

Decadal changes in the fish assemblage structure at a modified shore site in an urbanised estuarine canal

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Abstract: We analysed datasets of fish assemblages for two timescales (decadal and annual, composed of four periods: 1993–1994; 2004–2005; 2005–2006; 2006–2007) to estimate the temporal dynamics of assemblage structures and changes in estuarine use functional groups (EUFGs) along a modified shoreline. The datasets were obtained from monthly sampling using a light trap at a mooring berth site reinforced with a vertical hard structure in an estuarine canal in Tokyo, Japan. A comparison of the fish community parameters during the sampling periods showed significant decadal variation in some factors, but no significant variation across sequential annual timescales. Total species richness increased due to increased richness in fish in the marine EUFG category. The percent abundance of marine fish also significantly increased, whereas the abundance of estuarine fish (primarily *Acanthogobius flavimanus* predominated) decreased. Habitat degradation around the mooring berth site accompanying city planning might be responsible for the decline in estuarine fish species over several decades, whereas the increased species richness reflected a recent recovery in water quality in the Tokyo Bay. These results suggest that nowadays the study site functions as an ecological corridor between natural shore sites rather than as a true habitat for estuarine fish species.

Keywords : *Artificial structure, community dynamics, estuarine fish, Tokyo Bay*

Introduction

Estuaries, where rivers flow into the ocean forming a complex environment with transitional waters, represent a key ecosystem in coastal zones that fulfils various biotic and abiotic

functions, and is of both ecological and economic importance (COSTANZA *et al.*, 1997; McLUSKY and ELIOTT, 2004; BARBIER *et al.*, 2011). In addition, this ecosystem, which lies adjacent to many of the world's megacities (DAY *et al.*, 2012a), is highly

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vulnerable to anthropogenic impacts. Common artificial changes in coastal zones are modifications of the shoreline and construction of urban infrastructures, typically classified in terms of the materials used and purpose, such as riprap/rubble or vertical walls and their combination, breakwaters, groynes, jetties, seawalls, bulkheads, and pilings (BULLERI and CHAPMAN, 2010; SCYPHERS *et al.*, 2015). The negative effects of these artificial structures on estuarine ecosystems have been reported as various ecological responses of fish communities (e.g., decreases in native fish diversity and/or abundance) (ABLE *et al.*, 1998; PETERSON *et al.*, 2000; BILKOVIC and ROGGERO, 2008; MUNSCH *et al.*, 2014; MORENO-VALCÁRCCEL *et al.*, 2016), and degradation of habitats in relation to foraging (LOWE and PETERSON, 2015; DAVID *et al.*, 2016), growth (DUFFY-ANDERSON and ABLE, 1999; ABLE *et al.*, 1999) and reproduction (RICE, 2006; BALOUSKUS and TARGETT, 2012). In contrast, several studies have reported the possible function of artificial hard structures as habitats for coastal and estuarine fish assemblages (GUIDETTI, 2004; CLYNICK, 2006; SAKAI *et al.*, 2007; INUI *et al.*, 2012; TAKIGASAKI and SANO, 2013), and the lack of significant negative effects of modified shorelines on fish communities in estuarine environments compared to natural shorelines (MCKINLEY *et al.*, 2011; MORLEY *et al.*, 2012). However, some authors have noted the need for additional studies on the ecological effects of shoreline armouring (AIROLDI *et al.*, 2005; BULLERI and CHAPMAN, 2010; MORLEY *et al.*, 2012), particularly, over longer timescales (CHAPMAN and UNDERWOOD, 2011). Although the cumulative effects of artificially altered environments have been previously reported (PETERSON and LOWE, 2009), there have been few long-term studies on this modified environment. SCYPHERS *et al.* (2015) compared the stability of fish community structures among three types of modified shorelines

and a natural shoreline using a series of 11-year samples (based on a fisheries database) in the Mobile Bay of the northern Gulf of Mexico. The authors reported that the most simplified shoreline (vertical wall) had the lowest assemblage stability, and that the natural shoreline had the most stable assemblages. This indicates the need for long-term studies of several months or even years to accurately assess modified shorelines as habitats for aquatic organisms and elucidate the impacts on this ecosystem as a basis for implementing effective policies to support sustainable development.

Guild classification, the categorisation of each organism relative to its pattern of using the space and resources in an ecosystem, is a key approach for evaluating systems as habitats for organisms in the current context of the global decrease in biodiversity and increase in ecosystem disturbances (WHITFIELD and ELLIOTT, 2002; BLONDEL, 2003; CARDOSO *et al.*, 2011b). ELLIOTT *et al.* (2007) performed a global-scale review and defined estuarine fish guilds covering three dimensions of resource usage: 1) the ways in which the fish use the estuary during their entire life cycle (refined by POTTER *et al.*, 2015); 2) primary feeding method; and 3) use of the site to reproduce. This guild classification, which has been applied in the assessment of the ecosystem value of estuaries (FRANCO *et al.*, 2008), the understanding of the relationships between the condition of each estuary and structure of the functional groups (NICOLAS *et al.*, 2010), and the assessment of estuary habitat quality (CARDOSO *et al.*, 2011a; GAMITO *et al.*, 2012; PÉREZ-DOMÍNGUEZ *et al.*, 2012), has significantly contributed to enhancing our understanding of the connection between the structure of functional communities and the condition of the estuarine ecosystem. Moreover, long-term studies have revealed that extreme climate events have caused dramatic changes in

the functional trait structure of estuarine fish communities (NYITRAI *et al.*, 2012; BOUCEK and REHAGE, 2014). In addition, the long-term effects of anthropogenic impacts (such as hydrological changes) on guild structures in estuaries have only recently been detected, and the combined effects with those of climate change could cause marked changes in ecosystem function (BAPTISTA *et al.*, 2015).

Tokyo is one of the world's largest megacities, and is located along the shoreline of the innermost part of the Tokyo Bay. Numerous rivers flow into the bay, creating various estuarine environments. The inner part of the bay formerly comprised a wide area of shallow tidal flats, but currently, the natural shore has completely disappeared due to land reclamation for industrialisation, which has taken place at an increasing rate since the 1950s (ENDO, 2004; NOMURA, 2012). A number of studies on fish assemblage structures and their temporal changes have been performed during the last 20 years in several semi-natural shoreline areas (shallow tidal flats formed after reclamation) of the estuarine environment adjacent to the city, suggesting that environmental recovery is at least a short-term prerequisite as a habitat for marine and estuarine fish with fewer effects from severe pollutants and modified shoreline (NASU *et al.*, 1996; KANOU *et al.*, 2000; YAMANE *et al.*, 2003; KOHNO *et al.*, 2008; MOTEGI *et al.*, 2009; KANOU and KOHNO, 2014; MURASE *et al.*, 2014). Despite extensive shoreline development, few studies examining the function of modified shorelines as habitat have been performed in the inner part of the bay. Recent 1-year surveys on fish assemblages in the inner bay demonstrated that the artificial canal constructed with vertical walls might provide suitable habitat for parts of the lifecycle of several estuarine fish species (MURASE *et al.*, 2007; SAKAI *et al.*, 2007). However, there is little information

on whether modified shorelines in estuarine environments can function as a consistent long-term habitat for fish species. In this context to reveal temporal dynamics of fish community of modified estuarine shorelines, the present study examined the long-term changes of fish community structure including guild classification by combining previously published data (1993–1994: SAKAI *et al.*, 2007) with a more recent (2004–2007) dataset (collected using a method similar to that of the earlier dataset) of fish assemblages at an armoured site in the inner part of the Tokyo Bay.

Materials and Methods

Study site. The study site was located at the mooring berth of the Shinagawa Campus of Tokyo University of Marine Science and Technology, in the Keihin Canal in the inner part of the Tokyo Bay, central Japan (35° 37' 33" N, 139° 45' 04" E; Fig. 1), approximately 1.6 km north of the mouth of the Meguro River and 4.0 km south of Sumida River. The site is classed as estuarine based on its year-round salinity (SAKAI *et al.*, 2007). The entire shoreline at this site is armoured with vertical wall structures. The water depth ranges from 1.5 m to 3.0 m, and the bottom sediment comprises sandy mud including sludge. The armoured wall is almost fully covered in adhered oyster shells and blue sea mussels.

Sampling protocol. Although light-trap sampling has several problems caused by utilizing the positive phototaxis of fishes, it is a more favourable sampling method in habitats where it is difficult to draw plankton, seine, and other fishing nets (DOHERTY, 1987; SAKAI *et al.*, 2007). Following the sampling protocol of a previous study at the same site (SAKAI *et al.*, 2007), we conducted fish sampling twice a month between December 2004 and November 2007 (72 sampling events in total), using an aquatic lamp (300 W) and two hand nets

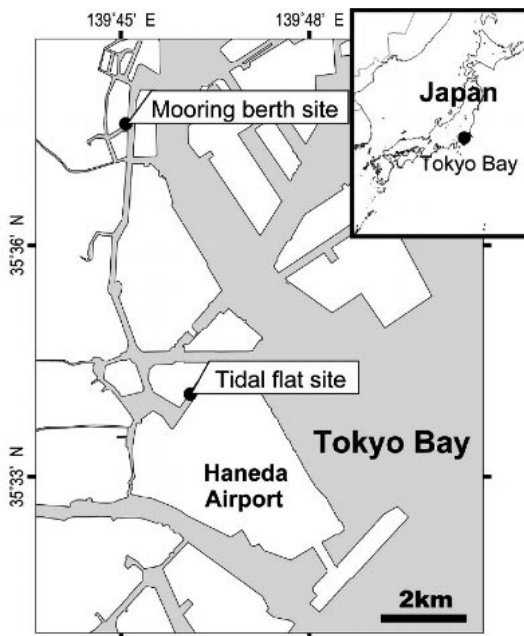


Fig. 1. Map showing the locations of the study site, a mooring berth in Keihin Canal, and a semi-natural site, a tidal flat of Keihin-jima Island, for comparison, in the inner part of the Tokyo Bay (partly modified from a 1:25000 topographic map from the Geospatial Information Authority of Japan).

(1 mm mesh, 40 cm diameter). We set the aquatic lamp 0.5 m below the surface 0.5 m from the mooring berth, and turned on the lamp 30–60 min after sunset but did not consider the tide and moon's age. Subsequently, we collected all fish attracted to the light for 1 h after the light had been turned on for 5 min. All of the samples were fixed in 5–10% formalin in the field, and later preserved in 70% ethanol in the laboratory. Before each fish sampling, the surface water temperature and salinity were measured using a standard mercury thermometer and salinity refractometer, respectively. Fish were picked from the samples using a dissecting microscope and identified to the lowest possible taxon following OKIYAMA (1988) and NAKABO (2002). Scientific names revised after NAKABO (2002), fol-

lowed NAKABO (2013) and HOSOYA (2015). All of the specimens were deposited in the Kanagawa Prefectural Museum of Natural History, Odawara, Japan (KPM-NI 18477–18511), the Laboratory of Ichthyology of Tokyo University of Marine Science and Technology, Tokyo, Japan (MTUF-P [L] 16385–16627), and the National Museum of Nature and Science, Tsukuba, Japan (NSMT-P 92707–92717).

Fish classification. ELLIOTT *et al.*, (2007) developed a classification of guilds for estuarine usage functional groups (EUFGs) for fish in estuarine environments and defined 10 traits. Refining this classification, POTTER *et al.*, (2015) divided the EUFGs into 4 main categories (marine, estuarine, diadromous, and freshwater), and subdivided these into a total of 14 categories. Using the sampled fish as general indicators to assess the temporal variability in habitat quality at the study site, we classified them into three main categories and three subcategories (six categories in total) following POTTER *et al.*, (2015): marine, estuarine, and freshwater, and anadromous, catadromous, amphidromous subcategories in the diadromous category. For this classification, we referred to KAWANABE *et al.*, (2001), KOHNO *et al.*, (2011) and HOSOYA (2015) for information on the ecological use of estuarine environments by each fish species.

Data analysis. To analyse the variation in structure of the fish assemblages and changes in EUFG composition on decadal and annual time-scales, we defined the following four sampling periods: Period 0 (P0), May 1993–April 1994 (Sakai *et al.*, 2007); Period 1 (P1), December 2004–November 2005; Period 2 (P2), December 2005–November 2006; and Period 3 (P3), December 2006–November 2007. Due to the difference in monthly sampling frequency between P0 (1–3

times per month) and P1-3 (2 times per month), the catch per unit effort (CPUE) was calculated for each month by comparing the mean abundance of fish among sampling periods. Monthly one-way repeated measures of analysis of variance (ANOVA) and a Tukey's test were performed to analyse the variability in each variable for the fish assemblages, predominant EUFG categories, and environments among the sampling periods. When the condition of normal distribution was violated based on a Shapiro-Wilk test, the data were $\log_{10}(x + 1.0)$ transformed or Friedman and Wilcoxon's signed rank tests were adopted. Furthermore, to analyse differences in community structure among sampling periods, the similarity index of CHAO *et al.*, (2005), which extended the Jaccard index so that it reflected unseen species and abundance data (DOI and OKAMURA, 2011), was calculated and non-metric multi-dimensional scaling (nMDS) was used to generate ordination plots based on the values of similarity index. All of the procedures were conducted using the software program R 3.2.2 (R DEVELOPMENT CORE TEAM, 2015).

Comparison with nearby tidal flat. The fish assemblage structures have been studied since 1994 on a semi-natural tidal flat of artificial Keihin-jima Island (35° 34'05"N, 139° 46'06"E; Fig. 1), close to the present study site, and the results have shown consistent predominance of estuarine gobies for almost 20 years (MOTEGI *et al.*, 2009; MURASE *et al.*, 2014), indicating a relatively stable long-term community structure. To compare the temporal stability of the community structure between modified (the study site) and semi-natural sites over similar time periods, abundance data on each species from the tidal flat site were extracted from published papers and reflected in the composition of the EUFG and nMDS. Then, the following time periods were fixed for the data

from the tidal flat site: Period 0 on Keihin-jima Island (P0, 1994–1995: NASU *et al.*, 1996); Period 1 (P1, 2006–2007: MOTEGI *et al.*, 2009); Period 2 (P2, 2007–2008); and Period 3 (P3, 2008–2009: MURASE *et al.*, 2014). The abbreviations for these periods are the same as those of the mooring berth site unless mentioned in the text.

Results

Composition of fish assemblages. A total of 4,211 individuals representing 47 fish species belonging to 28 families were captured during P0–3, with 1,249 individuals and 16 species in P0, and 925–1056 individuals and 29 or 30 species in P1–3 (Table 1). The total sampling frequencies in P0 (26 times) and P1–3 (24 times in each period) were almost equal, resulting in no significant differences in total abundance, but the number of species in P1–3 was almost two-fold that in P0 (Table 1). The number of species and abundance of each EUFG in each sampling period are shown in Table 2, with values from the nearby tidal flat for comparison. The marine category was predominant in terms of number of species across sites and sampling periods, but the most abundant group changed from estuarine in P0 to marine in P1–3 at the mooring berth site, whereas on the nearby tidal flat site the estuarine group was consistently dominant throughout all sampling periods. The four categories, freshwater, anadromous, amphidromous, and catadromous, were barely observed (0.00–0.95% in total abundance) throughout the sampling periods except for P1 (10.70% and 12.23% for the anadromous and amphidromous categories, respectively; Table 2). Corresponding to the changes in abundance of the EUFGs, the most abundant fish species also changed (Table 3), in that an estuarine gobiid, *Acanthogobius flavimanus*, was most abundant in P0 followed by a marine species, the marine pelagic clupeid (*Sardinella zunasi*) as the

Table 1. Fish species and their dominance (% abundance) in each sampling period collected at a mooring berth in the Keihin Canal in the inner Tokyo Bay during Periods 0–3 (P0–3)

Family	Species	EUFG	% Abundance in each period			
			P0	P1	P2	P3
Anguillidae	<i>Anguilla japonica</i>	C	0.00	0.00	0.32	0.19
Engraulidae	<i>Engraulis japonica</i>	M	17.05	4.89	35.57	16.29
Clupeidae	<i>Etrumeus teres</i>	M	0.00	0.31	0.22	0.76
	<i>Konosirus punctatus</i>	M	0.08	0.10	0.00	0.00
	<i>Sardinella zunasi</i>	M	1.20	30.58	36.65	60.04
	<i>Sardinops melanostictus</i>	M	3.12	0.00	0.00	0.00
Cyprinidae	<i>Tribolodon brandtii maruta</i>	An	0.00	10.70	0.11	0.28
Osmeridae	<i>Plecoglossus altivelis altivelis</i>	Am	0.08	0.00	0.11	0.09
	<i>Salangichthys ishikawae</i>	M	0.08	0.00	0.00	0.00
Mugilidae	<i>Mugil cephalus cephalus</i>	M	0.00	3.57	6.05	11.17
Atherinidae	<i>Hypoatherina valenciennei</i>	M	0.00	13.66	7.78	0.85
Adrianichthyidae	<i>Oryzias latipes</i>	F	0.00	0.00	0.11	0.00
Hemiramphidae	<i>Hyporhamphus sajori</i>	M	0.40	0.10	0.00	0.00
Belontiidae	<i>Strongylura anastomella</i>	M	0.00	0.00	0.00	0.09
Scomberesocidae	<i>Cololabis saira</i>	M	0.00	0.00	0.00	0.09
Poeciliidae	<i>Gambusia affinis</i>	F	0.08	0.00	0.11	0.00
Syngnathidae	<i>Hippocampus mohnikei</i>	M	0.00	0.10	0.00	0.00
Scorpaenidae	<i>Sebastes cheni</i>	M	0.00	0.82	2.59	0.09
	<i>S. pachycephalus pachycephalus</i>	M	0.00	0.10	0.22	0.09
Platycephalidae	<i>Platycephalus</i> sp.	M	0.00	0.10	0.22	0.09
Moronidae	<i>Lateolabrax japonicus</i>	M	0.88	3.98	1.73	0.09
Centrarchidae	<i>Lepomis macrochirus macrochirus</i>	F	0.00	0.20	0.00	0.00
Sillaginidae	<i>Sillago japonica</i>	M	0.00	0.00	0.00	0.28
Leiognathidae	<i>Nuchequula nuchalis</i>	M	0.00	0.00	0.00	0.09
Sparidae	<i>Acanthopagrus latus</i>	M	0.00	0.00	0.22	0.00
Kyphosidae	<i>Girella punctata</i>	M	0.00	0.20	0.11	0.09
Teraponidae	<i>Rhynchopelates oxyrhynchus</i>	M	0.00	0.00	0.00	0.09
	<i>Terapon jarbua</i>	M	0.00	0.10	0.00	0.00
Pholidae	<i>Pholis nebulosa</i>	M	0.00	0.31	0.11	0.00
Blenniidae	<i>Omobranchus fasciolatoceps</i>	E	0.00	0.00	0.11	0.19
	<i>Parablennius yatabei</i>	M	0.00	0.10	0.00	0.00
Gobiidae	<i>Acanthogobius flavimanus</i>	E	71.26	5.71	0.54	0.19
	<i>Acentrogobius virgatus</i>	M	0.00	0.10	0.32	0.00
	<i>Chaenogobius gulosus</i>	M	3.76	4.69	2.59	5.40
	<i>Gymnogobius breunigii</i>	E	0.32	0.20	0.11	0.47
	<i>G. heptacanthus</i>	M	0.00	0.61	0.11	0.19
	<i>G. macrognathos</i>	E	0.00	2.14	0.00	0.38
	<i>G. petschiliensis</i>	Am	1.20	11.93	0.54	0.76
	<i>Luciogobius</i> sp.	Am	0.32	0.31	0.00	0.09
	<i>Mugilogobius abei</i>	E	0.08	2.45	1.08	0.57
	<i>Pseudogobius masago</i>	E	0.00	0.00	0.00	0.09
	<i>Redigobius bikolanus</i>	E	0.00	0.00	0.65	0.09
	<i>Tridentiger</i> spp.	E	0.00	1.12	0.76	0.76
Ptereleotridae	<i>Ptereleotris evides</i>	M	0.08	0.00	0.00	0.00
Pleuronectidae	<i>Kareius bicoloratus</i>	M	0.00	0.51	0.86	0.00
	<i>Pleuronectes yokohamae</i>	M	0.00	0.00	0.11	0.00
Tetraodontidae	<i>Takifugu pardalis</i>	M	0.00	0.31	0.00	0.00
Sampling frequency in total			26	24	24	24
Total individuals in each period			1249	981	925	1056
Number of species in each period			16	30	29	30

EUFG, estuarine use functional group: Am, amphidromous; An, anadromous; C, catadromous; E, estuarine; F, freshwater; M, marine

Table 2. Summary of the composition of the estuarine use functional groups (EUFGs) in each sampling period (P0–3) during 1993–1994 (Period 0) and 2004–2007 (Periods 1–3) at a mooring berth in the Keihin Canal using light-trap sampling, and on a semi-natural tidal flat on Keihin-jima Island in the inner Tokyo Bay during 1994–1995 (P0) and 2006–2009 (P1–3) using seine net sampling

EUFG at each site	Number of species				% Abundance			
	P0	P1	P2	P3	P0	P1	P2	P3
Mooring berth								
Marine	9	21	17	17	26.66	65.24	95.46	95.83
Estuarine	3	5	6	8	71.66	11.62	3.24	2.75
Freshwater	1	1	2	0	0.08	0.20	0.22	0.00
Anadromous	0	1	1	1	0.00	10.70	0.11	0.28
Catadromous	0	0	1	1	0.00	0.00	0.32	0.19
Amphidromous	3	2	2	3	1.60	12.23	0.65	0.95
Total	16	30	29	30				
Tidal flat								
Marine	23	18	20	22	24.31	43.76	32.60	3.00
Estuarine	7	9	9	10	75.50	53.59	61.75	93.41
Anadromous	1	1	1	1	0.09	0.01	0.79	0.41
Amphidromous	2	3	3	3	0.11	2.65	4.86	3.19
Total	33	31	33	36				

Table 3. Percent abundance (%) of the five most abundant fish species and their estuarine use functional group (EUFG) classification (Am, amphidromous; An, anadromous; E, estuarine; M, marine) at the mooring berth in each sampling period

Rank	Period 0 (1993–1994)				Period 1 (2004–2005)			
	Family	Species	EUFG	%	Family	Species	EUFG	%
1	Gobiidae	<i>A. flavimanus</i>	E	71.26	Clupeidae	<i>S. zunasi</i>	M	30.58
2	Engraulidae	<i>E. japonica</i>	M	17.05	Atherinidae	<i>H. valenciennei</i>	M	13.66
3	Gobiidae	<i>C. gulosus</i>	M	3.76	Gobiidae	<i>G. petschiliensis</i>	Am	11.93
4	Clupeidae	<i>S. melanostictus</i>	M	3.12	Cyprinidae	<i>T. brandtii maruta</i>	An	10.70
5	Clupeidae	<i>S. zunasi</i>	M	1.20	Gobiidae	<i>A. flavimanus</i>	E	5.71
Period 2 (2005–2006)				Period 3 (2006–2007)				
Family	Species	EUFG	%	Family	Species	EUFG	%	
Clupeidae	<i>S. zunasi</i>	M	36.65	Clupeidae	<i>S. zunasi</i>	M	60.04	
Engraulidae	<i>E. japonica</i>	M	35.57	Engraulidae	<i>E. japonica</i>	M	16.29	
Atherinidae	<i>H. valenciennei</i>	M	7.78	Mugilidae	<i>M. cephalus cephalus</i>	M	11.17	
Mugilidae	<i>M. cephalus cephalus</i>	M	6.05	Gobiidae	<i>C. gulosus</i>	M	5.40	
Scorpaenidae	<i>S. cheni</i>	M	2.59	Atherinidae	<i>H. valenciennei</i>	M	0.85	

See Table 1 for initial of genera in each family

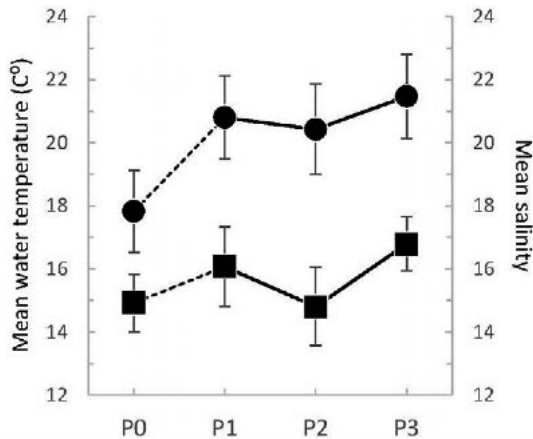


Fig. 2. Decadal (broken lines) and annual (solid lines) variation in the physical parameters over four time periods (P0–3): solid circles, mean water temperature; solid squares, mean salinity at the mooring berth site. Vertical bars indicate standard errors.

most abundant species during P1–3; 2–5 marine species were ranked in the top five abundant members over all sampling periods. This trend significantly differed from that of a nearby tidal flat, where estuarine gobiids were diverse and the most abundant group throughout 1994–2009 (MOTÉKI *et al.*, 2009; MURASE *et al.*, 2014).

Variation in environmental parameters. The temporal variation in the environmental parameters at the study site is shown in Fig. 2. Mean water temperature (17.8–21.5°C) varied significantly on a decadal time scale (Tukey’s test, $p < 0.001$ for P0 versus the other sampling periods), but no significant annual variation was observed. Mean salinity (14.8–16.8) showed no significant variation across all sampling periods (Friedman test, $p = 0.445$).

The mean total number of species increased significantly from P0 to P1 (Tukey’s test, $p = 0.047$) together with an increase in the marine category from P0 to P1 and from P0 to P2

(Tukey’s test, $p = 0.012$ and 0.039 , respectively), whereas no significant temporal variation was detected in the estuarine category (ANOVA, $p = 0.864$; Fig. 3a). The mean CPUE of the total fish abundance was constant throughout the sampling periods (ANOVA, $p = 0.995$; Fig. 3b), but the composition of those EUFGs that constituted the majority of the total abundance (marine and estuarine categories) in each sampling period changed with time. The percent abundance of the marine category increased from P0 to P1, and remained stable from P1 to P3 (Fig. 3c), varying significantly among the sampling periods (Friedman test, $p = 0.024$), although no significant differences between P0 and the other sampling periods were detected (Wilcoxon’s signed rank test, $p = 0.222$ for P0 versus P1; $p = 0.087$ for P0 versus P2; $p = 0.147$ for P0 versus P3). In contrast, the percent abundance of the estuarine group decreased from P0 to P1 and remained stable from P1 to P3 (Fig. 3c), varying significantly among sampling periods (Friedman test, $p = 0.027$), whereas no significant differences between P0 and the other sampling periods were detected (Wilcoxon’s signed rank test, $p = 0.480$ for P0 versus P1; $p = 0.570$ for P0 versus P2; $p = 0.480$ for P0 versus P3).

Multi-dimensional scaling. The stress value of the nMDS ordination was 0.053, indicating that it was well-fitted and that the relative distances of similarities among the sampling periods were substantially greater at the mooring berth site than at the tidal flat site (Fig. 4). In particular, the plot of P0 for the mooring berth site had a significantly greater distance of similarity than those of the other three periods (P1–3). Because there was only 1 year-round dataset in the earliest sampling period, analyses of similarities could not be performed between the earliest (P0) and more recent sampling periods (P1–3), but

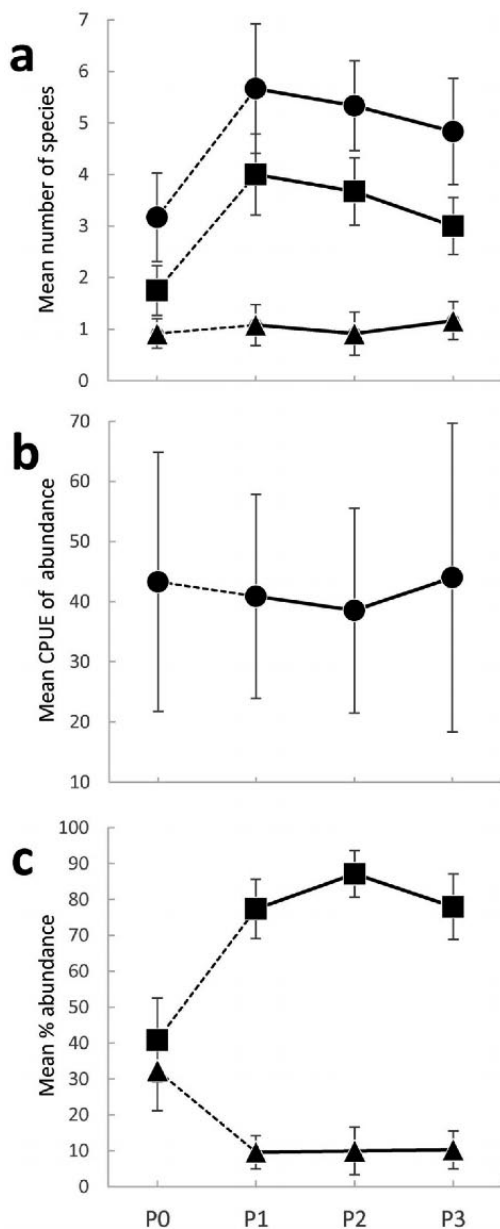


Fig. 3. Variation in the fish assemblage parameters at the mooring berth over decadal (broken lines) and annual (solid lines) time scales: a, monthly mean number of species in each sampling period (P0–3); b, monthly mean catch per unit effort (CPUE) of individuals; c, mean percent abundance of total catch. Solid circles, squares and triangles indicate total assemblages, and marine and estuarine categories, respectively.

the above community parameter variation, which reflect changes in the number of species and composition of the EUFGs from P0 to P1–3, were reflected well in the nMDS results.

Discussion

In general, the transitional water environment of estuaries results in lower biodiversity but a higher abundance of the surrounding freshwater/marine environments (McLUSKY and ELLIOTT, 2004; DAY *et al.* 2012b), and fish of the estuarine category are a common and abundant guild in many estuaries (ELLIOTT and DEWAILLY, 1995; KANOU *et al.*, 2000; PIHL *et al.*, 2002; HARRISON and WHITFIELD, 2008). Furthermore, a few generalist species tended to be abundant in some developed areas of estuaries (e.g., BILKOVIC and ROGGERO, 2008; MORENO-VALCÁRCCEL *et al.*, 2016), which were also observed by SAKAI *et al.*, (2007) at the mooring berth site. An estuarine gobiid, *Acanthogobius flavimanus*, which is the most abundant fish in the inner part of the Tokyo Bay (KANOU *et al.*, 2000; MURASE *et al.*, 2007, 2014), was dominant in terms of abundance during 1993–1994, whereas other estuarine gobies had low abundance at the mooring berth site. SAKAI *et al.*, (2007) concluded, on the basis of a 1-year dataset, that the mooring berth site could function as habitat primarily for estuarine gobies, and that its low-salinity conditions rendered it poorly suitable as a habitat for marine fish species. However, our dataset combined with the results of SAKAI *et al.*, (2007) revealed that the composition of the EUFGs changed markedly after 10 years, and this was reflected in the nMDS plot (Fig. 4), although salinity levels (Fig. 2) and total fish abundance (Fig. 3b) did not significantly vary during the entire study period. This change in community structure can be summarised as follows: the mean number of species in the marine category increased, whereas that in the estuarine category

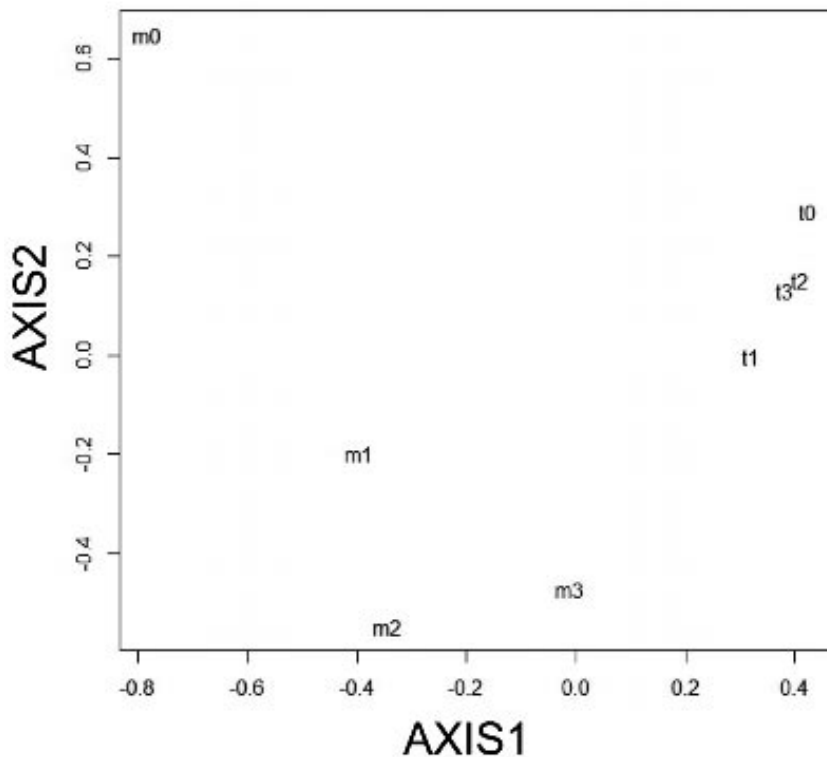


Fig. 4. Results of nMDS ordination based on Chao's adjusted Jaccard index at the mooring berth site (m) and the nearby tidal flat site (t). Numbers next to abbreviations of sites indicate each sampling period (P0–3) defined for each site (e.g., “m1” indicates Period 1 of mooring berth site).

remained unchanged, leading to an increase in the total number of species (Fig. 3a); and the percent abundance of the marine category increased while that of the estuarine category decreased. Most surprisingly, even an abundant generalist goby species (*A. flavimanus*) declined significantly after 10 years (in P1), and almost disappeared thereafter (in P2 and P3; Tables 1, 3), causing a decrease in the total abundance of the estuarine category. *A. flavimanus* is constantly predominant at the nearby tidal flat site also in terms of decadal and annual time scales, and predominance of this species and the other estuarine gobies (NASU *et al.*, 1996; MOTOKI *et al.*, 2009; MURASE *et al.*, 2014) resulted in that the fish

assemblage structure and EUFG composition at the nearby tidal flat site did not show any conspicuous change (i.e. constant predominance of estuarine category was detected: Fig. 4, Table 2). Contrary to this, abundance of *A. flavimanus* at an artificial riprap shoreline was almost half of tidal flat environment within artificial lagoon of the inner part of the Tokyo Bay (KANOU, 2006). Although there have been no data explaining habitat degradation around the study site, recent development of infrastructure for city planning in Tennozu Isle, an area of Shinagawa City, located in front of the mooring berth site, which started 1988 (SHINAGAWA CITY, 2005), might affect suitable habitat (such as soft-bottom

shallow environment) for estuarine category, especially *A. flavimanus*.

On the other hand, an increase in the total number of species (16 to 29 or 30) over the course of one decade was recorded at the study site, and the total number of species in the estuarine category also increased (from 3 to 8 species; Table 2) despite no variation in the mean number of estuarine species over the sampling periods (Fig. 3a). Improvement in water quality in estuaries can recover species richness (McLUSKY and ELLIOTT, 2004), and the increasing species richness over one decade at the study site may reflect water quality improvements in the inner part of the Tokyo Bay (NOMURA, 2012). In fact, population recoveries in several diadromous fish species (e.g., *Plecoglossus altivelis altivelis* and *Tribolodon blandtii maruta*) in the rivers flowing into the bay were reported (KOHNO *et al.*, 2011; HOSOYA, 2015). Low abundances in these diadromous and other estuarine fishes at the mooring berth site, despite increases in species richness, suggest that the modified shoreline without surrounding shoreline habitat such as tidal flat may only function as an ecological corridor connecting natural or semi-natural environments rather than as true habitat for the lifecycles of fish in the inner part of the Tokyo Bay. Hydrological changes relating to man-made changes (e.g., bank regulation and dam interventions) causing variation in salinity levels are also important in determining estuarine fish community composition (BAPTISTA *et al.*, 2015), and generally, high salinity attracts marine species into the estuary, leading to higher overall species richness (McLUSKY and ELLIOTT, 2004). However, because salinity showed no significant variation over the sampling periods in this study (Fig. 2), water quality improvements might be the major contributor to the increase in species richness and abundance in the marine category rather

than salinity changes at the mooring berth site.

In conclusion, this study highlights importance of maintaining surrounding natural/semi-natural environments in addition to water quality improvement whereas an artificial structure such as the mooring berth site can be habitat for estuarine fishes. Although the present study is based on data from a single site, it can further our understanding of how the deployment of coastal infrastructures influences coastal assemblages (AIROLDI *et al.*, 2005; BULLERI and CHAPMAN, 2010), which can guide interventions in the broader context of marine spatial planning (FIRTH *et al.*, 2014). In particular, greater understanding of the factors directly and/or indirectly causing instability in guild structures based on future studies will enhance the development of more effective shoreline engineering that takes into account the long-term ecological impacts.

Acknowledgements

We are grateful to Drs. T. Kadoya and I. Washitani for their valuable advice. The following people assisted in sampling: Dr. T. Yokoo, Mrs. A. Gokita, E. Harunari, Y. Ishida, H. Kageyama, J. Kaiga, T. Kaniwa, Y. Kashiwagura, Y. Niwa, T. Okada, D. Okazaki, G. Okuyama, S. Saegusa, Y. Tamura, Y. Tazaki, K. Uchida and R. Yamashita, and Ms N. Kakimoto, M. Kobayashi and H. Yuki. This research was partly supported by JSPS KAKENHI Grant Number 15K00654.

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Received: January 4, 2017

Accepted: April 8, 2017

