count*	*SL*	*Count*	*SL*	*Count*	*SL*	*Count*	*SL*	*Count*	*SL*	*Count*	*SL*	*Count*	*SL*	*Count*	*SL*
A. flavimanus																					
	J1			386	14.3	53	17.9	1	18.1												
	J2					169	26.5	7	26.8	1	31.8										
	J3					21	37.1			2	37										
	Adult					5	42.6	5	48.8	6	56.6			2	83.6	1	72.4				
A. lactipes																					
	J2	10	16.7											3	18.9						
	J3	9	26.5	7	32.1	1	33					1	31.1	1	20.5	1	23.8			9	25.2
	Adult	5	38.5	11	40.7	1	45.2	1	49												
C. heptacanthus																					
	Unknown					81	18.5	1	18.1												
E. gilli																					
	Larvae											90	7			1	5.5				
	J1									1	13.7	1	11.1								
	J2											2	13.5								
	J3											1	26.3								
	Adult	1	35.1									1	34.5								
F. gymnauchen																					
	Larvae											4	7.4	9	9.1						
	J1													14	11.3	1	12.5			3	13.3
	J2			1	18.2											3	17.9	1	15	4	17.1
	J3	6	27.5	1	30.8													6	28.4	6	26.2
	Adult	1	43.8	4	47.6	12	51.8	1	61					1	57.4			1	50	1	45.8
Gobiidae spp.																					
	Unknown											2	13			2	37.2				
G. breunigii																					
	Larvae					42	13.7														
	J1					129	17.1	5	19.3												
	J2					349	25.4	91	26	55	27.5	1	29.9								
	J3			1	36.4	75	31.1	305	34.2	142	34.2	37	36.4	97	36.7	22	37.6				
	Adult	2	47.8			1	49.6	1	47.2	6	41.1	11	41.3	57	41.5	96	43.5	1	43.1	2	44.7

G. macrognathos																					
	Larvae			1	14.4	101	14.1														
	J1					502	16.5														
	J2					29	20.7														
	J3			5	29.4	2	29													2	27.8
	Adult	13	34.4	13	32.6	11	32.5													1	32.4
G. uchidae																					
	J1					44	14.4														
	J2					555	16.4	15	16.4			2	19.2							1	20
	J3	41	23.8	19	24.2	66	24.1	1	20.1			1	22.9					4	23.7	21	23.4
	Adult	125	27.1	45	26.7	98	26.6											1	25.9	7	25.8
P. masago																					
	Larvae									1	5.6										
	J2															1	16				
	J3															2	18.4				
	Adult															1	21.3				
Rhinogobius spp.																					
	Larvae											6	8.4								
	Unknown													1	14						
S. japonicus																					
	Unknown													1	26.6						
Tridentiger spp.																					
	Larvae									2	9.1	62	8.2								
	Unknown													40	10						

Table 6

Actual count and mean standard length (SL) for each developmental stage of goby in the the 3 stations of Obitsu-gawa River Estuary within the 10-month sampling period

Taxon	*Stage*	*Lower estuary*		*Middle estuary*		*Upper estuary*	
		Count	*SL*	*Count*	*SL*	*Count*	*SL*
A. flavimanus							
	J1	6	18.1	203	14.9	231	14.5
	J2	39	27.2	92	25.8	46	27.4
	J3	4	36.1	13	36.8	6	38.6
	Adult	2	48.6	13	51.7	4	66.6
A. lactipes							
	J2			9	17.7	4	16.2
	J3	2	27.4	11	27.4	16	27.6
	Adult			5	43.3	13	39.8
C. heptacanthus							
	Unknown	81	18.5	1	18.1		
E. gilli							
	Larvae	89	7.1	2	5.6		
	J1			2	12.4		
	J2	2	13.5				
	J3	1	26.3				
	Adult	1	34.5	1	35.1		
F. gymnauchen							
	Larvae	3	7.3	1	7.5	9	9.1
	J1	1	13	1	14.8	16	11.4
	J2	4	17.1	1	18.2	4	17.2
	J3	3	27.5	7	26.3	9	28.5
	Adult	1	50	20	51		
Gobiidae spp.							
	Unknown					4	25.1
G. breunigii							
	Larvae	41	13.8	1	12.6		
	J1	114	16.9	9	18.6	11	19
	J2	44	22.2	189	25.7	263	26.4
	J3	9	34.9	200	34.1	470	34.6
	Adult	1	41.9	6	45.9	170	42.7
G. macrognathos							
	Larvae	101	14.1			1	14.4
	J1	491	16.5	10	18.5	1	15.5
	J2	24	20.6	5	21.4		
	J3	3	29.1	6	28.9		
	Adult	2	30.6	36	33.3		
G. uchidae							
	J1	44	14.4				
	J2	554	16.4	19	16.6		
	J3	14	23.6	138	24	1	22.5
	Adult	7	26	269	26.8		
P. masago							
	Larvae					1	5.6
	J2					1	16
	J3					2	18.4
	Adult					1	21.3
Rhinogobius spp.							
	Larvae	6	8.4				
	Unknown					1	14
S. japonicus							
	Unknown					1	26.6
Tridentiger spp.							
	Larvae			62	8.2		
	Unknown					42	9.9

Conclusions. High species richness and incidence of peak in fish abundance in Obitsu-gawa River Estuary was realized in months when the water temperature was increasing while months with very low temperature coupled with low salinity most likely limits fish colonization in this system. Species dominance was a coherent feature of the fish community in this estuary with marine species dominated the lower estuary while estuarine gobies in the middle and upper estuaries. The proportional contribution of marine teleosts to the fish community decreased with increase distance upstream while that of estuarine fishes increased with increase distance upstream.

Marine teleosts contributed greatly to the species richness and abundance of fish in this system and were prevalent in May, July, August and September emphasizing the tendency of this group to aggregate in this system during the warm months. Of particular interest was the remarkable number of *S. zunasi* in August that was in accordance with the spawning season of this species. It was likely that a considerable number of larvae of marine teleosts were attracted to this system immediately following the spawning event that took place in the adjacent euhaline waters and that the estuary in Obitsu-gawa served as a transient habitat for some marine species particularly during the warm months. The reliance of marine teleosts in this estuary can be categorized as estuarine opportunists if they were present in substantial number although only for a brief period or marine stragglers because they were very few but nevertheless contributed considerably to the species richness in this system.

The presence of amphidromous fish, *L. japonicus*, was coherent with the spawning period of this species and its occurrence in the estuary between March and April most likely signaled the commencement of larval migration towards the estuary and further upstream. In the case of the freshwater fish, *L. macrochirus*, its presence in the lower reaches of the river was attributed to periods when water salinity decrease to very low level given the fact that freshwater fish in general is incapable of osmoregulation in high saline waters.

Estuarine fishes were the second most abundant group that was primarily represented by species under family Gobiidae. Gobies had the most number of taxa in this system most likely because of their ability to inhabit a wide range of environments because of their resilience to fluctuating environmental gradients in this system. Juvenile recruitment was prominent from March to September but most importantly in April and May most likely due to the high productivity of this system during this period and the prevalence of warm waters that can promote temperature-mediated growth for the young fish. The developmental stages of gobies present in this system range from larvae to adult but the preponderance of juveniles suggest the importance of this system as a nursery habitat for the estuarine gobies especially during the juvenile stage. *F. gymnauchen, G. breunigii* and *G. macrognathos* can be further classified as estuarine residents because of their ability to complete their lifecycle within this estuary while *A. lactipes* was likely an estuarine migrant considering that the larval stage of this species was not found in this system. The distribution of developmental stages of estuarine gobies were coherent with the monthly water temperature and station or the interaction of both. In general, the size distribution of gobies across months either increased (e.g., *A. flavimanus* and *A. lactipes*) or decreased (e.g., *G. breunigii*, *G. macrognathos*, *F. gymnauchen* and *G. uchidai*) with increase in monthly water temperature. Although gradient in water salinity increased from a freshwater-dominated- (upper estuary) towards the seawater-dominated (middle and lower estuaries) stations and there was a mark variation in size of estuarine gobies across the stations, it was likely that the size distribution of these estuarine gobies cannot be explained by water salinity alone but can be attributed to other relevant factors such as change in prey items with growth as well as the preference for a particular estuarine habitat. Nevertheless, the distribution of these estuarine gobies either involve movement from very low saline- (upper estuary) to relatively high saline (middle estuary) waters (e.g., *A. flavimanus* and *F. gymnauchen*), movement from high saline- (lower estuary) to relatively high saline waters (e.g., *G. macrognathos* and *G. uchidai*), movement from relatively high saline- to very low saline waters (e.g., *A. lactipes*) and movement from high saline- to very low saline waters (e.g., *G. breunigii*) with growth. Adult estuarine gobies had the tendency to inhabit the middle estuary reflecting their high tolerance to a wide range of water salinity characteristic in this station but nevertheless avoided the lower estuary most likely due to the prevalence of high salinity waters in this station.

Acknowledgements. Gratitude is expressed to the anonymous referees for their constructive comments on the manuscript. This research was supported by the Ministry of Education, Culture, Sports, Science and Technology of Japan through a Student Research Scholarship grant (Monbukagakusho: MEXT) awarded to the main author.

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Received: 07 June 2012. Accepted: 30 June 2012. Published online: 20 July 2012.
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How to cite this article:
Hermosilla J. J., Tamura Y., Moteki M., Kohno H., 2012 Distribution and community structure of fish in Obitsu-gawa River Estuary of inner Tokyo Bay, central Japan. AACL Bioflux 5(4):197-222.