Journal of
Applied Ichthyology

J. Appl. Ichthyol. (2013), 1–7

ISSN 0175–8659

Received: May 30, 2012
Accepted: December 5, 2012
doi: 10.1111/jai.12163

Diel, semi-lunar and seasonal patterns in the fish community of an intertidal zone of the Yangtze estuary

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Summary

The structure and temporal variations of the fish community in the intertidal estuarine zone of shallow mud areas have been poorly studied in China. This paper analyses the diel, semi-lunar and seasonal patterns of fish assemblages in the Yangtze estuary in 2006. Fish were collected by consecutive day and night samplings using tide-stow-nets deployed parallel to each other in three stations. A total of 56 fish species belonging to 21 families was caught during the study period. The family Cyprinidae dominated with 25 species. Freshwater fish species were the important dominant commercial fishery species and well represented with five species (sharpbelly *Hemiculter bleekeri*, goldfish *Carassius auratus*, bream *Parabramis pekinensis*, likely-bream *Pseudobrama simony,* and glossy yellow catfish *Pelteobagrus nitidus*) in the three stations. Juvenile fishes dominated the fish community, comprising 93.9% in station 1 and 96.6% in station 2 of the total abundance. The number of fish species in day tides was slightly lower than those in night tides in spring and summer, but the opposite in other seasons. In neap tides, the numbers and abundance of fish species were both lower than those in the spring tides. Fish abundance was lowest in winter, increasing during spring and summer (March–September) in both stations 1 and 2, with obviously large fluctuations in each season. The pattern of habitat selection of fishes could effectively decrease the food competition of intraspecies or interspecies and favour the growth and nursing of young fishes. These findings indicate that the intertidal zones in the estuary may serve as important nursery areas for fish communities.

Introduction

Shallow coastal zones and especially estuaries are used extensively by many fish species as nursery and feeding grounds (Gibson, 1973; Beukema, 1992; Rachid and Catherine, 2003), and supporting rapid growth in juveniles during spring and summer (Gibson, 1973; Zhang and Zhu, 2009). Indeed, most marine or estuarine fish species migrate to shallow and turbid areas for feeding or shelter when they are young (Gibson, 1982; Maes et al., 1998; Rachid and Catherine, 2003; Zhong et al., 2005). For temperate estuaries or mudflats, these patterns of seasonal movement result in various ecological guilds and intricate species compositions in the fish community.

'Intertidal species', as opposed to 'subtidal' or 'shore species', are defined as those usually completing essential parts of their life cycle in such habitats (Gibson, 1982). Various environmental stresses affect the life of intertidal species, such as tide fluctuation, extreme temperatures and fluctuating salinity, all of which are characterised by a wide range of temporal variation (Berghahn, 2000; Jin et al., 2007). Hence, the fish species should be more tolerant to strong abiotic environmental fluctuations in the intertidal zone. Although many studies have reported the species composition and community structure of shallow water and estuarine organisms, only a few studies refer to muddy or sandy beaches in the tidal waters of China despite their ecological importance during the life history of many estuarine fauna (Jin et al., 2007).

A recent intertidal study in marsh creeks determined resident and transient fishes in the Yangtze estuary (Jin et al., 2007, 2010). Intertidal marshes have also been shown to provide important food sources for dominant nekton species by using stable isotope analysis (Quan et al., 2007). These findings indicate that the intertidal zones of the Yangtze estuary are very important fish nursery habitats. A better understanding of the patterns of how fishes use the intertidal zone will be helpful for assessing key functions of mudflats and implementing marine measures for management strategies in the sustainable use of the Yangtze estuary ecosystem (Jin et al., 2010). Since the 1970s, intertidal zones have experienced rapid man-made changes due to the development of industrialised cities within the Yangtze estuary. More than 70% of the intertidal zone area has been appropriated for industries, constructional reservoirs, dockyards and other human use installations in the southern branch of the Yangtze estuary. Unfortunately, for a long time the importance of their ecological functions attracted little attention from the governmental planning authorities. Therefore, the objectives of this study were to (i) emphasize the importance of the remaining area for fish and describe the fish assemblage composition in the low salinity intertidal zone; (ii) determine diel, semi-lunar and seasonal changes in the fish community structure; and (iii) define the nursery areas used by freshwater and estuarine fishes and highlight the serious need for their protection.

Materials and methods

Study area

The Yangtze estuary is the largest in China and among the largest worldwide. Divided by Chongming Island into the south and north branches, the former is the main discharge channel of the estuary (Ni et al., 1990; Shen et al., 2003). The study was carried out on a muddy beach near the western part (121°10′E; 31°48′N) of Chongming Island, which is a relatively undisturbed low salinity intertidal wetland. The distance between high and low watermarks during the study period was about 100 m at neap tide and 300 m at spring tide. Average tidal range was about 3.2 m at spring tide and 1.7 m at neap tide. The intertidal zone is flooded daily by semi-diurnal meso-tides, with a one-time ebb tide in the day and one in the night. Dominant vegetation in the upper beach is reed (*Phragmites australis*), mat bulrush (*Scirpus triqueter*) and wild rice stem (*Zizania caduciflora*). As in European salt marsh ecosystems (Cattrijsse et al., 1994; Laffaille et al., 2000), the entire vegetated wetland area in the zone is inundated only during high spring tides.

Sampling methods

We separately set one tide-stow-net parallel to each other in stations 1–3, in 2006 (Fig. 1). The tide-stow-net (50 m width × 0.5 m height, 10 mm mesh size, 8 mm cod-end mesh) with rectangular sides was set in station 1 on the intertidal flat near vegetation. Net specification in station 2 was the same as in station 1, but the height was 1.0 m and located 200 m distant from station 1. The station 3 net (50 m width × 2.0 m height, 30 mm mesh size, 20 mm cod-end mesh) was also set in deeper water near the low tide shoreline, with a rectangular side just to catch larger fish. Heights above sea level of all nets were the same at about 2.2 m, which favoured preserving a similar fishing efficiency when under water. At all sampling sites, the nets faced the outgoing ebb currents to sample fish leaving the beach with the ebb. Fishes at station 2 were separately sampled when the tide ebbed in order to compare day- and nighttime fish compositions. At least three samples were taken in neap and spring tides each month in stations 1 and 2, while semi-diurnal samples were taken in spring (May), summer (July–August), autumn (late September) and winter (February) in the latter station. We also collected 15 day consecutive samples beginning with neap tides as a tidal cycle in each representative month. Furthermore, at least three samples were taken each month in station 3 in spring tides from April to November. A few samples were incomplete owing to big storms (e.g. on 27 and 28 May).

Catches were stored in plastic casks and sorted in the laboratory within a few hours. All fishes were identified to species level and counted. Standard length was measured to the nearest millimetre (SL, mm). Temperature, salinity and tide height were also measured at station 2 during the sampling period. Classifications of ecological guilds (EG) of fishes were in reference to those of Zhuang et al. (2006) and Jin et al. (2010).

Data analysis

Gear efficiency for the tide-stow-net used in this study was similar to that reported by Zhang et al. (2007). For each species, the number of fishes was converted to abundance estimates (ind. 100 m^{-2}) per tide in order to analyse the differences in the fish community within and among the three stations.

To analyse the semi-lunar and seasonal patterns of fish species, the daytime and nighttime samples were pooled in a single composite sample in station 2, which was expressed as the fish abundance (ind. 100 m^{-2}). Because of a larger mesh size the samples from station 3 were used only to analyse the size composition of fishes in deeper water. In total, 84, 108 and 24 samples were used in the data analysis in stations 1, 2 and 3, respectively. Fish species, abundance and biomass of fish assemblages were analysed by Student's *t*-test to learn the effects of diel periodicity. Effects of the different stations on the dominant fish standard lengths were analysed by one-way analysis of variance (ANOVA). Spearman's *r* correlation coefficient was used in analysing the relationship between the environmental factors and the abundance of fish at these stations. SPSS 13.0 software was used.

Results

Environmental conditions

The average tidal height was lowest in winter, increased in the spring, and was highest in summer. Tidal height maximum was 4.6 m in August and a minimum 2.3 m in December (Fig. 2). The lowest water temperature was 6.4°C in January and highest at 32.5°C in August, and showed the obvious seasonal patterns. Variation in the salinity remained relatively small and was below 1. During the wet periods, observed values were 0 from May to September.

The fish community

A total of 56 fish species belonging to 21 families was caught during the study period. Among these, 23 species are of commercial value, such as the freshwater eel *Anguilla japonica* and estuarine tapertail anchovy *Coilia ectenes* (Table 1). The most dominant fish family was the Cyprinidae (25 species) in

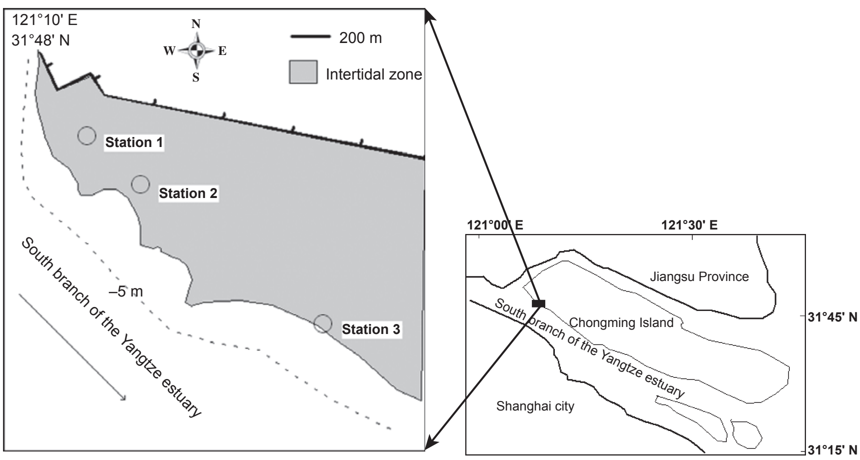

Fig. 1. Location of sampling sites in the intertidal zone (grey area), Yangtze River estuary, China

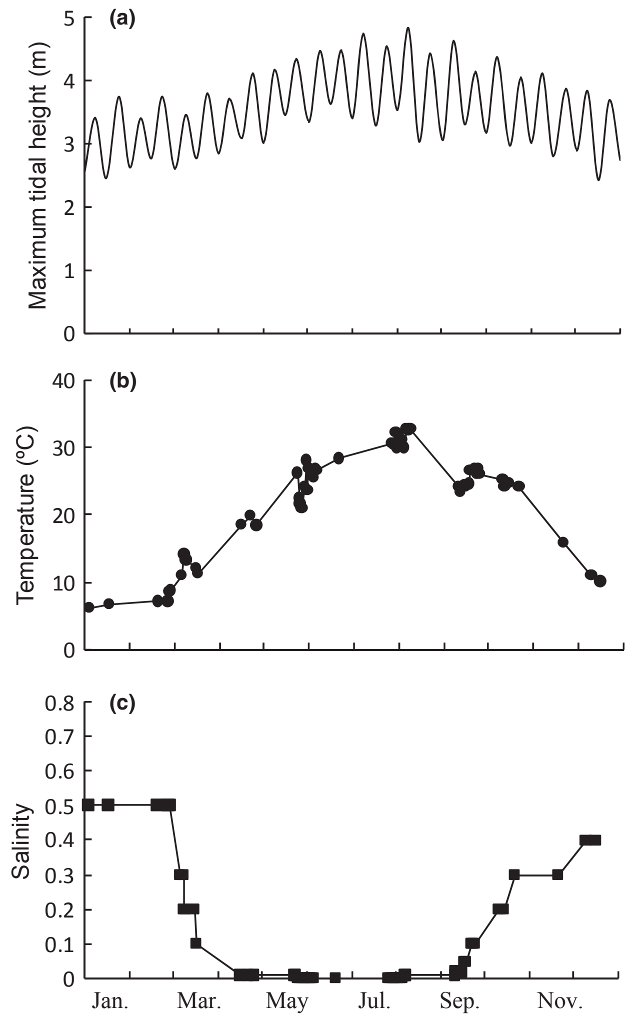

Fig. 2. Seasonal variations of (a) tidal height (m), (b) temperature (°C), and (c) salinity during monthly sampling periods in 2006

all stations, including important commercial species such as sharpbelly *Hemiculter bleekeri*, goldfish *Carassius auratus*, bream *Parabramis pekinensis*, likely-bream *Pseudobrama simony* and glossy yellow catfish *Pelteobagrus nitidus*). We collected 36 species in the shallowest water (station 1) and 54 species in deeper waters (station 2). However, in the deepest water (station 3), only 20 species were collected because the smaller fish species could escape owing to the largest mesh size. Two species (silver carp *Hypophthalmichthys molitrix* and spotted silver carp *Aristichthys nobilis*) occurred only in station 3 and generally did not come into shallower intertidal zone waters.

Sharpbelly (*Hemiculter bleekeri*) juveniles were the most abundant species (at stations 1 and 2), contributing 32.5% of the total fish catch (Table 1). Bream was the most abundant species at station 3 with 44.2% of the total catch. Four freshwater species (*Hemiculter bleekeri*, *Parabramis pekinensis*, *Pseudobrama simony* and *Carassius auratus*) were often found at stations 1–3 (frequency of occurrence >20%); goby *Acanthogobius ommaturus* and glossy yellow catfish *Pelteobagrus nitidus* were also important components of the fish community in stations 1 and 2. Hence, six fish species (sharpbelly, bream, likely-bream, goldfish, glossy yellow catfish and goby) can be considered as regular species in the area. The other 27 species are relatively rare (frequency of occurrence <10%), e.g. spotted silver carp *Aristichthys nobilis*, barbel chub *Squaliobarbus curriculus*, halfbeak *Hyporhamphus intermedius* and red eelgoby *Odontamblyopus rubicundus* (Table 1).

Freshwater and brackish fish species dominated the community, comprising about 98% of the total abundance in all three stations (Table 1). Only two marine and five estuarine transient species were collected. Juveniles dominated the fish community with 93.9% in station 1 and 96.6% in station 2 of the total abundance. More adults were caught in station 3, reaching overall 45.2% of the total abundance.

Effect of diel changes in the fish community

Average daily tide heights were lower than those at night during May–September (*t*-test, $P = 0.001 < 0.01$) (Fig. 3a). The number of species in daytime tides was slightly lower than during night-time tides in spring and summer, but were just the opposite in the other seasons (Fig. 3b). In summer, abundances during daily tides were significantly lower than those during nightly tides (*t*-test, $P = 0.002 < 0.01$). Biomass of daily tides was generally 10–64% higher than those at night, except for April, August and December. We also found that abundance, biomass and the number of species during daily tides were significantly higher than those in nightly tides in the autumn, although not significantly different in tide heights (Fig. 3).

Effect of semi-lunar phase on the fish community

The average number of fish species over a tidal cycle was highest in spring and summer (12 and 13, respectively), lower in autumn and lowest in winter (eight species) (Fig. 4). The highest abundance of fish was about 270 individuals per 100 m^2 in summer and lowest in winter (46 individuals per 100 m^2). During neap tides, numbers and abundances of species were both lower than during spring tides.

Effect of seasonal change on the fish community

Lowest fish abundance was at stations 1 and 2 in winter, increasing during spring and summer (March–September), with obvious, large fluctuations in each season (Fig. 5a). In station 1, average fish abundance was highest in spring, slightly decreasing in summer and autumn. In station 2, average abundance was highest in autumn (max. 540 ind. 100 m^{-2}). In station 3, abundance was highest in summer and lowest in late autumn (November) (Fig. 5b).

In order to investigate seasonal patterns on utilizing the intertidal zone for dominant species, we collected the samples in 1- or 2-week intervals in station 2 (Table 2). *Hemiculter bleekeri* and *Pseudobrama simony* occurred every month in the intertidal zone, but their abundances obviously changed seasonally. Most *Hemiculter bleekeri* entered the intertidal zone from late autumn to spring the following year, but a few were also found in summer. *Pseudobrama simony* seldom occurred in the winter, but appeared more frequently in spring and autumn. Other dominant species also entered seasonally: *Carassius auratus* occurred most frequently between January and May but declined rapidly in the following months; *Parabramis pekinensis* stayed a long time in this zone, about 9 months, but was also seldom found in winter; glossy yellow catfish *Pelteobagrus nitidus* appeared 2–3 months later than *Hemiculter bleekeri*, *Carassius auratus* and *Parabramis pekinensis*; and goby *Acanthogobius ommaturus* had a seasonal pattern similar to *Pelteobagrus nitidus*.

Table 1
Species composition, mean abundance (ind. 100 m^{-2}) and frequency of occurrence in three intertidal sites in 2006

		Mean abundance			Frequency of occurrence (%)				
Family	Species	S1	S2	S3	S1	S2	S3	EG	J (%)
Engraulidae	*Coilia ectenes*	0.29	1.0	0.75	2.6	20	62.5	T	100
Salangidae	*Salanx ariakensis*	0	0.03	0	0	0.8	0	M	100
Anguillidae	*Anguilla japonica*	0	0.06	0.06	0	1.6	12.5	T	100
Cyprinidae	*Mylopharyngodon piceus*	0	0.06	0	0	1.6	0	F	0
	Ctenopharyngodon idellus	0.20	0.7	0.06	1.7	2.6	12.5	F	71
	Hypophthalmichthys molitrix	0	0	0.5	0	0	37.5	F	0
	Aristichthys nobilis	0	0	0.09	0	0	25.0	F	0
	Squaliobarbus curriculus	0.10	0.03	0	0.8	0.8	0	F	100
	Ochetobius elongatus	0	0.03	0	0	0.8	0	F	100
	Culter erythropterus	0.10	1.73	0	0.8	18.3	0	F	100
	Erythroculter ilishaeformis	0.41	1.68	0.38	3.5	24.3	25	F	100
	Parabramis pekinensis	6.42	7.38	22.69	26.9	58.3	100	F	84
	Hemiculter leucisculus	3.89	3.01	0.5	8.7	28.7	37.5	F	77
	Hemiculter bleeleri	27.60	57.25	1.25	49.6	85.2	50	F	94
	Pseudolaubuca engraulis	4.70	10.68	0	19.1	57.4	0	F	88
	Pseudobrama simony	14.50	30.12	7.06	36.5	79.1	87.5	F	83
	Pseudorasbora parva	0.90	1.57	0	6.9	27.8	0	F	75
	Abbottina rivularis	0.48	0.80	0	3.5	20	0	F	97
	Saurogobio dumerili	0.90	2.80	0.75	5.2	40	50	F	59
	Saurogobio dabryi	0	0.05	0	0	2.6	0	F	0
	Saurogobio gymnocheilus	0	0.03	0	0	0.8	0	F	100
	Squalidus argentatus	4.46	5.29	0	25.2	63.5	0	F	54
	Squalidus sihuensis	0	0.06	0	0	1.6	0	F	100
	Rhodeus sinensis	0.30	0.18	0	2.6	4.3	0	F	98
	Rhodeus ocellatus	0	0.03	0	0	0.8	0	F	100
	Acheilognathus macropterus	0.41	0.14	0.13	2.6	5.2	12.5	F	89
	Acheilognathus chankaensis	0.29	0.17	0	2.6	10.4	0	F	80
	Carassius auratus	4.91	3.40	7.44	21.5	34.8	100	F	86
Cobitidae	*Misgurnus anguillicaudatus*	0.10	0.06	0	0.8	1.6	0	F	100
	Paramisgurnus dabryanus	0.10	0.09	0	0.8	2.6	0	F	0
Bagridae	*Pelteobagrus nitidus*	2.69	16.79	3.63	12.2	53	87.5	F	95
	Leiocassis longirostris	0	0.03	0.06	0	0.8	12.5	B	50
Poeciliidae	*Gambusia affinis*	0	0.09	0	0	2.6	0	F	0
Hemirhamphidae	*Hyporhamphus intermedius*	0	0.06	0	0	1.6	0	T	50
Mugilidae	*Mugil cephalus*	1.31	1.78	3.06	7.8	33	87.5	B	93
	Liza haematocheila	0	0.03	0	0	0.8	0	B	0
	Liza affinis	0.29	0.59	0	3.5	9.6	0	B	96
Serranidae	*Lateolabrax maculatus*	0.99	1.07	0.19	4.3	12.1	37.5	T	100
	Siniperca chuatsi	0.10	0.27	0.31	0.8	6.1	3	F	100
Synbranchidae	*Monopterus albus*	0	0.15	0	0	3.4	0	F	100
Callionymidae	*Callionymus olidus*	0.10	0.11	0	0.8	4.3	0	B	30
Eleotridae	*Eleotris oxycephala*	0.10	0.21	0	0.8	5.2	0	F	15
	Hypseleotris swinhonis	0	0.06	0	0	1.7	0	F	89
Gobiidae	*Triaenopogen barbatus*	0	0.03	0	0	0.8	0	B	100
	Ctenogobius giurinus	0.71	5.17	0	5.2	23.5	0	B	80
	Tridentiger trigonocephalus	2.69	1.27	0	16.5	24.3	0	B	90
	Acanthogobius ommaturus	6.30	14.92	0	24.3	53.9	0	B	100
	Acanthogobius elongate	0.21	0.63	0	1.7	16.5	0	B	100
Periophthalmidae	*Periophthalmus cantonensis*	0	0.09	0	0	2.6	0	B	100
	Boleophthalmus pectinirostris	0.20	0.18	0	1.7	16.5	0	B	100
Taenioididae	*Odontamblyopus rubicundus*	0.09	0.06	0	0.8	1.6	0	B	100
Belontiidae	*Macropodus chinensis*	0.33	0.39	0	2.6	6.9	0	F	95
Channidae	*Channa arga*	0	0.15	0	0	2.6	0	F	100
Platycephalidae	*Cociella crocodiles*	0.20	0.06	0	1.7	1.6	0	M	100
Cynoglossidae	*Cynoglossus gracilis*	0.10	1.13	2.38	0.8	20	100	B	100
Tetraodontidae	*Takifugu ocellatus*	0	0.03	0	0	0.8	0	T	100
	Total abundance	87.47	173.81	51.26					
	Number of fish species	36	54	20					

EG, ecological guilds; F, freshwater species; B, brackish species; M, marine species; T, estuarine transient species; J (%), percentage of juveniles; S1–3, Station 1–3.

Average SL of some important fish species was generally shorter than 100 mm in stations 1 and 2, significantly less than those of station 3 (ANOVA, $P = 0.004 < 0.01$) (Table 3). Average length of bream *Parabramis pekinensis* in stations 1 and 2 increased about 35 and 5% from spring to summer, respectively. Average length of *Pseudobrama simony* increased 4.0–6.1 mm from spring to summer-autumn in both stations 1 and 2. Conversely, the length of *Pelteobagrus nitidus* in stations 1 and 2 decreased about 15 and 27% from spring to summer. The length of grey mullet *Mugil cephalus* rapidly decreased from spring to summer, then increased in autumn. This meant that many *Pelteobagrus nitidus* and

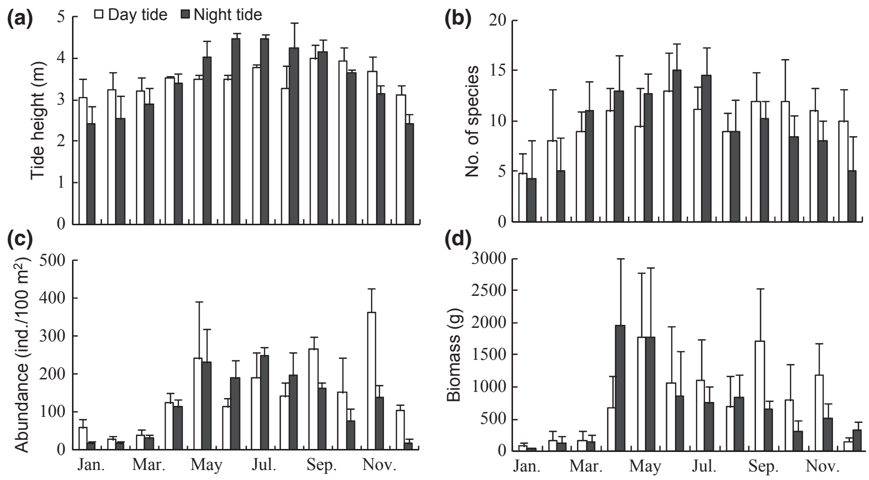

Fig. 3. Station 2 seasonal changes in (a) tide height, (b) number of species, (c) abundance and (d) biomass (mean values + SE) between day and night tides in 2006

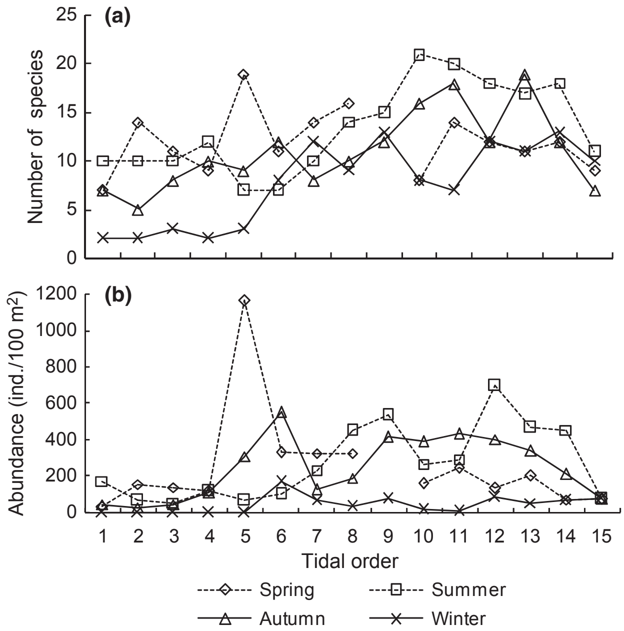

Fig. 4. Station 2, semi-lunar changes in (a) number of fish species; (b) abundance (ind. 100 m^{-2}) per tide cycle in four seasons

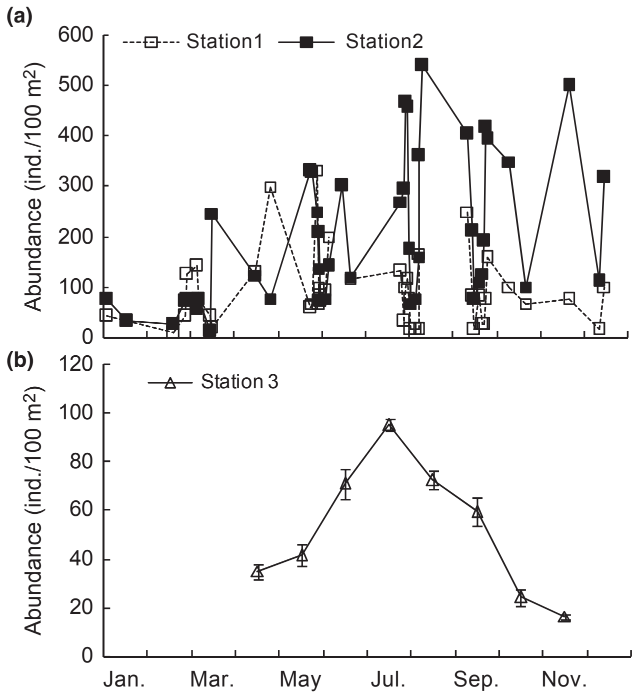

Fig. 5. Seasonal changes in fish abundances (ind. 100 m^{-2}) in (a) stations 1 and 2; (b) station 3. (mean ± SE)

Mugil cephalus juveniles entered the intertidal zone to live in the summer.

The correlation coefficients between abundance and temperature were 0.333 ($P \leq 0.022$) in spring and 0.593 ($P \leq 0.002$) in winter, higher than those of summer and autumn. There was almost no correlation between seasonal abundance and salinity. However, we found that the correlation coefficients between abundance and tide height increased from 0.272 ($P \leq 0.02$) in spring to 0.672 ($P \leq 0.001$) in autumn, and decreased to 0.609 ($P \leq 0.002$) in winter. Hence, the temperature and tide height play important roles in the abundance of intertidal fishes in the low salinity estuary.

Discussion

Composition of the fish community

Fish composition and biodiversity in the creeks and salt marsh of the Yangtze estuary are under increasing study, but few studies refer to the fish composition in the low salinity or freshwater intertidal zone (Jin et al., 2007; Zhang et al., 2007). The present study describes the spatial occurrence patterns of fish assemblages with various water depths in the freshwater intertidal zone. Compared to a previous study, 23 fish species and 65% freshwater fishes were found in this area in winter (Zhang et al., 2007); our study identified 56 species. Dominance by a few species is a common feature in estuarine fish assemblages (Kneib, 1997; Paterson and Whitfield, 2003; Green et al., 2009). Most other studies reported Gobiidae as a numerically dominant family in estuarine salt marshes (Cattrijsse et al., 1994; Mathieson et al., 2000; Jin et al., 2007). Because of low salinity at the survey locations, Cyprinidae were the most dominant in the ecological guild (65.5% of total species), whereas brackish species represented only 25%. This indicated that the fish assemblages in low salinity intertidal zones mainly resemble the riverine component of those in the slightly brackish waters of the Yangtze estuary.

Table 2
Seasonal changes in abundance (ind. 100 m^{-2}) of some dominant fishes in the intertidal zone, Yangtze River estuary (station 2)

Species	Date											
	7/1	18/2	25/2	3/3	9/3	16/3	15/4	25/4	23/5	30/5	5/6	14/6
Hemiculter bleeleri	52.5	6.9	161.1	40.3	6.9	155.5	106.3	19.4	237.5	37.5	25	12.5
Pseudobrama simony	2.5	2.1	0	5.6	0	52.8	51.4	8.3	417.5	32.5	17.5	32.5
Parabramis pekinensis	0	0	0	2.8	0	1.4	20.2	2.8	100	7.5	5	45
Carassius auratus	2.5	1.4	1.4	2.1	0.7	1.4	9.7	23.6	120	5	0	12.5
Pelteobagrus nitidus	0	0	0	0	0	0	0	0	5	0	0	12.5
Acanthogobius ommaturus	2.5	0	0	0	0	0	0	0	2.5	2.5	22.5	92.5
	Date											
	20/6	26/7	3/8	10/8	10/9	17/9	24/9	10/10	21/10	20/11	11/12	13/12
Hemiculter bleeleri	7.5	25	0	212.5	50	0	95	112.5	30	425	72.5	280
Pseudobrama simony	30	40	5	72.5	197.5	12.5	122.5	100	27.5	17.5	2.5	5
Parabramis pekinensis	20	2.5	2.5	7.5	35	0	10	7.5	5	2.5	5	0
Carassius auratus	0	5	0	0	2.5	0	0	5	0	0	0	0
Pelteobagrus nitidus	2.5	47.5	2.5	42.5	47.5	10	15	47.5	5	5	0	0
Acanthogobius ommaturus	37.5	75	17.5	82.5	17.5	7.5	7.5	15	2.5	2.5	0	0

Table 3
Average standard length (mm) of some important fishes in three stations from spring to autumn (number of fishes measured in bracket)

Species	Spring			Summer			Autumn		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Parabramis pekinensis	73.8 (27)	85.3 (117)	139.2 (23)	100.2 (30)	89.2 (88)	128.4 (56)	88.3 (5)	89.3 (53)	132.2 (15)
Pseudobrama simony	78.9 (39)	73.3 (222)	125.4 (10)	82.6 (18)	79.9 (97)	125.5 (23)	82.3 (68)	77.3 (173)	123.8 (5)
Pelteobagrus nitidus	83.0 (2)	89.2 (13)	116.2 (26)	69.5 (22)	64.8 (113)	110.8 (21)	54.6 (5)	55.0 (180)	112.1 (10)
Mugil cephalus	91.1 (2)	106.6 (18)	224.9 (11)	37.3 (3)	55.3 (6)	190.3 (13)	71.9 (9)	84.7 (32)	232.3 (15)

The frequency of fish occurrence and abundance could potentially reflect the level of their dependency on the intertidal zone habitats, because of their need for food or shelter (Amara and Paul, 2003; Zhang and Zhu, 2009). Several aquatic vascular plants are found in the low salinity or freshwater intertidal zone of the Yangtze estuary, such as *Phragmites communis* and *Zizania caduciflora*. These plants and their detritus are very important foods for *Hemiculter bleekeri*, *Parabramis pekinensis*, *Pseudobrama simony* and *Carassius auratus* (Ni et al., 1990; Zhang et al., 2007). Although a few carnivorous species were observed in the intertidal zone, their numbers were limited; *Siniperca chuatsi* and *Lateolabrax maculatus,* for example, were observed only in the spring and summer. Thus, the predator pressure for small juveniles seems to be limited at the study sites. The low salinity intertidal zone of the Yangtze estuary seems to play an important nursery role for a number of freshwater and resident fish. Species such as *Coilia ectenes*, *Hypophthalmichthys molitrix* and *Aristichthys nobilis* were often caught in deeper waters or subtidal areas (Table 1; Zhuang et al., 2006) and were seldom found in the intertidal zone. However, 'abundance' should be taken as a relative measure and not an absolute value in this paper, and has been calculated as a basis for comparisons among the three stations.

Effect of diel, semi-lunar and seasonal changes on fish abundance

Tide and temperature fluctuations are important environmental variables in the intertidal wetland, playing important roles in the timing behaviour of fish entering the ecosystem. Several studies found a diel change in the estuary fish community, with the abundance of fish being higher in nightly tides than during daytime tides from spring to summer, whereas no differences were found in other seasons (Morrison et al., 2002; Hampel et al., 2003). In the present study, there was no significant difference in fish abundance between daily and nightly tides in the spring, but were obviously different in the summer, autumn and winter (Fig. 3). The abundance of summer nightly tides was higher than those of daily tides, and the opposite in autumn and winter. The possible reason is the diel difference of tide heights in each season.

For a semi-lunar change in the fish community, the higher average abundance and number of fish species were observed during spring tides. This illustrates that more fishes can enter the intertidal zone for food intake or movement when the tide is higher (Amara and Paul, 2003; Zhang et al., 2007). Generally, the tides from spring to autumn were higher than those in winter. Juvenile fish move into the intertidal zone with the increase in temperatures from spring to autumn. Owing to exposure to the extreme environmental conditions, relatively few intertidal fishes adapt to the fluctuation of tide, salinity and temperature (Berghahn, 2000). This study found that few species dominated every season and that most species occurred occasionally in the intertidal zone.

Analysing the correlation coefficients between fish abundance and temperature, we knew that there were higher relationships during winter–spring and lower negative relationships in summer-autumn. This suggests that more fishes like to enter the intertidal zone with increasing temperatures from late winter to spring (Krumme, 2004). However, extremely high temperatures (26–32°C) might adversely affect the movement of fishes in summer-autumn (June–October).

In the present study we found that the tide size mainly affected the changes in fish abundance in this period.

Body size composition and habitat selection

Many fish species were distributed according to size, with the smallest individuals preferring the upper intertidal zone. The main reason is that the smaller fish species can avoid predators and find a mass of small-sized prey in shallow waters (Edwards and Steele, 1968; Gibson, 1973; Ruiz et al., 1993; Amara and Paul, 2003). A few studies have described the patterns of fishes using the intertidal zone of the Yangtze estuary, but no study has referred to the intraspecific differences in depth distribution. In the present study, the number of species occurring in the upper intertidal zone (station 1) was obviously lower than in the middle intertidal zone (station 2) and about 50% that of the latter station. This implies that many fish species enter the intertidal zone, but few species such as the goby *Acanthogobius ommaturus* enter the shallower waters because of the very poor environmental conditions. This habitant selection pattern effectively decreases the food competition of intraspecies or interspecies and favours the growth and nursery of the young fish (Gibson, 1973; Amara and Paul, 2003). This phenomenon was also observed in the present study. The data suggests that larger size fish species more often occur at the edge of the subtidal zone, and occasionally in shallower waters of the intertidal zones. This is in good agreement with observations from North American marshes (Bretsch and Allen, 2006). Two smaller sizes of carnivorous fishes (*Siniperca chuatsi* and *Lateolabrax maculatus*) occasionally entered the shallower intertidal zone whereas bigger size fishes were distributed within the deeper zones. Comparisons between subtidal and intertidal feeding conditions and analyses of interspecific competition for food are necessary in order for future studies to verify whether the intertidal zone of the Yangtze estuary is propitious for the growth of juveniles.

Acknowledgements

We thank Dr Harald Rosenthal for the useful suggestions during the manuscript revision. This study was supported by the programme, The National Natural Science Funds of China (31170508), and the National '863' planned project (2007AA092202) and would not have been accomplished without the help of many people.

References

Amara, R.; Paul, C., 2003: Seasonal patterns in the fish and epibenthic crustacean community of an intertidal zone with particular reference to the population dynamics of plaice and brown shrimp. Estuar. Coast. Shelf Sci. **56**, 807–818.

Berghahn, R., 2000: Response to extreme conditions in coastal areas: biological tags in flatfish otoliths. Mar. Ecol. Prog. Ser. **192**, 277–285.

Beukema, J. J., 1992: Dynamics of juvenile shrimp *Crangon crangon* in a tidal-flat nursery of the Wadden Sea after mild and cold winters. Mar. Ecol. Prog. Ser. **83**, 157–165.

Bretsch, K.; Allen, D. M., 2006: Tidal migrations of nekton in salt marsh intertidal creeks. Estuar. Coast. Shelf Sci. **29**, 474–486.

Cattrijsse, A.; Makwaia, E. S.; Dankwa, H. R., 1994: Nekton communities of an intertidal creek of a European estuarine brackish marsh. Mar. Ecol. Prog. Ser. **109**, 195–208.

Edwards, R.; Steele, J. H., 1968: The ecology of 0-group plaice and common dabs at Loch Ewe. I. Population and food. J. Exp. Mar. Biol. Ecol. **2**, 215–238.

Gibson, R. N., 1973: The intertidal movements and distribution of young fish on a sandy beach with special reference to the plaice *Pleuronectes platessa* L. J. Exp. Mar. Biol. Ecol. **12**, 79–102.

Gibson, R. N., 1982: Recent studies on the biology of intertidal fishes. Oceanogr. Mar. Biol. Annu. Rev. **20**, 363–414.

Green, B. C.; Smith, D. J.; Earley, S. E.; Hepburn, L. J.; Underwood, G. J. C., 2009: Seasonal changes in community composition and trophic structure of fish populations of five salt marshes along the Essex coastline, United Kingdom. Estuar. Coast. Shelf Sci. **85**, 247–256.

Hampel, H.; Cattrijsse, A.; Vincx, M., 2003: Tidal, diel and semilunar changes in the faunal assemblage of an intertidal salt marsh creek. Estuar. Coast. Shelf Sci. **56**, 795–805.

Jin, B. S.; Fu, C. Z.; Zhong, J. S.; Li, B.; Chen, J. K., 2007: Fish utilization of a salt marsh intertidal creek in the Yangtze River estuary. Chin. Estuar. Coast. Shelf Sci. **73**, 844–852.

Jin, B. S.; Qin, H. M.; Xu, W.; Wu, J. H.; Zhong, J. S., 2010: Nekton use of intertidal creek edges in low salinity salt marshes of the Yangtze River estuary along a stream-order gradient. Estuar. Coast. Shelf Sci. **88**, 41–428.

Kneib, R. T., 1997: The role of tidal marshes in the ecology of estuarine nekton. Oceanogr. Mar. Biol. Annu. Rev. **35**, 163–220.

Krumme, U., 2004: Patterns in tidal migration of fish in a Brazilian mangrove channel as revealed by a split-beam echosounder. Fish. Res. **70**, 1–15.

Laffaille, P.; Feunteun, E.; Lefeuvre, J. C., 2000: Composition of fish communities in a European macrotidal salt marsh (the Mont Saint-Michel Bay, France). Estuar. Coast. Shelf Sci. **51**, 429–438.

Maes, J.; Van Damme, P. A.; Taillieu, A.; Ollevier, E., 1998: Fish communities along an oxygen-poor salinity gradient (Zeeschelde Estuary, Belgium). J. Fish Biol. **3**, 534–546.

Mathieson, S.; Cattrijsse, A.; Costa, M. J.; Drake, P.; Elliott, M.; Gardner, J.; Marchand, J., 2000: Fish assemblages of European tidal marshes: a comparison based on species, families and functional guilds. Mar. Ecol. Prog. Ser. **204**, 225–242.

Morrison, M. A.; Francis, M. P.; Hartill, B. W., 2002: Diurnal and tidal variation in the abundance of the fish fauna of a temperate tidal mudflat. Estuar. Coast. Shelf Sci. **54**, 793–807.

Ni, Y.; Wang, Y. H.; Xu, C. Y., 1990: Shanghai fishes. Shanghai Technology Press, Shanghai, pp. 1–56. (in Chinese).

Paterson, A. W.; Whitfield, A. K., 2003: The fishes associated with three intertidal salt marsh creeks in a temperate southern African estuary. Wetl. Ecol. Manage. **11**, 305–315.

Quan, W. M.; Fu, C. Z.; Jin, B. S.; Luo, Y. Q.; Li, B., 2007: Tidal marshes as energy sources for commercially important nektonic organisms: stable isotope analysis. Mar. Ecol. Prog. Ser. **352**, 89–99.

Rachid, A.; Catherine, P., 2003: Seasonal patterns in the fish and epibenthic crustacean community of an intertidal zone with particular reference to the population dynamics of plaice and brown shrimp. Estuar. Coast. Shelf Sci. **56**, 807–818.

Ruiz, M. G.; Hines, A. H.; Posey, M. H., 1993: Shallow water as a refuge habitat for fish and crustaceans in non-vegetated estuaries: an example from Chesapeake Bay. Mar. Ecol. Prog. Ser. **99**, 1–16.

Shen, H. T.; Mao, Z. C.; Zhu, J. R., 2003: Invasion of salt water of Yangtze estuary. Marine Press, Beijing, pp. 1–60. (in Chinese).

Zhang, H.; Zhu, G. P., 2009: Spatio-temporal changes of fish community in the Yangtze estuary intertidal zone. Chin. J. Appl. Ecol. **10**, 2519–2526. (in Chinese).

Zhang, H.; He, W. S.; Tong, C. F.; Lu, J. J., 2007: An analysis on fish community structure in winter in the Chong-xi wetland. Res. Environ. Yangt. Bas. **3**, 308–313. (in Chinese).

Zhong, J. S.; Yu, W. W.; Liu, B. L., 2005: Seasonal occurrences of fish larvae and juveniles in the surf zone of the Yangtze River estuary. J. Shanghai Fisher. Univ. **4**, 375–382. (in Chinese).

Zhuang, P.; Wang, Y. W.; Li, S. F.; Deng, S. M., 2006: Fishes of the Yangtze estuary. Shanghai Science and Technology Press, Shanghai, pp. 50–230. (in Chinese).

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