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RESEARCH ARTICLE

Seasonal changes in fish diversity, density, biomass, and assemblage alongside environmental variables in the Yangtze River Estuary

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Abstract

The present study used multivariate techniques, to analyze the fish species diversity and distribution patterns in order to determine the possible role of environmental parameters as drivers of fish community structure and composition in the Yangtze River Estuary (YRE). This analysis was conducted using data obtained in the YRE from February 2012 to December 2014. Analysis of the catch data showed that species composition, total density, and total biomass varied significantly between stations and seasons. Thirty-eight species belonging to 18 families were collected. Sciaenidae was the most dominant family accounting for 40.8% of total captured specimens. In descending order, *Collichthys lucidus*, *Cynoglossus gracilis*, *Chaeturichthys stigmatias*, and *Lophiogobius ocellicauda* dominated catches in the YRE. These four species constituted 64.2% of the total catches and showed average dissimilarities of 74.19% between stations and 81.3% between months. The highest number of fish specimens captured was recorded in August 2012 while the highest species richness was observed in December 2013. The mean fish density and biomass for the YRE was 0.35 individuals/m^2 and 2.5 g/m^2, respectively. The mean density and biomass for the most important and dominant species changed significantly between stations and seasons. Canonical correspondence analysis indicated that salinity and chlorophyll-a were the key variables that structured the fish assemblage in the YRE. High total species density and biomass were recorded in high saline stations (North Branch) of the YRE. This study confirms that most species captured in the YRE needs estuarine conditions to complete their growth and development. Hence, the findings in this study are important to understanding and developing suitable conservation plans for the management of fish resources in the YRE.

Keywords Multivariate techniques · Fish community · Fish assemblage · Species distribution · Ecosystems

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Introduction

Fisheries populations in estuaries are very much dynamic in both temporal and spatial spectrums. Quite a lot of authors highlighted the importance of estuaries for marine fisheries, by indicating that more than half of the world's landings are comprised of species that spend part of their lives in estuaries (Pauly 1988; Barletta et al. 1998, 2005, 2010, 2016). Estuaries, interfaces between land, freshwaters, and the sea, are locations where hydrological (e.g., river discharge), oceanographic, and anthropogenic processes interact (Merigot et al. 2016). Estuaries are dynamic habitats characterized by large variations in hydrological conditions (Hossain et al. 2012). Estuarine milieus in tropical, sub-tropics, and temperate regions create more organic matter on a yearly basis, making them the most productive on earth when compared to forests or grasslands. Estuarine zones also have products (such as fish) of high socioeconomic value that serves particularly as

a source of income and food to the neighboring populations. Fish species proving tolerant toward hydrological changes use estuaries as their breeding grounds, migratory pathways, hibernating areas, feeding, and as refuge zones (Barletta-Bergan et al. 2002a, b; Barletta et al. 2003; Kamrani et al. 2015; Islam et al. 2017).

Dominance, evenness, Margalef, and Shannon-Weiner are biodiversity indicators that are often used as reference to determine the assortment status of aquatic populations (Vyas et al. 2012). Nevertheless, relationships between fish species and their habited environments play vital roles in the preservation and management of estuarine species. The concentration of environmental factors such as water quality variables has been noted to be highly influential to fish assemblages and distributions in both marine and inland waters (Islam et al. 2017). Some fish species are forced to stay in intertidal zones or move to the sub-littoral on receding tides when environmental conditions change (Barletta et al. 2000, 2003). Salinity change causes a good number of fish species to migrate, moving up and down the estuary while some few fish species either move from less deep to deeper waters, or move straight toward less variable water states such as seas due to changes in temperature (Barletta et al. 2003, 2005, 2016).

Seasonal changes in species assemblage, species number, biomass, density, and their importance as nursery areas have been discussed in some estuarine main channels worldwide, such as, in south Florida, USA (Thayer et al. 1987), in Australia (Gibbs and Matthews 1982; Laegdsgaard and Johnson 1995), and in some South Western Atlantic Estuaries (Brazil; Barletta et al. 2003, 2005, 2010, 2016). These studies differed in estimating the importance of salinity gradients to the distribution of fish assemblages in estuaries. These disagreements have been attributed to differences in seasonal fluctuations in large-scale salinity gradients, and the integration of sequential recruitment of species throughout years in these estuaries (Ramos et al. 2016). Ecological studies of estuaries through their fish communities is known to be fundamental in understanding the functioning of their entire ecosystems (Barletta-Bergan et al. 2002a, b; Barletta et al. 2005, 2008; Barletta and Blaber 2007; Barletta and Barletta-Bergan 2009; Dantas et al. 2010, 2015; Lima et al. 2015, 2016; Ramos et al. 2016). Many past studies have emphasized on the importance of estuarine ecosystem for marine, estuarine, and freshwater fish species at each phase of their lives. Some of these fishes have socioeconomic importance for the local populations (Barletta and Costa 2009; Barletta et al. 2010).

The Yangtze River Estuary (YRE) is the largest estuary in China, and the Yangtze River, the third largest river in the world. The former is a critical system where geological, biological, and socioeconomic processes interact, and the latter deposits about five billion tons per year of fine sediments into the East China Sea with more than half of these sediments deposited in the estuarine area (Yu and Xian 2009; Quan et al. 2009; Shan et al. 2010). This YRE is economically important thanks to these deposited sediments which provide advantageous living conditions for many fish species (Yu and Xian 2009). The ecological importance of the YRE is a result of high biodiversity level and wide habitats range its offers (Zhang et al. 2015). For the past years, completed projects such as the Three Gorges Dam, South to North Water Diversion, and Yangtze–Taihu Water Diversion reduced the rate of freshwater inflow into the YRE which expansively modified and threatened the its ecosystem, and probably bringing heavy contamination to the estuarine habitation, and deteriorating water quality (Yu et al. 2007; Yu and Xian 2009; Quan et al. 2009; Shan et al. 2010).

Previous studies carried out in the YRE focused mainly on ichthyoplankton assemblage compositions, species distribution (Jiang and Shen 2006), and few studies on relationships between assemblage structure of ichthyoplankton and environmental factors (Yang et al. 1990; Jiang and Shen 2006; Yu and Xian 2009; Zhang et al. 2015, 2016). However, these past studies used data from the last decades for their analyses; given the fact that the world is facing some drastic climatic changes, we deemed it necessary to effectuate a study in the YRE using recently collected fisheries and environmental data. For that reason, the spatio-temporal changes of environmental variables in relation to fish assemblage, diversity, density, and biomass was analyzed in the YRE using data from 2012 to 2014.

Materials and methods

Data on fish assemblage and environmental conditions were collected from bottom trawl surveys done in the YRE from 2012 to 2014. The surveys were carried out seasonally (winter, spring, summer, and autumn) using a fixed-station sampling design with a total of 19 stations located around southeast Chongming Island (Fig. 1). However, only samples obtained in 18 stations were used in this study, as insignificant sample numbers were observed in the omitted station. Sampling area was divided into three locations as per the fishermen; North Branch (NP), Open Sea (EP), and South Branch (SP). Fin fish samples were collected during the day. The actual number and period of survey months changed among seasons and years due to weather conditions (2012: February, May, June, August, November, December), in 2013 (March, May, August, September, November, December), and in 2014 (March, May, August, November). Sampling was conducted using a 6-m-wide beam trawl with a 20-mm cod end; width (6 m) and height (2 m) of the trawl mouth opening. The beam trawl was towed once at a constant speed (0.56 m s^{-1}) for 30 min during each sampling process at each survey station. Collected specimens were identified to

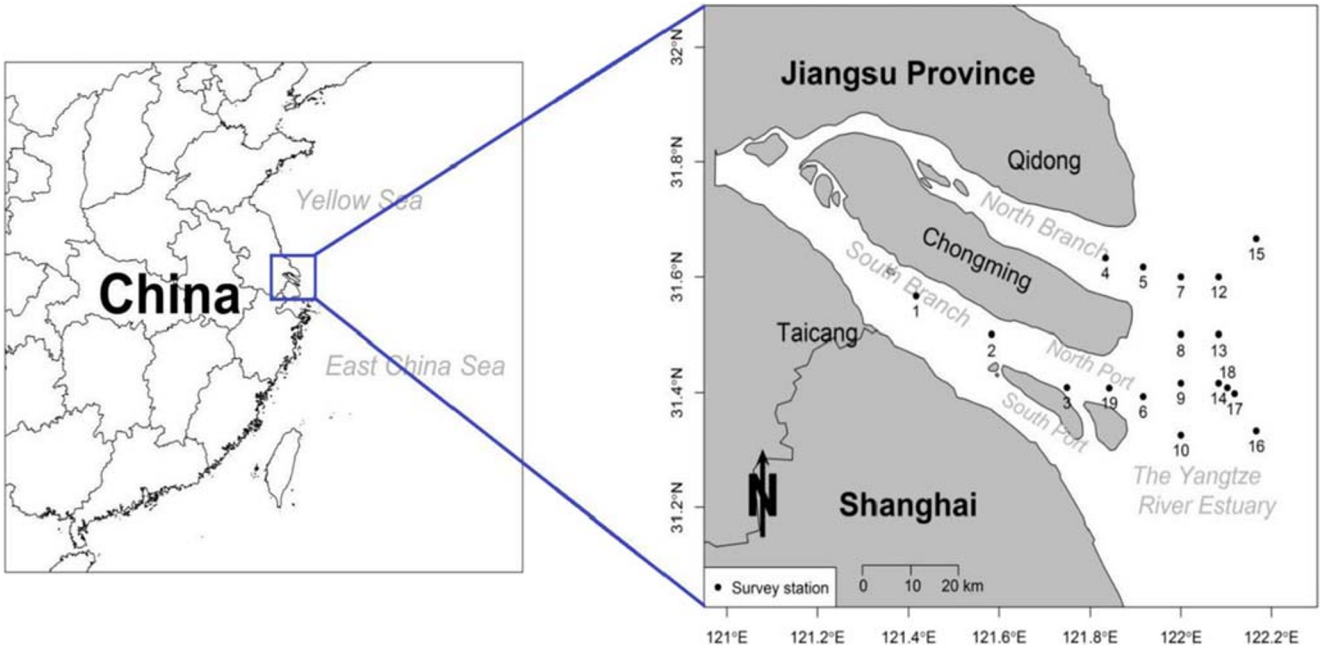

Fig. 1 Study area and sampling stations of fish assemblages and environmental variables in Yangtze River Estuary

the lowest taxonomic level possible then measured (length), counted and weighed (g). Few species of interest were later preserved in 10% formalin and transported to the Shanghai Ocean University laboratory for further analysis.

A GPS was used to record the boat's position before and after sampling and was later used to estimate the swept area. For each haul sample, the swept area (A) was calculated from:

$$A = DhX2,$$

where D is the length of the path, h is the length of the head-rope, and $X2$ is the fraction of the head-rope ($hX2$) which is equal to the width of the path swept by the trawl, the wing spread (Sparre and Venema 1995; Barletta et al. 2005). The fraction of the head-rope which was close to the width of the swept area by the net during a haul was assumed to be $X2 = 0.5$ as in Barletta et al. (2005). Density (D) and biomass (B) were estimated by dividing the Catch per unit area (CPUA) by the swept area, A (ha):

$$\mathrm{D} = \mathrm{CN}/\mathrm{A}\left(individuals/m^2\right) \text{and } \mathrm{B} = \mathrm{CM}/\mathrm{A}\left(\mathrm{g}/\mathrm{m}^2\right),$$

where CN is the catch in numbers and CM is the catch in mass of fish. The total mean density (DT) and biomass (BT) was estimated from DT = DaX1 and BT = BaX1, where D and B are the mean catch, in number and in mass respectively, per unit area of all hauls, a is the total sampled area, and X1 is the catchability coefficient (in this study X1 = 1).

Environmental parameters were measured after hauling at each sampling station during monthly surveys. A CTD (SEADIRD SBE-19) rosette apparatus and a depth sampler were used to measure these environmental variables that included water depth, temperature, salinity, dissolved oxygen (DO), PH, chlorophyll-a (Chla), and chemical oxygen demand (COD).

Data analyses

Four major biodiversity indices namely Shannon-Wiener diversity index (H'; Shannon and Weaver 1949), Simpson index of diversity (D; Simpson 1949), and species richness (d; Margalef 1968) were used for species diversity; Pielou's evenness index (J'; Pielou 1966) was used for evenness. High values of M, H', and J' were assumed to represent high ecological quality status. High values of Simpson's index were indicative of low ecological quality status. These indices are usually applied to evaluate the discrepancies of aquatic communities or populations. Hence, for us to evaluate the status of fish community structure and assemblage in the YRE, data was collected seasonally throughout the 3-year survey period. Diversity indices were calculated for sampled months and then yearly; the following expressions below were used for the analyses.

Shannon Weiner diversity index (Shannon and Weaver 1949) considers both the number of species and the distribution of individuals among species and is described by the following formula:

$$H' = -\sum[(n_i/N)*Ln(n_i/N)] \quad (3)$$

where n_i is the number of individuals of each species (the ith species), N is the total number of all the

individuals for captured species at that station, and *Ln* is the natural logarithm (Shannon and Weaver 1949).

The dominance or Simpson's dominance index *D* (Simpson 1949) is measured to determine whether or not particular species dominate in a particular aquatic system, and is calculated using the equation:

$$D = (n/N)^2 \quad (4)$$

where *n* is the number of individuals of each specie and *N* is the overall number of all sampled individuals.

The species evenness *J′* (Pielou 1966) was determined using the formula:

$$J = H'/Ln(S) \quad (5)$$

where *H′* is the number derived from Shannon and Wiener diversity index, *S* is the total number of species available in the community during the survey period, and *Ln* is the natural Logarithm.

The species richness (*d*) was calculated using Margalef's diversity Index (*d*) with the help of the formula:

$$d = S{-}1/Ln(N) \quad (6)$$

where *Ln* is the natural Logarithm (Margalef 1968).

Kruskal-Wallis test and one-way analysis of variance (ANOVA) were used to analyze the differences in the observed diversity indices among sampling months and years. Kruskal-Wallis test was also used to test temporal changes among environmental variables. All multivariate statistical analyses were done on the relative abundances of fish species caught.

Analysis of similarities (ANOSIM) is usually used for taxa-in-samples data, where groups of samples are to be compared (Clarke and Warwick 2001). Based on a Bray-Curtis similarity matrix obtained using ln $(x + 1)$ transformed data (Clarke and Warwick 2001), a non-parametric ANOSIM was performed to test the inter-annual significant differences of fish assemblages and environmental variables in the YRE. To determine the inter-annual dissimilarity among parameters, R-statistical values for pair-wise comparisons provided by ANOSIM were used. *R* values close to 1 indicated a very high different composition, and values close to 0 represented slight differences among parameters (Clarke and Warwick 2001).

Similarity percentages (SIMPER) analysis was used to analyze the dissimilarity of fish communities and identify those fish species that contributed most to the average dissimilarity (months and stations; and inter-annual) among groups and determined the percentage contribution of each fish species to the overall group dissimilarity (Clarke and Warwick 2001). Cluster analysis based on Bray-Curtis similarity (Clarke and Warwick 1994) was calculated to produce a dendrogram for investigating fish abundance similarities presented as groups among stations. Groups observed in the cluster analysis were later used to observe the structure of fish assemblages in each station (Hammer et al. 2001, PAST 3.19).

Canonical correspondence analysis (CCA) is an analysis which considers unimodal relations among dependent and independent parameters. CCA was used to investigate associations between fish species' abundance and environmental variables (Lepš and Šmilauer 2003). Monte Carlo permutation test (no. of permutations = 999) was used to assess the statistical significance of fish abundance and environmental variables. Seven environmental variables were used for the CCA analysis and fish species were ordinated to indicate the relative strengths among those associations. Species located near the origin of the CCA plot observed little associations with environmental variables tested or presents no particular preference. Those proximal to the distal portion of each vector and beyond indicate strong positive relationships with the environmental parameters. Species located directly in line, in the opposite direction from each vector, indicate strong negative relationships with that parameter. A significance difference of a minimum of $P < 0.05$ was considered in all test procedures. Species that represented less than 1% of the total catch were excluded from multivariate analyses. Analyses were performed using MS excel 2016 and a statistical package PAleontological STatistics (PAST) version 3.19 (Hammer et al. 2001).

Results

Spatio-temporal variation of diversity indices

The values of Shannon-Wiener diversity index (*H′*), Simpson index of diversity (*D*), species richness (Margalef: *d*), and Pielou's evenness index (*J′*) were determined spatially and temporally (Table 1). The monthly values of *H′* ranged from 0 to 2.25 (Table 1); values of *H′*, *d*, and *J* were zero for the month of December 2012, as just one specie was observed for that month. Highest values of *H′*, *d*, *J′*, and *D* were observed in December (winter). Inter-annual species diversity and richness indices were also checked using ANOSIM; significant differences occurred for species richness (*d*) among years; the other indices did not show significant inter-annual variations (Table 1).

Spatio-temporal variation of environmental parameters

All environmental variables measured in this study showed a seasonal trend. Maximum water depth (20 m) was recorded during November 2012 at stations Z1 and Z3, while the minimum water depth (1.5 m) was observed in June in 2012 at station Z6. Water temperature ranged from 5.6 °C (February

Table 1 Spatio-temporal variation of diversity and evenness indices obtained across sampling stations

Years	Months	*H*		*d*		*D*		*J*			*H*		*d*		*D*		*J*	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD	Mean	SD
2012	February	1.753	0.12	2.105	0.32	0.232	0.02	0.683	0.14	2012	1.189[a]	0.13	1.509[aa]	0.23	0.494[a]	0.08	0.480[a]	0.08
2012	May	0.996	0.08	2.120	0.31	0.597	0.05	0.352	0.07									
2012	June	0.557	0.05	0.851	0.16	0.737	0.12	0.402	0.08									
2012	August	1.981	0.1	2.433	0.35	0.196	0.02	0.673	0.17									
2012	November	1.847	0.12	1.545	0.23	0.201	0.01	0.770	0.2									
2012	December	0.000	0.0	0.000	0.0	1.000	0.08	0.000	0.0									
2013	March	1.542	0.11	1.994	0.28	0.272	0.04	0.621	0.13	2013	1.708[a]	0.18	2.602[aa]	0.35	0.268[a]	0.05	0.645[a]	0.16
2013	May	1.557	0.09	2.382	0.31	0.337	0.09	0.575	0.10									
2013	August	1.560	0.09	2.982	0.35	0.326	0.04	0.521	0.11									
2013	September	1.702	0.07	2.162	0.33	0.258	0.07	0.710	0.19									
2013	November	1.645	0.1	3.044	0.37	0.289	0.10	0.540	0.1									
2013	December	2.250	0.09	3.05	0.39	0.125	0.01	0.901	0.26									
2014	March	1.211	0.10	1.883	0.26	0.444	0.07	0.487	0.09	2014	1.560[a]	0.16	1.756[aa]	0.25	0.296[a]	0.02	0.645[a]	0.14
2014	May	1.439	0.11	1.520	0.24	0.307	0.03	0.625	0.14									
2014	August	1.630	0.10	1.633	0.25	0.251	0.04	0.680	0.16									
2014	November	1.961	0.09	1.989	0.29	0.182	0.06	0.789	0.21									
Mean		1.47		1.981		0.359		0.583										
Std. error		0.14		0.19		0.06		0.05										
Range		(0–2.25)		(0- 3.05)		(0.12–1)		(0–0.90)										

Ecological classifications (Kamrani et al. 2015): diversity: (for *J, D*; 0~low, 1~high; for *d*, low diversity = low value; for *H,* 0 ~ low, ≥ 5~high diversity)
a Indicate no significant difference among years while values with aa indicate significant difference among years ($P < 0.05$)

2012, Z12) to 30.1 °C (stations Z5 and Z9, August 2014). Maximum pH (9.03) was observed during September 2013 at Z9 and minimum pH (6.62) at Z16 in May in 2012. Maximum DO was recorded at Z10 (29.8 mg/l) and lowest (Z4; 6.6 mg/l) during August 2012. A high concentration of COD was registered at Z16 (3.12 mg/l) during February 2012, with a minimum concentration (0.16 mg/l) observed at Z12 (March, November 2013). A peak value for chlorophyll-a was recorded at Z15 (11.25 mg/m^3) in August in 2012, and a minimum value (0.086 mg/m^3) at Z16 (August 2014). The North Branch of the YRE was the highest saline zone, with the maximum value obtained at Z15 (29.8 ppt) during February 2012 (Table 2). Inter-annual changes of environmental factors were also analyzed (Table 3). Chla varied significantly throughout sampling years ($P < 0.05$). COD did not show inter-annual (2012 vs. 2014) changes ($P > 0.05$). Significant changes were observed for pH (2013 vs. 2014; $P < 0.05$). Although, salinity did not vary significantly among years; however, the lower values of salinity recorded in this study were from sampling stations found in the South Branch and Open Sea areas of the YRE.

Composition of the fish fauna

During the survey period, a total of 7984 individuals weighing 56,970 g belonging to 18 families, comprising 38 finfish species were harvested in the YRE, representing a total swept sampled area of 22,680 m^2 (Table 4). The absolute mean density and biomass estimated from all collected samples was 0.35 individuals/m^2 and 2.5 g/m^2, respectively, with the North Branch having the highest mean values of density and biomass. The most abundant fish species was *Collichthys lucidus* (2888 individuals and represented 36.2% of the total individuals) and the less abundant registered for *Paraplagusia japonica*, *Rhinogobius cliffordpopei*, *Platycephalus indicus*, *Zebrias zebra*, *Takifugu obscurus*, and *Takifugu xanthopterus*. In this study, four families were highly represented notably, Gobiidae, Cynoglossidae, Engraulidae, and Sciaenidae. The Sciaenidae family (four species) recorded the highest fish abundance and represented 40.8% of the total individuals harvested; this high abundance was greatly influenced by the presence of the marine species *Collichthys lucidus*. *Collichthys lucidus* had the highest sampled density and biomass throughout the study period, and *Lateolabrax japonicus* (Japanese seabass) was the heaviest species (427.5 g) recorded. The highest number of species and individuals were harvested in summer in 2012, notably in the months of May and August (Fig. 2). The highest number of individuals (2038) was observed at station Z7 in the North Branch of the YRE, and a peak of 2673

Table 2 Environmental variables (means and range) measured per sampling stations and different sampling months from 2012 to 2014 in the Yangtze River Estuary

	Depth (m)	Temperature (°C)	Salinity (ppt)	DO (mg/l)	pH	Chlorophyll (μg/l)	COD (mg/l)
Sampling stations							
Z1	12.79 (9.5–20)	17.80 (6.4–29.4)	0.08 (0–0.26)	10.63 (6.9–29)	7.73 (6.7–8.5)	1.92 (0.1–7.8)	1.13 (0.7–1.6)
Z2	7.23 (4.8–15)	13.13 (6.2–27.5)	0.06 (0–0.29)	11.07 (7.6–12.2)	7.74 (7.3–8.2)	1.52 (0.9–3.2)	1.10 (0.9–1.3)
Z3	6.23 (4–20)	18.89 (7.4–29)	0.11 (0–0.8)	11.77 (6.8–29.2)	8.00 (7.2–8.3)	1.92 (0.3–8.7)	0.90 (0.4–1.6)
Z4	4.55 (3–6)	19.25 (6.1–30)	18.20 (6–26.1)	9.52 (6.6–12.5)	7.95 (7.5–8.4)	2.24 (0.4–7.7)	0.88 (0.3–1.8)
Z5	4.48 (3.2–6.5)	19.65 (6.8–30)	17.72 (8.1–24.9)	9.38 (6.8–12.3)	7.99 (7.5–8.5)	2.40 (0.3–7.8)	0.87 (0.5–1.7)
Z6	5.68 (1.5–7)	15.64 (6.6–29.2)	0.64 (0–4)	11.59 (7.5–29.1)	8.10 (6.8–8.6)	1.40 (0.2–6.6)	1.04 (0.6–1.6)
Z7	5.71 (3.5–7.5)	19.91 (6.8–29.7)	18.35 (3.5–25.9)	9.44 (6.9–12.6)	8.14 (7.8–8.5)	1.89 (0.2–7.7)	0.67 (0.3–1.7)
Z8	3.66 (1.8–6)	19.83 (5.7–28.5)	19.92 (11.2–27.3)	9.25 (7–12.7)	8.08 (7.8–8.3)	1.78 (0.9–3.4)	0.66 (0.3–1.1)
Z9	5.77 (4–7)	18.20 (6.6–30.1)	1.79 (0–9.4)	11.38 (7.1–29.3)	8.30 (6.8–9)	1.06 (0.2–5.44)	1.08 (0.72–1.8)
Z10	6.88 (5.3–8.5)	16.76 (6.7–29.8)	0.97 (0–4.6)	12.41 (7.8–29.8)	7.71 (7.12–8.03)	2.03 (1.34–6.9)	1.18 (0.96–1.8)
Z12	6.77 (6–7.5)	17.94 (5.6–29.6)	18.32 (4–29.4)	9.82 (6.9–12.9)	8.09 (7.9–8.3)	2.56 (0.9–6.8)	0.64 (0.2–1.5)
Z13	5.59 (3–6.5)	18.22 (5.8–29.1)	16.83 (1.1–29.5)	9.70 (6.8–12.8)	8.03 (7.7–8.3)	1.55 (0.24–5.1)	0.76 (0.28–1.77)
Z14	3.13 (2–7)	17.83 (6.5–29.6)	0.30 (0–4.9)	11.65 (7.24–29.2)	7.98 (7.32–8.25)	1.35 (0.1–5.7)	1.51 (0.9–1.9)
Z15	4.95 (3–6)	15.04 (5.8–29.3)	*20.28* (0.14–29.8)	9.58 (7.4–12.9)	8.12 (7.2–8.4)	3.38 (0.2–11.3)	0.75 (0.3–1.4)
Z16	9.64 (7–13.5)	18.84 (6.4–29.4)	2.16 (0–13.6)	11.53 (7.2–28.7)	7.95 (6.6–8.4)	1.59 (0.1–5.3)	1.19 (0.48–3.12)
Z17	5.74 (4–6.5)	12.95 (8.3–19.7)	0.44 (0–0.7)	10.20 (8.7–11.5)	8.15 (8–8.3)	0.39 (0.33–0.44)	1.64 (1.44–1.84)
Z18	4.07 (4–5)	*21.31* (17.6–29.8)	0.06 (0–0.1)	8.48 (7.2–9.1)	8.19 (8.18–8.2)	0.41 (0.12–0.44)	1.46 (1.12–1.6)
Z19	7.33 (7–8)	21.20 (8.9–29.4)	0.17 (0–0.5)	8.76 (7.1–11.5)	8.32 (8.15–8.6)	0.47 (0.3–0.7)	1.08 (0.6–1.8)
Sampling months							
Feb 2012	6.2 (2.5–9.5)	6.16 (5.6–6.8)	16.85 (0.14–29.8)	12.4 (11.9–12.9)	7.8 (7.2–8.2)	2.18 (1.6–4)	1.1 (0.4–2.3)
May 2012	4.95 (3–7)	22.5 (21–24.1)	10.34 (0.13–20.4)	8.49 (7.96–8.83)	8.31 (6.6–8.4)	3.37 (8.2–6.9)	0.76 (0.3–3.12)
June 2012	11.6 (1.5–16)	22.1 (21.6–22.4)	0.127 (0.1–0.14)	8.33 (8.12–8.75)	6.84 (6.79–7.12)	3.97 (2.2–5.4)	1.28 (0.96–1.8)
Aug 2012	4.61 (2–16)	25.6 (6–30)	13.84 (0–23)	9.45 (6.6–29.8)	8.05 (7.9–8.2)	7.14 (3.4–11.3)	1.32 (0.96–1.8)
Nov 2012	5.86 (3.4–20)	14.2 (12.4–15.2)	21.43 (0–25.4)	9.97 (9.7–10.9)	8.15 (8.07–8.2)	1.7 (1.2–2.7)	0.82 (0.3–1.3)
Dec 2012	6.67 (3–8)	12.1 (11.6–12.4)	0	10.9 (10.77–10.95)	0/	1.7 (1.59–1.86)	1.2 (0.92–1.4)
March2013	5.5 (2.1–9.5)	11.2 (9.3–11.8)	20.72 (0–26.2)	12.2 (11.9–12.6)	7.83 (7.5–8.1)	0.94 (0.4–1.4)	0.39 (0.16–0.94)
May 2013	6.21 (1.8–11)	21.2 (11.5–23.3)	11.85 (0–24.9)	9.2 (8.9–12.1)	8.14 (7.5–8.2)	1.5 (1.1–1.8)	0.6 (0.4–1.2)
Aug 2013	4.46 (2–6.5)	28.4 (28.1–29)	18.81 (17.1–19.9)	7.3 (7.1–7.5)	7.84 (7.7–7.9)	1.2 (0.9–1.4)	0.5 (0.46–0.55)
Sept 2013	7.84 (2–15)	27.2 (22.7–29.3)	8.428 (0–17.9)	7.71 (7.5–8)	8.12 (7.7–9)	1.24 (0.9–1.4)	0.92 (0.46–1.23)
Nov 2013	5.27 (2.1–7.5)	11.4 (11–11.8)	*24.72* (23.1–26.4)	12.2 (11.9–12.6)	7.77 (7.5–8.1)	1 (0.8–1.4)	0.31 (0.16–0.44)
Dec 2013	6.93 (2–11)	9.87 (8.5–11.1)	0.131 (0–0.4)	12.3 (11.9–12.6)	7.86 (7.71–8.1)	1.19 (0.88–1.35)	0.89 (0.84–1)
March 2014	5.05 (2–9.5)	9.17 (8.3–10.2)	7.209 (0.5–24.5)	11.4 (11.15–11.52)	8.27 (8.1–8.6)	0.44 (0.23–0.66)	1.34 (0.7–1.8)
May 2014	5.64 (2.5–12)	19.6 (17.9–21.2)	9.566 (0–18.8)	8.8 (8.62–8.89)	8.17 (8.11–8.53)	0.41 (0.1–0.76)	1.38 (0.8–1.84)
Aug 2014	5.44 (2.5–10)	*29.5* (29–30.1)	5.324 (0–13.6)	7.59 (6.87–8.48)	8.29 (8.08–8.5)	0.5 (0.1–0.95)	0.94 (0.56–1.36)
Nov 2014	6.05 (3–11)	16.1 (14.6–18.4)	10.87 (0.1–22.3)	9.78 (8.78–10.3)	8.12 (7.96–8.45)	0.43 (0.22–0.79)	0.94 (0.4–1.6)

individuals was recorded in August (2012). Fourteen fish species (species codes on Table 4; sp2, sp4, sp5, sp9, sp10, sp13, sp14, sp16, sp17, sp20, sp29, sp31, sp32, and sp35) mainly dominated by marine species constituted 96.5% (7705 individuals) of the total individuals captured during this study. Inter-annual-wise, more individuals per m^2 were observed in the year, 2012 while in 2013, the total mean biomass of individuals was the highest among years (Table 4).

Multivariate analyses of the fish fauna and environmental parameters

Based on SIMPER analysis, 74.19% and 81.1% average dissimilarity were found among stations and months, respectively (Table 5). The four fish species that greatly contributed to this dissimilarity were *Collichthys lucidus* (25.8% and 25.29%), *Lophiogobius ocellicauda* (12.4% and 13.95%), *Cynoglossus gracilis* (11.36% and 11.91%), and

Table 3 Environmental variables (means, range, and ANOSIM significant differences) throughout the sampling period

Environmental variables	2012	2013	2014	2012 vs. 2013 *P* value	2012 vs. 2014 *P* value	2013 vs. 2014 *P* value
D (m)	5.430 (1.5–20)	5.758 (1.8–15)	5.56 (2–12)	0.771	0.692	0.851
COD (mg/L)	1.031 (0.32–3.12)	0.533 (0.16–1.23)	1.131 (0.4–1.840)	0.023[aa]	0.575	0.045[aa]
Chla (mg/m^3)	3.943 (1.2–11.25)	1.162 (0.409–1.84)	0.446 (0.086–0.95)	0.001[aa]	0.005[aa]	0.004[aa]
S (‰)	15.215 (0–29.8)	16.321 (0–26.2)	8.269 (0–24.5)	0.963	0.35	0.255
T (°C)	18.348 (5.6–30)	17.753 (8.5–29.3)	18.677 (8.3–30.1)	0.711	0.910	0.752
DO (mg/L)	9.917 (6.6–29.8)	10.34 (7.1–13)	9.392 (6.87–11.52)	0.436	0.9	0.666
pH	8.032 (6.62–8.44)	7.895 (7.532–9.03)	8.212 (7.96–8.55)	0.24	0.72	0.017[aa]

Values with aa indicate significant difference between years ($P < 0.05$)

Chaeturichthys stigmatias (7.05% and 6.9%) for stations and months, respectively. There was no significant difference in species occurrence for stations in the South Branch (SP) and Open Seas (EP); significant difference was observed in species occurrence among stations in the North (NP) and South Branches of the YRE. ANOSIM analysis showed significant differences in the structure of the fish assemblages among the three parts of the YRE (Table 6). Fish community differed among different parts in the YRE, confirming ecological segregation in this Estuary (ANOSIM, $P < 0.05$, global $R = 0.38$). Also, species assemblage varied significantly between 2012 and 2013 ($P < 0.05$, $R = 0.23$; Table 6); these years showed a more diverse species composition as compared to the other inter-annual interactions (highest R value; Table 6).

As shown by the Bray-Curtis's cluster analysis, two distinct assemblage structures via stations similarity were observed in the YRE (Fig. 3). The first major cluster showed 32% similarity between stations mostly comprised of those found in the SP and Open Seas of the YRE. Stations Z14/Z16 presented high similarity patterns between them. Principal fish species in the first cluster were comprised of freshwater and marine species (*Pelteobagrus nitidus*, *Cynoglossus gracilis*, *Coilia mystus*, *Coilia nasus*, *Lophiogobius ocellicauda*, *Synechogobius ommaturus*). The second cluster was merely formed by stations in the NP presenting 45% similarity between stations, with Z4/Z5 showing highest resemblance between them while dissimilarity was observed among stations Z3, Z7, and Z18. Dominant species in this cluster were comprised of marine species notably *Chaeturichthys stigmatias*, *Cynoglossus joyneri*, *Collichthys lucidus*, and *Nibea albiflora*.

The importance of the CCA axes is shown by eigenvalues varying between 0 and 1. For this study, the CCA was performed following Monte-Carlo permutations (999 iterations) based on the first two axes (axis 1: eigenvalue = 0.42 and axis 2: eigenvalue = 0.24) which expressed 79.53% of the cumulative percentage variance of the species data (Table 7). Salinity was highly associated to species denoted sp13, 17, 20, 32, and sp35; and chlorophyll-a was associated to species such as sp13, 29, and sp31 (Fig. 4). Salinity and chlorophyll-a had the highest influence on the fish species composition and structure in the YRE, while water depth had an insignificant effect on species composition. The family Sciaenidae, particularly *Collichthys lucidus*, had the highest captured individuals in the YRE, with most individuals occurring at stations in the North Branch and Open Seas.

Discussion

Due to changes in sampling methods and efforts, as well as differences in geomorphology of estuaries, much care is needed when comparing the fish biomass, density, and fish species assemblages in estuarine ecosystems. Therefore, the present results are mostly compared with those studies that used similar sampling methods in the same habitats, though we also compared changes in environmental parameters with estuaries in other localities.

As one of the basic concepts of ecology, species diversity has gained grounds in ecosystems and communities' characterizations (DeJong 1975; Kamrani et al. 2015). The Shannon-Weaver biodiversity index (H') obtained in this study shows an intermediate biodiversity for the YRE, since the values obtained are neither high nor low (Table 1; Kamrani et al. 2015). Variations of H' were not observed among stations in the region; according to Hossain et al. (2012), this might be due to the selective nature of the trawl gear used during sampling. However, as reported by other studies, the Shannon-Weaver diversity may have a tendency to miscalculate the condition of fish communities in situations where certain species are dominating, as is the case in this study (Salas et al. 2006; Kamrani et al. 2015). Therefore, the value obtained for the Shannon-Weaver diversity may have been underestimated because of the overall dominance of *Collichthys lucidus* in the YRE. Species richness number peaked during cold seasons (autumn and winter), with the highest in December in 2013. This result corroborates partly with reports by Zhang et al. (2015, 2016), confirming fish richness in autumn for the YRE. Our study also showed that the highest species richness

Table 4 Total mean density, biomass, finfish species codes, occurrence, and range of measured weight of fish species from the Yangtze River Estuary

Family	Scientific name	Spe code	*N*	Total mean density (Ind./m^2 * 10^4)			Total mean biomass (g/m^2 * 10^4)			W-range (g)	*N*%
				2012	2013	2014	2012	2013	2014		
Bagridae	*Leiocassis longirostris*	sp1	7	–	1.5	3.8	0	21	67.5	5.5–22.3	0.09
Bagridae	*Pelteobagrus nitidus*	sp2	210	6.1	18.9	133.8	63.5	121.5	471.4	1.3–26	2.63
Callionymidae	*Repomucenus olidus*	sp3	2	0.7	0.7	–	0.7	2	–	1–2.7	0.03
Cynoglossidae	*Cynoglossus gracilis*	sp4	971	83.9	435.5	214.7	419.2	5390	2552	1.17–79	12.2
Cynoglossidae	*Cynoglossus joyneri*	sp5	460	347.7	–	–	3846.1	–	–	1.14–33.13	5.76
Cynoglossidae	*Paraplagusia japonica*	sp6	1	0.7	–	–	6.8	–	–	9.05	0.01
Cyprinidae	*Hemiculter bleekeri*	sp7	6	3.7	0.7	–	23.4	17	–	5.6–22.5	0.08
Cyprinidae	*Saurogobio dumerili*	sp8	7	3	2.3	–	39	81.6	–	8.2–68	0.09
Engraulidae	*Coilia mystus*	sp9	224	136.1	31	2.3	331.8	138.5	12.6	1.1–7.9	2.81
Engraulidae	*Coilia nasus*	sp10	232	121.7	35.5	18.1	2751.8	215.1	143.6	1.1–244	2.91
Engraulidae	*Setipinna taty*	sp11	2	0.7	0.7	–	6.8	6.3	–	8.2–8.9	0.03
Engraulidae	*Thryssa kammalensis*	sp12	13	0.7	9.1	–	0.7	102.1	–	1–11.5	0.16
Gobiidae	*Chaeturichthys stigmatias*	sp13	654	468.7	3	22.7	2543.7	11.2	307.7	1.2–24.1	8.19
Gobiidae	*Lophiogobius ocellicauda*	sp14	605	105.1	177.6	174.6	378.2	1701.7	1204.1	1–35.5	7.58
Gobiidae	*Odontamblyopus lacepedii*	sp15	28	21.2	–	–	195	–	–	7.1–13.1	0.35
Gobiidae	*Synechogobius ommaturus*	sp16	83	1.5	3.8	57.5	31.8	25.4	52.5	1–41.7	1.04
Gobiidae	*Taenioides anguillaris*	sp17	366	43.8	192	41	294.8	489.8	167	1.1–11.3	4.58
Gobiidae	*Tridentiger barbatus*	sp18	65	46.9	2.3	–	114	12.2	–	1.1–8.1	0.81
Gobiidae	*Tridentiger trigonocephalus*	sp19	5	3	–	0.7	2.7	–	23	1–30.4	0.06
Gobiidae	*Trypauchen vagina*	sp20	323	64.3	48.4	131.5	414	427.1	868.3	2.5–14.9	4.05
Gobiidae	*Rhinogobius cliffordpopei*	sp21	1	0.7	–	–	0.7	–	–	1	0.01
Lateolabracidae	*Lateolabrax japonicus*	sp22	11	1.5	3	3.8	5.1	355	765.2	2–427.5	0.14
Mugilidae	*Liza haematocheila*	sp23	8	1.5	1.5	3	8.4	20	57.7	4.7–22.1	0.1
Mugilidae	*Mugil cephalus*	sp24	3	–	1.5	0.7		36.4	260.8	22.4–345	0.04
Muraenesocidae	*Muraenesox cinereus*	sp25	3	1.5	0.7	–	87.7	44.6	–	32–59	0.04
Platycephalidae	*Platycephalus indicus*	sp26	1	–	0.7	–	–	1.6	–	2.1	0.01
Polynemidae	*Eleutheronema rhadinum*	sp27	6	3	1.5	–	6	20.6	–	1.1–14.4	0.08
Salangidae	*Protosalanx hyalocranius*	sp28	4	–	3	–	–	13.4	–	3.2–6.7	0.05
Sciaenidae	*Collichthys lucidus*	sp29	2888	1557.1	493	133	3085.2	8099	994	1.3–38.3	36.2
Sciaenidae	*Miichthys miiuy*	sp30	14	9.1	1.5	–	790	48.1	–	31.4–111.2	0.18
Sciaenidae	*Nibea albiflora*	sp31	195	141.4	6	–	147.7	113.6	–	1–38.1	2.44
Sciaenidae	*Pennahia argentata*	sp32	163	16.6	11.3	95.3	50.6	233	270.3	0.9–43.9	2.04
Soleidae	*Zebrias zebra*	sp33	1	0.7	–	–	82	–	–	108.5	0.01
Stromateidae	*Pampus argenteus*	sp34	17	5.3	7.5	–	43.5	41.5	–	2–11.5	0.21
Synodontidae	*Harpadon nehereus*	sp35	331	164.1	55.2	31	693.7	181	85.4	1.1–18.6	4.15
Tetraodontidae	*Takifugu obscurus*	sp36	1	–	0.7	–	–	4.2	–	5.5	0.01
Tetraodontidae	*Takifugu xanthopterus*	sp37	1	–	–	0.7	–	–	146.7	194	0.01
Triglidae	*Chelidonichthys kumu*	sp38	72	54.4	–	–	78.8	–	–	1.4	0.9

occurred in the North branch (NP) of the YRE which doubled as the most saline zone. Changes in evenness observed in this study might be related to the fact that the YRE is a spawning ground (as many juvenile specimens were collected during our study) to many fisheries in this region. So, the highest values of evenness obtained in this study could be attributed to the period when many fish species are recruited to different fisheries. This result corroborates with past studies that observed captures of many small individuals in the YRE, and attributed this area as a spawning ground to many species (Yang et al. 1990; Jiang and Shen 2006; Yu and Xian 2009).

Many studies have reported that temperate estuarine fish assemblages are dominated seasonally by estuarine spawners, including species in the Clupeidae and Engraulidae families

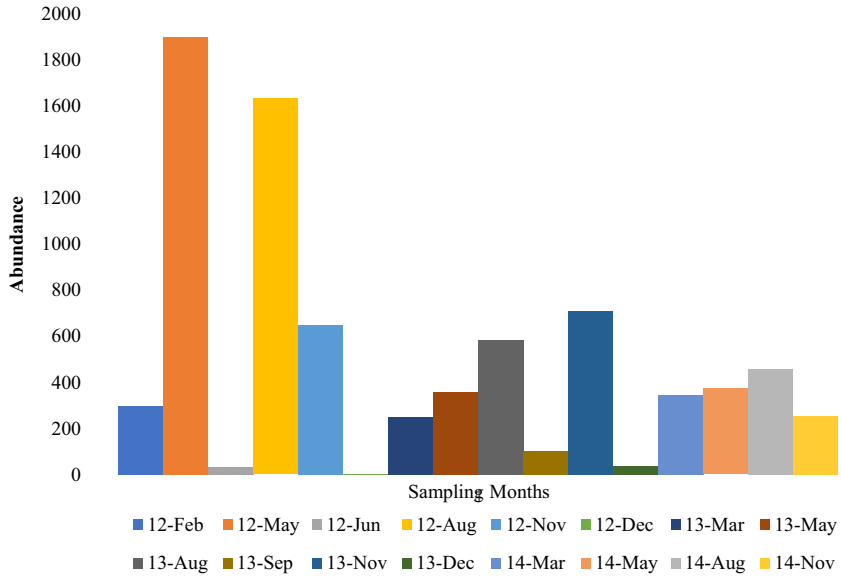

Fig. 2 Relative abundance of fish species caught per sampling month (2012–2014) in Yangtze River Estuary

(Monteleone 1992; Harris and Cyrus 2000; Strydom et al. 2003; Ramos et al. 2006). Four species from these two families dominated throughout our study; they represented 64.2% (*Collichthys lucidus* (36.17%), *Cynoglossus gracilis* (12.16%), *Chaeturichthys stigmatias* (8.19%), and *Lophiogobius ocellicauda* (7.6%)) of the total species number captured in the YRE. The present study show a small number of species composition in the YRE as compared to surveys done in 1998–2001 (48 species, 28 families were collected) reported by Yu and Xian (2009), and higher numbers as compared to the report by Quan et al. (2009) in the 2006–2007 survey (26 species, 15 families). The species composition differences observed in these studies could mainly have been caused by seasonality, as shown in this study. Seasonality is responsible for changes in environmental factors and spawning actions, and can hugely influence fish assemblages in estuaries (McErlean et al. 1973; Whitfield 1989; Loneragan and Potter 1990; Young and Potter 2003). Nonetheless, we reported many rare species and four dominant and abundant species. This result corroborates with many studies that the fish fauna in estuaries are mostly composed of few dominant species and a large number of rare species (Harris and Cyrus

Table 5 Results from SIMPER analysis showing average dissimilarity of most representative species (%) for stations and months based on a priori sampling design using data set of Yangtze River Estuary

Stations (average dissimilarity: 74.19%)				Months (average dissimilarity: 81.3%)			
Contributory species	Av. Diss	Contri. %	Cum. %	Contributory species	Av. Diss	Contri. %	Cum. %
Collichthys lucidus	19.14	25.8	25.8	*Collichthys lucidus*	20.56	25.29	25.29
Lophiogobius ocellicauda	9.202	12.4	38.2	*Lophiogobius ocellicauda*	11.34	13.95	39.24
Cynoglossus gracilis	8.431	11.36	49.56	*Cynoglossus gracilis*	9.683	11.91	51.15
Chaeturichthys stigmatias	5.227	7.046	56.61	*Chaeturichthys stigmatias*	5.61	6.9	58.05
Pelteobagrus nitidus	5.185	6.988	63.6	*Pennahia argentata*	4.783	5.884	63.93
Taenioides anguillaris	3.566	4.806	68.4	*Taenioides anguillaris*	4.278	5.261	69.19
Cynoglossus joyneri	3.47	4.677	73.08	*Cynoglossus joyneri*	3.886	4.78	73.97
Coilia mystus	2.913	3.927	77.01	*Coilia mystus*	3.456	4.251	78.22
Trypauchen vagina	2.754	3.712	80.72	*Harpadon nehereus*	2.896	3.562	81.79
Harpadon nehereus	2.707	3.648	84.37	*Trypauchen vagina*	2.617	3.219	85.01
Synechogobius ommaturus	2.677	3.608	87.97	*Coilia nasus*	2.554	3.141	88.15
Coilia nasus	2.533	3.415	91.39	*Nibea albiflora*	2.329	2.865	91.01
Nibea albiflora	1.552	2.092	93.48	*Tridentiger barbatus*	2.206	2.713	93.73
Pennahia argentata	1.251	1.686	95.17	*Pelteobagrus nitidus*	1.884	2.318	96.04

Table 6 Inter-annual comparison of species assemblage with one-way ANOSIM (*R* value and statistical significances) and SIMPER (average dissimilarity and top 3 contributory species)

Years	ANOSIM		SIMPER	
	R value	*P*	Average dissimilarity (%)	Contributory species
Overall	0.165	0.054	82.8	*Collichthys lucidus* *Pennahia argentata* *Cynoglossus gracilis*
2012 vs. 2013	0.232	*0.046*	86.67	*Collichthys lucidus* *Pennahia argentata* *Cynoglossus gracilis*
2012 vs. 2014	0.155	0.187	88.95	*Pennahia argentata* *Collichthys lucidus* *Lophiogobius ocellicauda*
2013 vs. 2014	0.079	0.256	70.85	*Collichthys lucidus* *Lophiogobius ocellicauda* *Cynoglossus gracilis*

NB. There is a significant difference among species assemblage between 2012~2013 ($P < 0.05$)

1995; Whitfield 1999; Zhang et al. 2015, 2016). *Collichthys lucidus* was abundant throughout our study period, be it seasonally or yearly although their percentage of contribution differed (Tables 5 and 6).

This study indicates that the total mean density (0.35 individuals/m^2) and biomass (2.5 g/m^2) of fish species in the YRE were higher than reports (total mean density (0.25 individuals/m^2) and biomass (0.9 g/m^2)) presented by Barletta et al. (2005) in the Caete River Estuary, but lower than the report by Barletta et al. (2016) of 2 individuals/m^2 and 104 g/m^2 after dredging was done in the Paranaguá Estuary (south Brazil). The differences in density and biomass observed from various studies could be attributed to the sampling frequency and dissimilarities in geographical locations. However, the high density and biomass values obtained in the Paranaguá Estuary could be attributed to the fact that dredging operations were done in this estuary, which apparently attracted some species as food supply increased thanks to disposals from dredged materials (Barletta et al. 2016). In our study, total mean density and biomass was regulated mainly by the presence of *Collichthys lucidus* as this species registered the highest individuals seasonally as well as annually.

Fish assemblage composition in estuaries is formed by both abiotic and biotic ecological components (Marshall and Elliott 1998; Elliott and Hemingway 2008; Garcia et al. 2012; Kamrani et al. 2015). The idea that abiotic factors play a role in the estuarine fish assemblage was established in this study. A strong spatial variation of fish assemblage was observed

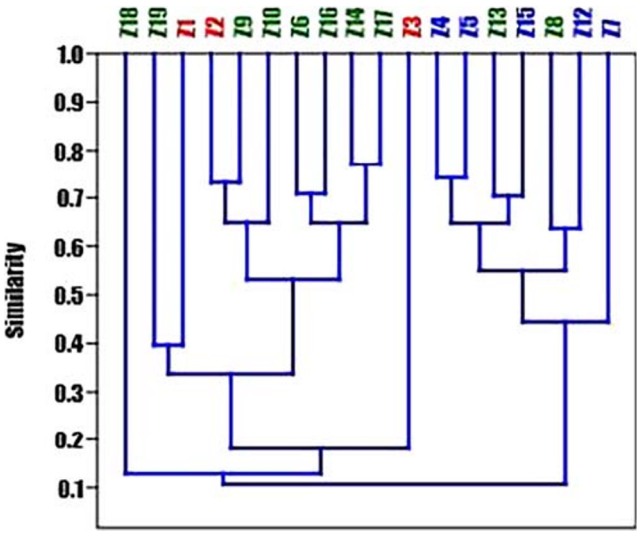

Fig. 3 Cluster analysis (Hierarchical) of the Bray-Curtis similarity matrix among the fish assemblages found in different stations samples. Stations samples clustered by locations (NP, EP, and SP)

Table 7 Results of the CCA analysis performed on the biotic and abiotic data matrices

Axes	Axis 1	Axis 2
Correlation of hydrological variables		
Depth	0.326	0.059
Temperature	0.027	*− 0.635*
Salinity	*− 0.669*	*− 0.388*
DO	0.404	0.494
PH	0.118	*− 0.349*
Chlorophyll-a	*− 0.369*	*− 0.253*
COD	0.227	0.617
Eigenvalues	0.425	0.242
Taxa explained data % variance	50.7	28.83
Cumulative % variance explained	50.7	79.53

Values in italics were considered important in structuring the fish community

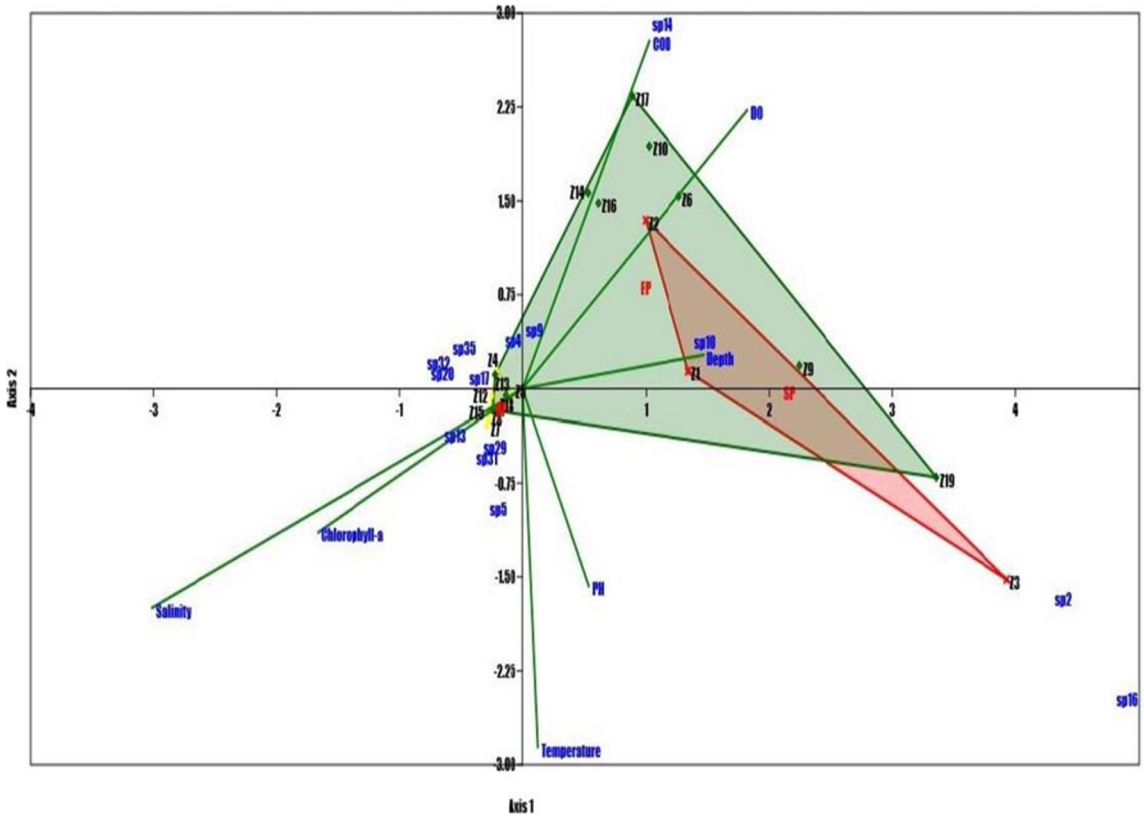

Fig. 4 CCA ordination diagram based on species abundances, with environmental variables for species codes, see Table 4

throughout our study period. The high number of individuals collected at station Z7 in the NP of the YRE could be as a result of the presence of dominant species and favorable environmental conditions with high salinity and slow water currents, whereas the low number of individuals observed at Z18 in the EP could be due to extreme human interference in this area of the studied site. High catches were recorded in May and August of 2012 (Fig. 2) representing periods of high temperatures; this corroborates with reports by Zhang et al. (2016) that species abundance in the YRE was high during summer. This could be explained by the fact that most fish species particularly marine species enter the YRE during this period for spawning thereby increasing the catch rates. Moreover, high salinities trigger the influx of most marine species (Sciaenidae) running from predators into the YRE and also due to the availability of food in the YRE.

As presented by the CCA analysis, salinity and chlorophyll-a influenced the most the fish community structure in the YRE. These environmental variables were associated with axes 1 and 2 (Table 7). Salinity and chlorophyll-a had the greatest effect on fish species distribution and abundance, consistent with findings of fish communities from other estuaries (Eick and Thiel 2014; Roux et al. 2015; Kamrani et al. 2015; Liu et al. 2015). Salinity is the most important environmental variable for estuarine animals, influencing not only growth development and reproduction of living organisms but also the temporal and spatial distribution of larval fish assemblages (Zhang et al. 2015). Salinity has a considerable influence on the species distribution within the YRE as it is the key factor affecting fish assemblage structure. Nevertheless, in many cases, the range of salinity values at which most fish species are habitually found are much narrower than their tolerance range. Hence, the response of many species to salinity may vary with different life stages. Seasonal fluctuation in fish composition, density, and biomass in the Caete River estuary (eastern Amazon), Goiana Estuary (eastern Amazon), and the Paranaguá Estuary (south Brazil) were positively correlated with salinity (Barletta et al. 2005; Barletta et al. 2008; Barletta et al. 2010; Dantas et al. 2010; Barletta et al. 2016). These reports corroborate with our result confirming salinity as the most influential parameter causing changes of biomass, density, and species composition in the YRE.

Chlorophyll a also influenced the most species composition in the YRE. This variable indicates the abundance of nutrients (such as standing crop of phytoplankton); the greater the phytoplankton biomass, the higher the primary productivity (Zhang et al. 2015). Chlorophyll-a and nutrients from freshwater flow entering the YRE have a close relationship. Therefore, the higher the nutrient levels, the higher the chlorophyll-a levels in the YRE; thus, abundant food resources necessary for the development and growth for

juveniles. Chlorophyll-a and salinity had a major impact on the distribution of *Chaeturichthys stigmatias*, *Collichthys lucidus*, and *Nibea albiflora* particularly at stations found in the North Branch of the YRE. Past studies also reported that salinity and chlorophyll-a had a strong influence in the distribution of phytoplankton in the YRE (Zhang et al. 2015, 2016).

The other environmental parameters recorded during sampling also had some slight impacts on species distribution. Species like *Coilia nasus* were comfortable in deeper zones, i.e., stations in the South Branch, while *Lophiogobius ocellicauda* preferred stations with higher COD values such as Z14, Z16, and Z17 in the Open Seas. Stations Z4 and Z5 were perfect habitat for *Cynoglossus gracilis*, *Coilia mystus*, *Taenioides anguillaris*, *Trypauchen vagina*, *Pennahia argentata*, and *Harpadon nehereus*, zones with lower temperatures. High pH zone such as Z3 was favorable for *Pelteobagrus nitidus* and *Synechogobius ommaturus*.

Conclusion

The species composition structure of the YRE was composed of four species with high abundance and a large number of rare species, which is a common phenomenon in estuarine milieus. Cluster analysis revealed the formation of two distinct assemblages, which clearly differed in their salinity tolerance. Seasonal and inter-annual changes in fish community structure in the YRE were observed and most of these were associated to salinity and chlorophyll-a. *Collichthys lucidus* was the most abundant species harvested in this estuary; its composition and distribution were shaped mainly by salinity as they tend to be concentrated in the North Branch of the YRE, branch containing high salinity values. The highest number of specimens collected was recorded during summer while the highest species richness was observed during autumn and winter.

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Compliance with ethical standards

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