AACL BIOFLUX

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

Seasonal pattern and community structure of fishes in the shallow tidal creek of Obitsu-gawa River Estuary of inner Tokyo Bay, central Japan

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Abstract. Seasonal pattern and the community structure of fishes in the shallow tidal creek of Obitsu-gawa River Estuary of inner Tokyo Bay was studied for one year. Family Gobiidae corresponded to 98% of the total catch. Dominant species were *Gymnogobius uchidai*, *Gymnogobius macrognathos*, *Gymnogobius breunigii*, *Eutaeniichthys gilli*, *Pseudogobius masago* and *Favonigobius gymnauchen*. Stepwise modelling in canonical correspondence analysis indicated that season ($p=0.02$) best explained the variation in abundance of fish in this shallow habitat. There was a difference in fish community between spring and summer while only a small difference was observed between summer and autumn as well as winter and autumn. Species dominance was an inherent property of the tidal creek fish community particularly in spring beacuse of the remarkable abundance of *G. uchidai*. However, the fish community had the tendency to become proportionately even as the season progresses from spring to winter. The occurrence of a particular life history stage generally showed a strong association with month and water temperature. Adults substantially contributed to the population size structure of *P. masago* and *G. uchidai* while juvenile 2 for *G. breunigii* and *E. gilli*. Larvae significantly contributed to the population size structure of *F. gymnauchen* while juvenile 1 and juvenile 2 for *G. macrognathos*. The current study indicated that natural shallow habitat within a highly urbanized metropolitan area in inner Tokyo Bay can serve as a habitat for fishes and the prevalence of certain life history stages of estuarine species indicated the importance of the said habitat at certain part of their life history.

Key words: Gobiidae, species richness, species dominance, indicator species.

Introduction. Tokyo Bay is a hydrographically semi-closed temperate coastal system situated in central Japan. It is a partially mixed estuary (Matsukawa & Sasaki 1990) with its coast surrounded with dense urban population and industrialized metropolitan areas. Eutrophication and diminished local zones of high biological productivity are constant threats to this system. However, the diversity of fishes in the tidelands of Obitsu-gawa River Estuary, which is an important part of the only remaining natural tideland of inner Tokyo Bay, indicates that such system is capable of supporting a diverse fish community and the prevalence of some early life history stages suggest dependence of some of these species to the said habitat (Kanou et al 2000). Given the fact that estuaries are complex systems that are compose of several biological niches that serve as habitats for many fish species (Selleslagh & Amara 2008; França et al 2009; Inui et al 2010), different estuarine fish communities therefore represent species-specific differences in habitat use (Rakocinski et al 1992; Whitfield 1999; Ramos et al 2006). Information as to the range of habitats that an estuarine fish inhabit still needs further research and of particular interest is the dynamics of the fish community in the shallow tidal creek of Obitsu-gawa River Estuary. Intertidal fishes can be categorized as “transient” when they temporally occur in the intertidal zone mainly during high tide or “residents” when they occur almost permanently in the intertidal habitats (Gibson & Yoshiyama 1999). The species composition as well as the life history stage of fishes present in the shallow tidal creek of Obitsu-gawa River Estuary have not been describe to date. Given that the risk 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 paucity of information can impede efforts to restore the estuarine habitats of inner Tokyo Bay together with its resident fish fauna. The objectives of this study were to describe the seasonal pattern in the occurrence of fishes in a natural tidal creek of Obitsu-gawa River Estuary and generate a diversity profile of this fish community as well as to search for indicator species and to explore patterns in the occurrence of fish life history stages in relation to month, water temperature and salinity. Efforts to rehabilitate the biological productivity of estuaries in highly urbanized areas will require some knowledge on the seasonal dynamics of the fish community while diversity profiling will provide some insight as to the structural stability of this community across the seasons. This study provided some insights about the fish community that inhabits the shallow tidal creek of Obitsu-gawa Estuary, which is part of the only remaining natural tideland habitat of inner Tokyo Bay. Understanding the dynamics of the fish community in this shallow estuarine habitat will provide some relevant knowledge as to the importance of this habitat to the local fish fauna and to the entire estuarine system.

Material and Method. Fishes were collected in the shallow tidal creek and soft sediment pools of Obitsu-gawa River Estuary of Inner Tokyo Bay, Japan from July 2009 to June 2010. The estuary is part of the Boso Peninsula on the northeast shore of the bay particularly near Egawa, Kisarazu City, Chiba Prefecture. This natural creek is situated west of the river mouth with its east channel open towards the river and the west channel into the bay. It has an average depth of 20 cm and width of 4 m at low tide. Soft sediment pools are situated along the edge of the creek fringe by reed vegetation *Phragmites* sp. and the water from the creek. Fishes were collected monthly at fix stations near the east channel (station A), west channel (station C) and between these two stations (station B) (Figure 1).

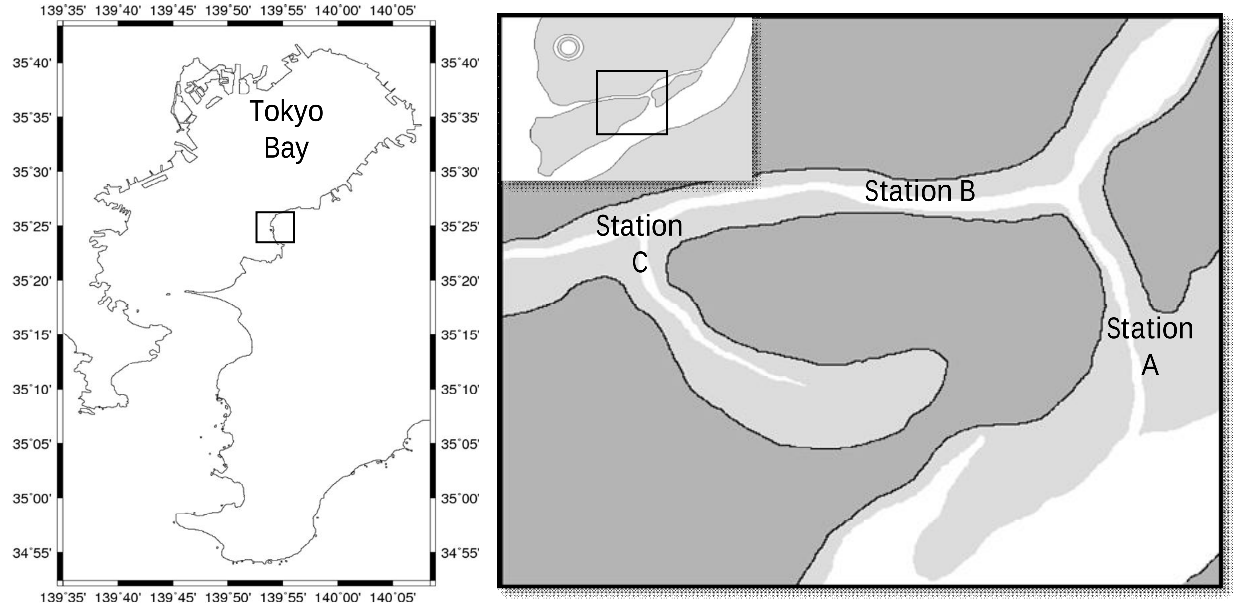


Figure 1. Map of Tokyo Bay and the location of the sampling stations in the shallow tidal creek of Obitsu-gawa River Estuary [Tokyo Bay map courtesy of the National Geophysical Data Center (http://www.ngdc.noaa.gov/mgg/coast/)].

Nets were installed at two points along the tidal creek covering an area of 10 m^2 for each station. One net blocked the incoming water while the other was fixed 2 m away that was design to catch fish. It was an open nylon mesh with length of 2 m on each side, 50 cm in depth and a mesh size of 330 μm. The net extends the entire width of the creek and fixed to the substrate by PVC pipes. It tapered medially into an opening that was supported by PVC pipes attached to the net along its lateral margins and fixed to the substrate. From the mouth, it tapered into a conical net that was 1.2 m in length (Figure 2). Fishes were caught by carefully sweeping the water just above the substrate towards one side of the net by two individuals using a polyethylene board. In addition, four soft sediment pools were randomly sampled for each station. Generally, the sediment pools were irregular in shape with an average area of 0.62±0.34 m^2 and average depth of 5.97±1.13 cm. Fishes that were visible in each pool were scooped out until all the fish were taken in three consecutive sweeps similar to the procedure of Okazaki et al (2011). The dip net was 15 cm wide, 12 cm deep and with a mesh size 1 mm. Fishes were placed in pre-labelled, plastic containers with the addition of 10% formalin as initial fixative. Water temperature and salinity were also recorded from these habitats.

Figure 2. The nets were installed in each station spanning the entire width of the creek with one net blocked the incoming water while the other was designed to catch fish.

Fishes were identified to species level as possible. Developmental stages were based on the descriptions of Kendall Jr. et al (1984). Juveniles were further divided into three distinct groups on the basis of their body pigmentation patterns (Kanou et al 2004, 2005). Briefly, juvenile one (J1) has pigmentation similar to post flexion larvae (L) while juvenile two (J2) corresponds to the transition period between J1 and J3. Juvenile three (J3) has the similar pigmentation pattern as adults (A). Standard length (SL) was measured to the nearest 0.1 mm. Each species was further categorized based on life cycle (E, estuarine; M, marine) in accordance with the work of Kanou et al (2000). Fish samples were fixed in 70% ethanol and were kept for further analysis.

Statistical tests were carried out under the statistical computing language R (version 2.12.0). Actual fish count from the three stations in the tidal creek and soft sediment pools were pooled for each month. Constrained ordination technique particularly the canonical correspondence analysis (CCA) was the method of choice to describe the fish community in relation to the most relevant explanatory variables. *Tridentiger* spp. was removed from the species pool prior to the actual statistical test considering its very few number and ubiquitous occurrence. Stepwise model building for constrained ordination was carried out in the “vegan” package (Oksanen et al 2011) with the smallest (e.g., no environmental variables) and the largest (e.g., all environmental variables) model considered. The chosen model was further tested using a permutation test similar to analysis of variance to assess the significance of the constraining variable. The same procedure was performed to test the marginal effect of the constraining variable and the significance of each axis in CCA. A minimum spanning tree was produced to investigate the ecological distances among months. To do this, dissimilarity indices that were good in detecting the underlying ecological gradients (Faith et al 1987) were compared based on rank correlation coefficients and the index with high rank-order similarity was selected. The chosen dissimilarity index was used to compute the dissimilarity values between months, which were then used to generate the minimum spanning tree.

Species accumulation curve was generated for each season by random selection of months that belong to a particular season through a bootstrap method and means were obtained. The Rényi diversity was the method used for diversity ordering of the fish community according to season. Rényi diversity utilizes 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 completely even community has a perfect horizontal profile while a community with high degree of dominance has a steep profile. Diversity profiling was carried out in the "BiodiversityR" package (Kindt & Coe 2005). 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, ≈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. A fish community in a given season was diverse if all its α values were higher than the other seasons. In addition, the evenness profile was calculated by subtracting the profile value at scale 0 (species richness) from all the scale values.

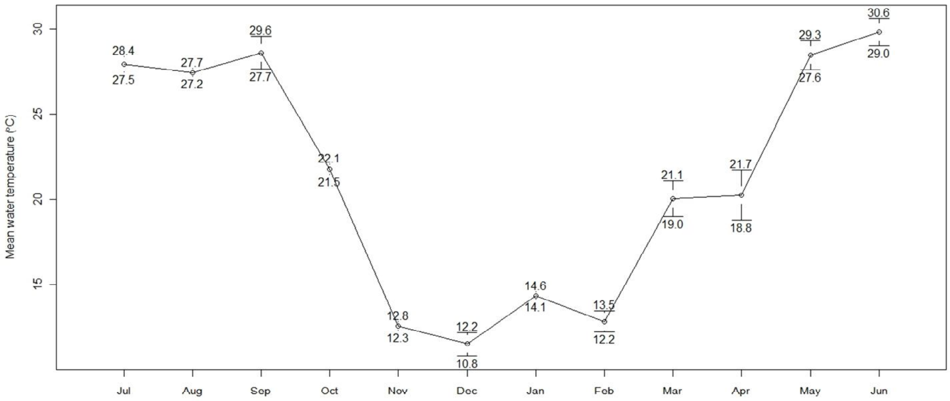
Indicator species was determined by first transforming the community matrix using Hillenger distance as recommended by Legendre & Gallagher (2001). Months were then clustered using K-means, which is a Euclidean-base partitioning method. The search for indicator species was carried out in the "indicspecies" package (De Cáceres & Legendre 2009a) by generating a combination of the input clusters from the results of K-means and compared each combination with the species matrix (De Cáceres & Legendre 2009b; De Caceres et al 2010). For each species it chose the combination with the highest association value. The square root of the "IndVal" index by Dufrêne & Legendre (1997) was the association index used. Best matching patterns were then tested for statistical significance of the associations (Györe et al 2011).

Classification and regression trees were created for the 6 most abundant species to explore patterns in the distribution of life history stages in relation to the most relevant physical variable. Initially, a model was developed for each species with standard length as the response variable while month, water temperature, water salinity and station as the covariates. The "rpart" package by Therneau et al (2010) was used for this analysis. Since the expected endpoint of the regression tree was a continuous variable (e.g., mean SL), analysis of variance was the statistics used to discriminate these size classes and subsequently associate these size classes to the relevant covariates.

Results and Discussion. Elevated water temperature (27.5±0.1 – 29.8±1.6°C) was evident from May to September while low temperature (11.6±0.8 - 14.4±0.3°C) was observed from November to February (Figure 3A). High salinity water (22.7±1.3 - 26.9±1.5) was evident from May to September as well as January while low salinity (13.4±3.4 - 17.6±1.6) was observed in November, March and April (Figure 3B).

A total of 9,315 individuals were collected from the tidal creek and soft sediment pools of Obitsu-gawa River Estuary with 10 species from two families (Gobiidae, Mugilidae) were identified, in addition to several unidentified gobiids from at least 2 different genera. There were eight estuarine species and two marine species (Table 1). The fish community in this shallow habitat was relatively different from what was observed by Hermosilla et al (2012) in the main river channel of the same estuary considering that marine teleosts contributed substantially to the fish abundance in the latter habitat. Estuarine gobies (family Gobiidae) constitute 98% of the total catch in the shallow tidal creek suggesting that the community structure and diversity of fishes in the tidal creek of Obitsu-gawa River Estuary was regulated by the presence as well as abundance of gobies.

A. Water temperature



B. Water salinity

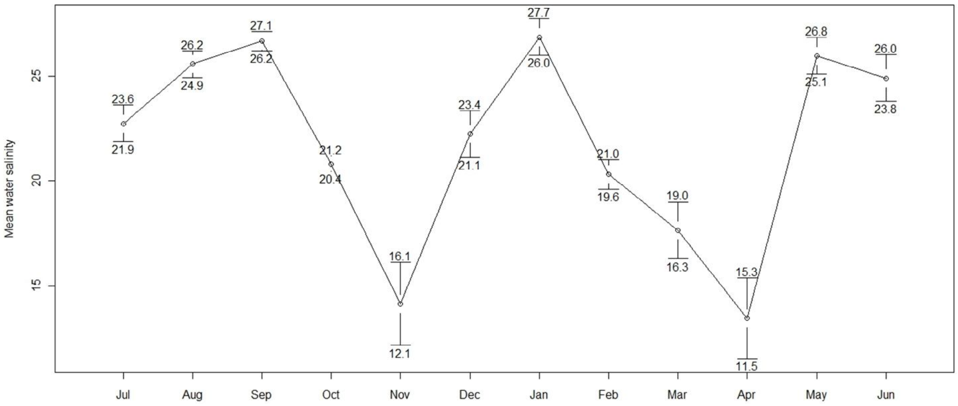


Figure 3. Variation in water temperature (A) and water salinity (B) in the tidal creek from July 2009 to June 2010. Interval end values were also shown at the end of the upper and lower confidence interval bars.

Nevertheless, estuarine gobies had the most number of species in both the main river channel (Hermosilla et al 2012) and the tidal creek, which can be attributed to the resilient physiological-adaptation ability of gobies (Fonds & Van Buurt 1974; Akihisa & Seiichi 2005; Taylor et al 2005; Eme & Bennett 2009) that allowed them to inhabit the shallow intertidal habitats (Taylor et al 2005) while marine teleosts avoided the tidal creek because of its shallow nature coupled with its highly unstable environmental conditions. This pattern in species composition and abundance of fishes between the main river channel and the adjacent tidal creek of Obitsu-gawa River Estuary suggest that the shallow tidal creek is a specialized habitat that can be an alternative habitat for fishes particularly for the estuarine gobies. However, access to this shallow estuarine habitat was likely regulated by patterns of flooding events (Kneib & Wagner 1994; Rozas 1995; Hampel et al 2003; Teo & Able 2003; Kanou et al 2005; Bretsch & Allen 2006; Islam et al 2006; Kimball & Able 2007) that resulted to habitat exploitation such as foraging (Cattrijsse et al 1994; Laffaille et al 2000; Nemerson & Able 2003) and refuge from predators (Paterson & Whitfield 2000; Kimball & Able 2007). Gobies such as *Gymnogobius uchidai* (Takagi 1957) (42.13%), *Gymnogobius macrognathos* (Bleeker 1860) (16.34%), *Gymnogobius breunigii* (Steindachner 1879) (14.45%), *Eutaeniichthys gilli* Jordan & Snyder 1901 (12.74%), *Pseudogobius masago* (Tomiyama 1936) (5.54%) and *Favonigobius gymnauchen* (Bleeker 1860) (4.54%) were important components of the fish community in the tidal creek. Developmental stages were from juvenile to adult except for *F. gymnauchen* and *G. breunigi* wherein the larval stage was also present. The adult stage was absent in *Acanthogobius flavimanus* (Temminck & Schlegel 1845). *A. flavimanus* was the most abundant goby in the main river channel of Obitsu-gawa River Estuary (Hermosilla et al 2012) but had a noticeably low abundance in the tidal creek of the same estuary suggesting that the tidal creek was not the preferred habitat for this species. Kanou et al (2005) observed a much higher abundance of epibenthic juveniles of

A. flavimanus in the subtidal zone of Tama-gawa River Estuary of inner Tokyo Bay at low tide but also noted that this species may also utilized the intertidal zone especially during flood tide. On the contrary, there was a paucity in the numerical abundance of *P. masago* in the main river channel of Obitsu-gawa (Hermosilla et al 2012) while the same species was an important component of the fish community in the tidal creek. *P. masago* was the most abundant species in the tidepools of Tama-gawa River Estuary comprising 62.3% of the total number of fish in the said habitat (Okazaki et al 2011) indicating that the shallow estuarine habitats such as tidepools and creeks were important for the said species.

Table 1

Life history, life cycle categories as well as total count and standard length of fishes obtained from the tidal creek and soft sediment pools of Obitsu-gawa River Estuary at low tide. Codes for each species were shown as reference for Figures 4 and 7.

Taxonomic classification	*Code*	*Life history*	*Life cycle*	*Minimum SL (mm)*	*Maximum SL (mm*	*Mean SL(mm)*	*Total count*	*Proportional abundance(%)*
Family Gobiidae								
Acanthogobius flavimanus	A.fl	J-A	E	14.4	46.5	23.5	58	0.62
Acanthogobius lactipes	A.la	J-A	E	9.1	50.9	29.4	83	0.89
Eutaeniichthys gilli	E.gi	J-A	E	9.2	26.2	24.7	1,187	12.74
Favonigobius gymnauchen	F.gy	L-A	E	6.0	61.4	17.3	427	4.58
Gobiidae spp.	Go.sp	L		6.2	7.7	6.7	5	0.05
Gymnogobius breunigii	G.br	L-A	E	4.9	54.5	33.5	1,346	14.45
Gymnogobius macrognathos	G.ma	J-A	E	15.1	41.6	28.8	1,522	16.34
Gymnogobius spp.	Gy.sp	L		3.1	4.0	3.5	46	0.49
Gymnogobius uchidai	G.uc	J-A	E	5.6	34.8	22.5	3,924	42.13
Mugilogobius abei	M.ab	A	M	19.5	29.7	24.4	12	0.13
Pseudogobius masago	P.ma	J-A	E	7.3	26.3	18.7	516	5.54
Tridentiger spp.		A		25.7	55.4	39.1	3	0.03
Family Mugilidae								
Mugil cephalus cephalus	M.ce	J-A	M	22	43.3	28.0	186	2.00

L=Larva; J=juvenile; A= Adult; E=Estuarine; M=Marine; SL=standard length

Kodama et al (2002) stressed that the community assemblage of demersal fauna in Tokyo Bay changed synchronously with the changes in environmental conditions and this contention holds true for the demersal fishes such as the gobies. Stepwise modelling under CCA had shown that season (p=0.02) rather than water temperature (p=0.23) and water salinity (p=0.57) best describe the variation in abundance of fishes in the tidal creek. The marginal effect of season was highly significant (p=0.015). The CCA in Figure 4 showed 51.57% of the variance (0.3327 of the inertia out of 0.6451) that can be explained by season. The current study proposed that the community structure of fishes in this temperate tidal creek habitat change syncronously with the season. *Mugilogobius abei* (Jordan & Snyder 1901) and *P. masago* were prevalent during summer (June to August). Prevalent species in autumn (September to November) were some unknown gobies (Gobiidae spp.). Fishes that were prominent in spring (March to May) were *M. cephalus cephalus*, *A. flavimanus*, *G. uchidai* and *Gymnogobius* spp. (Figure 5). Indicator species analysis showed that *Acanthogobius lactipes* (Hilgendorf 1879)(p=0.021) and *F. gymnauchen* (p=0.031) were the indicator species from mid-autumn (October) to early winter (December). *G. macrognathos* (p=0.008) was the indicator species from mid-winter (January) to late spring (May) while *G. breunigii* (p=0.034) from early summer (June) to mid-summer (July). The minimum spanning tree in Figure 6 showed an overlap between winter (December to February) and spring (March to May) indicating that these seasons shared some congruent properties in their community structure. Rank abundance curve based on the proportional abundance of the most abundant species (Figure 7) in a given season confirmed the dominance of *G. uchidai* and *G. macrognathos* as well as the presence of *E. gilli*, *G. breunigii*, *F. gymnauchen*, and *P. masago* as the conspicuous components of the fish community in winter and spring. Although they were distinguished from each other considering that a remarkable increase in abundance of *G. uchidai* was realized in spring combined with the high species richness and abundance of fishes in *spring*. Further analysis of the tree in figure 6 revealed a noticeable disparity of the fish community between summer and spring that was attributed to the remarkable increase in abundance of *G. uchidai* in spring, the dominance of *G. uchidai* and *G. breunigii* in summer while *G. uchidai* and *G. macrognathos* in spring. The disparity in the community structure between summer and winter was attributed to the dominance of *G. uchidai* and *G. breunigii* in summer while *G. uchidai* and *G. macrognathos* in winter. The autumn and spring fish community also showed a difference in their community that was attributed to the dominance of *G. uchidai* and *E. gilli* in autumn and *G. uchidai* and *G. macrognathos* in spring (Figure 7). In addition, the minimum spanning tree (Figure 6) also showed that the community structure in autumn shared some complementary properties with summer and winter indicating that the fish community in autumn represents a transition between the summer and winter fish community. Particularly, the fish community in early autumn (September) to mid-autumn (October) had close concordance with summer fish community while the late autumn (November) had a property that was coherent with the winter fish community (Figure 6).

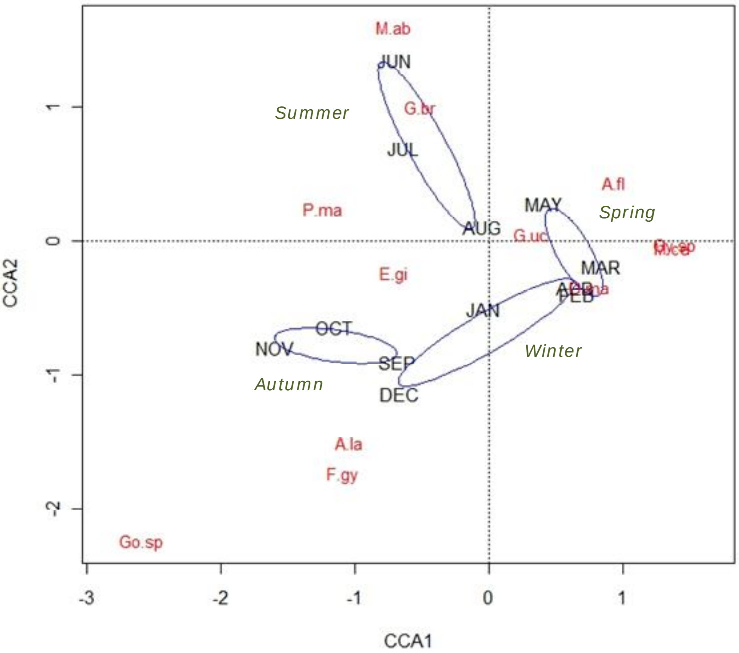
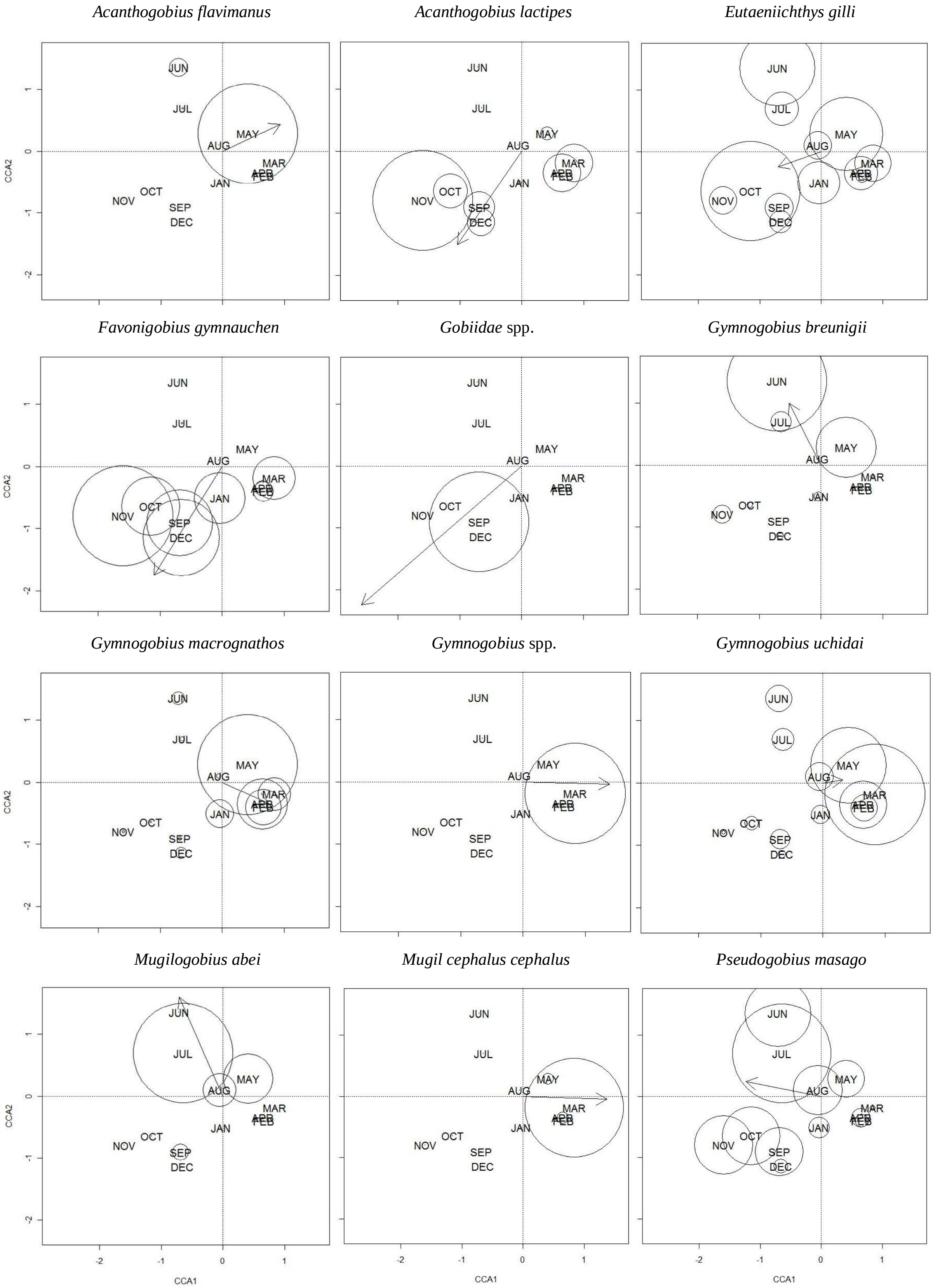


Figure 4. Canonical correspondence analysis base on actual count of fish per month constrained by season. The confidence ellipses were drawn to indicate the relationship of seasons in the ordination. Species and months were scaled symmetrically by the square root of their eigenvalues. Permutation test for each constrained axis showed significant results for CCA1 (p=0.01) and CCA2 (p=0.04). The cumulative proportion of the variance that can be explained by CCA1 (eigenvalue=0.1942) and CCA2 (eigenvalue=0.1171) was 48.26%.



Acanthogobius flavimanus *Acanthogobius lactipes* *Eutaeniichthys gilli*

Favonigobius gymnauchen *Gobiidae* spp. *Gymnogobius breunigii*

Gymnogobius macrognathos *Gymnogobius* spp. *Gymnogobius uchidai*

Mugilogobius abei *Mugil cephalus cephalus* *Pseudogobius masago*

Figure 5. Canonical correspondece analysis based on actual count of the 12 species of fish in the tidal creek across the sampling months. The vector (arrow) points to the month or months with substantial number of individuals as indicated by a bubble plot whose size was proportional to the actual individual count of a particular species in a given month.

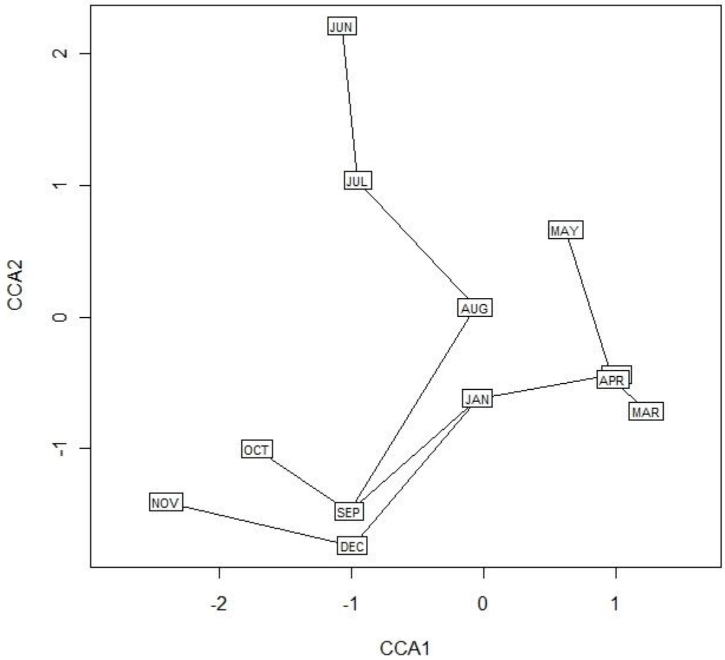


Figure 6. Minimum spanning tree that showed months that were joined by segments equivalent to their ecological distances. The Kulczynski index was used to generate the dissimilarity values in constructing the minimum spanning tree.

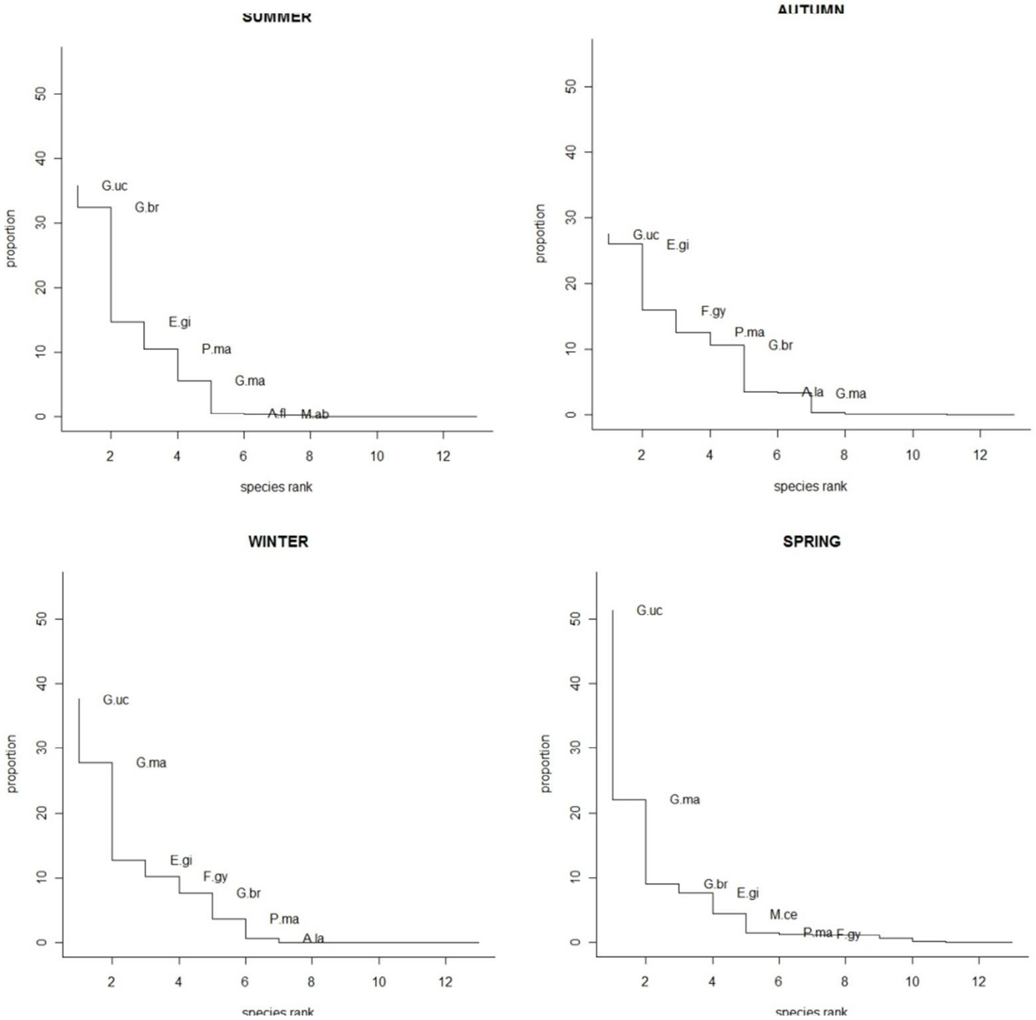


Figure 7. Rank abundance curve based on proportional abundance (%) of the seven most abundant fish species per season.

Species accumulation curve in Figure 8 showed an increase in species richness in spring (12 species) and autumn (11 species) while there was no apparent increase in species richness in winter (7 species). Moreover, an increase in species richness was realized from early summer (7 species) to mid-summer (9 species) but no substantial change in species richness was found from mid-summer to late summer (7 species).

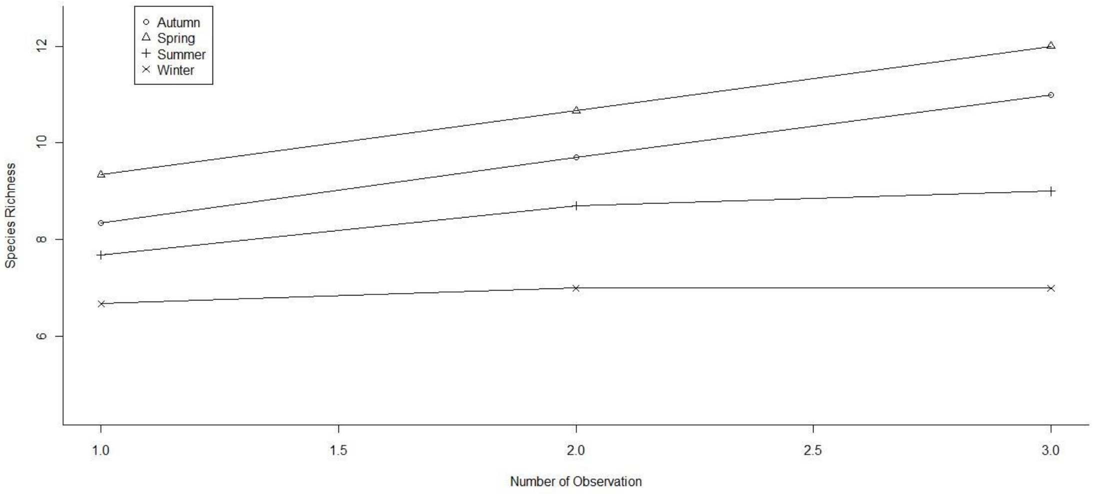
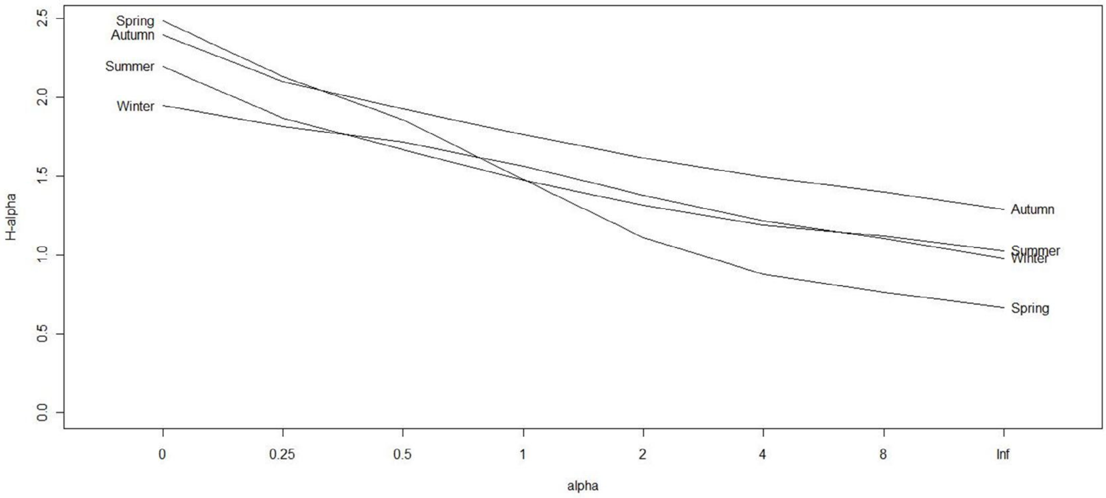


Figure 8. Species accumulation curve of the fish community in the intertidal tidal creek of Obitsu-gawa River Estuary compared by seasons.

Rényi diversity showed profiles that drop steeply for the four seasons indicating that species dominance was an inherent property of this tidal creek fish community (Figure 9A). This property was attributed to the substantial increase in abundance of *G. uchidai* and *G. breunigii* in summer, *G. uchidai* and *E. gilli* in autumn as well as *G. uchidai* and *G. macrognathos* in winter and spring. The diversity scores were higher in autumn as compared to summer and winter as indicated by clear separation between summer and autumn as well as winter and autumn profiles suggesting that the fish community in autumn was more diverse as compared to summer and winter. In addition, the species evenness profile also indicated that the fish community becomes relatively even as the season progressed from spring to winter (Figure 9B). The fish community in winter was in fact almost exclusively composed of the six most abundant goby species coupled with considerable decrease in abundance of the dominant species such as *G. uchidai* and *G. macrognathos*. Conversely, species dominance was exceptionally evident in spring that was attributed to a remarkable increase in abundance of *G. uchidai*.

In inner Tokyo Bay, an increase in water temperature and nutrient loads from rivers during the stratification period from June to October generally resulted in short-term fluctuations in phytoplankton abundance while decrease water temperature and radiation in late autumn to late winter (November to February) resulted in low primary productivity and at the time of spring bloom from March to May, a gradual increase in phytoplankton number was evident followed by a decrease in nutrient levels (Nakane et al 2008). It was likely that the high species richness and the remarkable high species dominance of the tidal creek fish community in spring were consistent with increase primary productivity of the bay. However, the low nutrient levels coupled with highly stratified water from summer to mid-autumn resulted in short-term fluctuations in primary productivity that can be mended when the estuary received significant nutrient loads from rivers. Although species dominance was a coherent feature of this habit, the tidal creek fish community had an episode of low species richness particularly during summer but the community tends to recover with increase species richness in early autumn.

A. Rényi diversity



B. Evenness profile

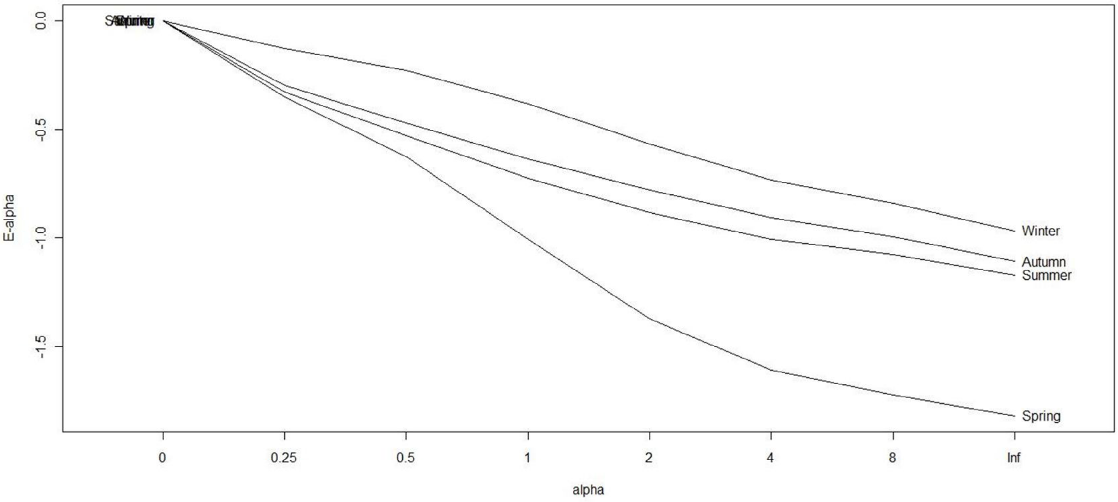


Figure 9. Seasonal pattern in diversity (A) and species evenness (B) profiles of the fish community in the shallow tidal creek of Obitsu-gawa River Estuary.

Bouman et al (2010) stressed that it was the heavy precipitation and high surface temperatures in the late spring and summer that gave rise to a highly stratified water column and stimulated a series of phytoplankton blooms in Tokyo Bay and a decrease in water temperature and radiation from late autumn to late winter resulted in lower primary production. This in turn resulted to low species richness and abundance of fish in the tidal creek, which eventually culminated into fewer species and individuals during winter. Despite the seasonal changes in community structure of fish in the tidal creek, *G. uchidai* was the consistent dominated species in the tidal creek in most months indicative of the importance of this shallow habitat to the said species. Adults of *G. uchidai* were known to inhabit the river mouths (Hermosilla et al 2012; Masuda et al 1984) and it was likely that the dominance of *G. uchidai* in the tidal creek was a reflection of the distribution of breeding adults considering that the time and location in the capture of young fish cohorts most often correlates with adult distribution and breeding periods especially for estuarine fishes that deposit demersal eggs to maximize larval retention (Neira et al 1992).

E. gilli in autumn-winter (September to February) was predominantly J2 (mean SL=18.8 mm; n=517) with few J3 (mean SL=27.2 mm; n=23). J2 was prevalent when the water temperature was < 29.6°C while J3 was prevalent when the water temperature was ≥ 29.6°C. Developmental stages in spring-summer (March to August) were predominantly compose of adult (mean SL=30.9 mm; n=493) and few J3 (mean SL=23.4 mm; n=56). Adult was present when water temperature was ≥ 19.05°C while J3 was prevalent when water temperature was < 19.05°C. Moreover, the J3 in autumn-winter was noticeably larger than that in spring-summer (Table 2).

The developmental stages in early autumn-mid-autumn (September to October) for *F. gymnauchen* were primarily larvae (mean SL=8.4 mm; n=103) with very few J2 (SL=15.2 mm; n=19). Larva was prevalent when the water temperature was ≥ 21.25°C while J3 was evident when the water temperature was < 21.25°C. The late autumn-summer (November to August) was primarily of J2 with few J3 and adult. This was further divided into late autumn-early spring (November to March) and mid-spring-summer (April to August) with J2 and J3 occurred in late autumn-early spring and adult (mean SL=32.4 mm; n=20) in mid-spring-summer period. In late autumn-early spring, J2 (mean SL=17.5 mm; n=115) was prevalent in station C while both J2 (mean SL=19.3 mm; n=100) and J3 (mean SL=23.2 mm; n=70) were prevalent in stations A and B. The size of J2 in stations A and B were noticeably larger than in station C (Table 2).

G. breunigii was predominantly composed of two developmental stages. J2 was prevalent in late spring-summer (May to August) while adult in autumn-mid-spring (September to April). There was a difference in size class for J2 and adults. J2 in late spring-early summer (May to June) was noticeably smaller (mean SL=24.6 mm; n=256) as compared to the SL (mean SL=29.8 mm; n=131) observed in mid-summer-late summer (June to August). Large size adult (mean SL=44.6 mm; n=158) was prominent in winter-mid-spring (December to April) while smaller size group (mean SL=40.5 mm; n=146) was prevalent in autumn (September to November) (Table 2).

The developmental stage of *G. macrognathos* in late spring-autumn (May to November) was primarily juvenile (J1, J2 and J3) while the winter-mid-spring (December to April) was composed of adult (mean SL=32.4 mm; n=631). The distribution of juveniles in late spring-autumn varied with water temperature. J1 (mean SL=19.4 mm; n=128) was prevalent when the water temperature was ≥ 29.75°C while J2 (mean SL=21.6 mm; n=125) was present when water temperature was between 25.8-29.55°C. On the other hand, J3 had a wider temperature range from < 25.8°C (mean SL=26.9 mm; n=125) to 29.55-29.75°C (mean SL=27.1 mm; n=50) (Table 2).

G. uchidai in summer (June to August) was primarily J2 (mean SL=18.9 mm; n=756). J3 was prevalent in autumn-early winter (September to January) but a noticeable difference in size was observed with smaller individuals (mean SL=20.9 mm; n=201) in early autumn (September) and larger individuals (mean SL=23 mm; n=258) in mid-autumn-early winter (October to December). Adult (mean SL=25.3 mm; n=1,063) was evident in mid-winter-spring (January to May) (Table 2).

P. masago in autumn-mid-spring (September to April) was essentially J2 while adult was prevalent in late spring-summer (May to August). A noticeable difference in size class was found for J2 with smaller individuals (mean SL=13.7 mm; n=112) in early autumn-mid-autumn (September to November) while larger individuals (mean SL=16.8 mm; n=139) in late autumn-mid-spring (November to May). In late spring-summer, adult that was of small size group (mean SL=21.2 mm; n=145) was prevalent when the water temperature was < 28.6°C while the large size group (mean SL=22.7 mm; n=120) was evident when the water temperature was ≥ 28.6°C (Table 2).

The significant number of adult *G. uchidai* and early juveniles of *G. macrognathos* in spring was likely attributed to the high primary productivity in this season (Ogawa & Ogura 1997; Nakane et al 2008; Bouman et al 2010) especially if the utilization of the intertidal habitat by these epibenthic fishes was related to feeding (Cattrijsse et al 1994; Kneib 1997; Laffaille et al 2000; Nemerson & Able 2003). In addition, the prevalence of high temperature waters from late spring to early autumn can promote temperature-mediated growth (Krück et al 2009) for the early juvenile stages of *G. macrognathos* and *G. breunigii*, which was further substantiated by *P. masago* whose growth was noticeably fast from a J2 in spring to an adult stage in summer. This finding concurred with the *Pseudogobius olorum* (Sauvage 1880) of Swan Estuary in Western Australia wherein growth of the spring-spawned progeny was relatively fast at high temperature between late spring and mid-autumn (Gill et al 1996). However, a considerable number of *F.*

gymnauchen larvae and J2 of *E. gilli* were present in autumn that was inconsistent with the previous finding regarding the importance of high temperature water in promoting fast growth of gobies during the early stages of development. *F. gymnauchen* was known to spawn in brackish waters near the river mouth of Ikisan River Estuary in northern Kyushu, Japan between June and October (Inui et al 2010) and considering its protracted spawning period (Inui et al 2010) and a pelagic larval life of gobies of at least a month (Fonds 1970; Fonds & Van Buurt 1974), a more or less similar trend likely to occur in Obitsu-gawa River Estuary that contributed to a considerable increase in abundance of larvae in autumn. It appears that the timing of spawning and the subsequent benthic deposition of eggs around summer were more important for *F. gymnauchen* and *E. gilli*. Strategic deposition of eggs during summer when the estuary was experiencing high water temperatures can promote faster development of eggs as well as survival of the embryos that resulted to a noticeable increase in abundance larvae and early juveniles in autumn. This contention was coherent with the findings of Fonds & Van Buurt (1974) that accelerated egg development and survival of the estuarine goby *Pomatoschistus microps* (Krøyer 1838) of the western European coast was correlated with high temperature waters (25°C).

Table 2

Summary results for the recursive partitioning of the 6 gobiid species in relation with the relevant explanatory variables (e.g., month, water temperature and station). Life history stages were larva (L), juvenile (J1, J2 and J3) and adult (A)

Species	*Regression tree node*				*Samples (n)*	*Deviance score*	*Mean SL (mm)*	*Life history*
	1	2	3	4				
Eutaeniichthys gilli					1,089	132,180	24.7	
	Dec, Feb, Jan, Nov, Oct, Sep				540	26,741	19.2	
		<29.6°C			517	23,520	18.8*	J2
		≥29.6°C			23	1,697	27.2*	J3
	Apr, Aug, Jul, Jun, Mar, May				549	72,897	30.1	
		<19.05°C			56	3,267	23.4*	J2
		≥19.05°C			493	66,792	30.9	
			<30.1°C		411	12,376	30.1*	A
			≥30.1°C		82	52,915	34.8*	A
Favonigobius gymnauchen					427	28,414	17.3	
	Oct, Sep				122	1,981	9.4	
		≥21.25°C			103	383	8.4*	L
		<21.25°C			19	841	15.2*	J2
	Apr, Aug, Dec, Feb, Jan, Jul, Jun, Mar, May, Nov				305	16,002	20.4	

		Dec, Feb, Jan, Mar, Nov			285	8,938	19.5	
			Station C		115	3,411	17.5*	J2
			Stations A, B		170	4,756	20.9	
				Feb, Jan, Nov	100	1,535	19.3*	J2
				Dec, Mar	70	2,578	23.2*	J3
		Apr, Aug, Jul, Jun, May			20	3,989	32.4*	J3
Gymnogobius breunigii					691	63,907	33.5	
	Aug, Jul, Jun, May				387	11,950	26.4	
		Jun, May			256	7,755	24.6*	J2
		Aug, Jul			131	1,880	29.8*	J2
	Apr, Jul, Jun, May, Apr, Dec, Feb, Jan, Mar, Nov, Oct, Sep				304	7,121	42.6	
		Nov, Oct, Sept			146	1,652	40.5*	A
		Apr, Dec, Feb, Jan, Mar			158	4,197	44.6*	A
Gymnogobius macrognathos					966	41,610	28.8	
	Aug, Jul, Jun, May, Nov, Oct, Sep				335	11,157	22.1	
		≥29.75°C			128	1,509	19.4*	J1
		<29.75°C			207	8,150	23.7	
			<29.55°C		157	3,670	22.7	
				≥25.8°C	125	2,296	21.6*	J2
				<25.8°C	32	640	26.9*	J3
			≥29.55°C		50	3,716	27.1*	J3
	Apr, Dec, Feb, Jan, Mar				631	7,062	32.4*	A

Gymnogobius uchidai			2,278	26,801	22.5	
	Aug, Jul, Jun, Sep		957	5,123	19.3	
		Aug, Jul, Jun,	756	3,936	18.9*	J2
		Sep	201	555	20.9*	J3
	Apr, Dec, Feb, Jan, Mar, May, Nov, Oct		1,321	4,969	24.8	
		Dec, Nov, Oct	258	1,151	23.0*	J3
		Apr, Feb, Jan, Mar, May	1,063	2,798	25.3*	A
Pseudogobius masago			516	9,797	18.7	
	Apr, Dec, Feb, Jan, Mar, Nov, Oct, Sep		251	2,861	15.4	
		Oct, Sep	112	1,630	13.7*	J2
		Apr, Dec, Feb, Jan, Mar, Nov	139	631	16.8*	J2
	Aug, Jul, Jun, May		265	1,514	21.9	
		<28.6°C	145	985	21.2*	A
		≥28.6°C	120	395	22.7*	A

* Indicates terminal node in the regression tree.

Conclusions. The community structure of fishes in the shallow tidal creek of Obitsu-gawa River Estuary was regulated by the presence as well as abundance of fishes under family Gobiidae that were of different life history stages. This study proposed that change in fish community structure in this temperate tidal creek was strongly influenced by season. There was a difference in the community structure between spring and summer. The spring community had high species richness and dominance while the summer community had relatively low species richness and although species dominance was prevalent, it was not as remarkable as compared with spring. The fish community in autumn shared some properties with the fish community in summer and winter suggesting that the autumn fish community was likely a transition between these two seasons, which explains why the autumn fish community was more diverse with high species richness as compared with summer and winter. Nevertheless, the fish community in this shallow habitat had the tendency to become proportionately even as the season progresses from spring to winter. The winter fish community was substantially low in species richness when compared with the rest seasons. However, despite the seasonal changes in community structure of fish in the tidal creek, *G. uchidai* consistently dominated this fish community in most months indicative of the importance of this habitat to the said species.

The shallow tidal creek of Obitsu-gawa River Estuary function as a habitat for estuarine gobies that were considered residents of the estuarine tidelands of Tokyo Bay with life history stages ranging from larvae to adults and access to this estuarine habitat was likely regulated by patterns of flooding events that resulted to habitat exploitation such as foraging as well refuge from predators. Estuarine gobies such as *G. uchidai*, *G. macrognathos*, *G. breunigii*, *E. gilli*, *P. masago* and *F. gymnauchen* were important components of this fish community. The occurrence of a particular life history stage of goby showed a strong association with month and water temperature. In the tidal creek of Obitsu-gawa Estuary, adults substantially contributed to the population size structure of *P. masago* and *G. uchidai* while juveniles for *G. breunigii* and *E. gilli*. Larvae significantly contributed to the population size structure of *F. gymnauchen* while early stage juveniles for *G. macrognathos*.

Acknowledgements. 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. We are indebted to anonymous referees for their constructive comments on the manuscript.

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Received: 16 September 2012. Accepted: 08 October 2012. Published online: 09 October 2012.

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How to cite this article:
Hermosilla J. J., Tamura Y., Okazaki D., Hoshino Y., Moteki M., Kohno H., 2012 Seasonal pattern and community structure of fishes in the shallow tidal creek of Obitsu-gawa River Estuary of inner Tokyo Bay, central Japan. AACL Bioflux 5(5):337-355.