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The impact of geomorphology of marsh creeks on fish assemblage in Changjiang River estuary*

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Abstract Tidal marshes are an important habitat and nursery area for fish. In the past few decades, rapid economic development in the coastal areas of China has led to the interruption and destruction of an increasing number of tidal marshes. The growing interest in tidal marsh restoration has increased the need to understand the relationship between geomorphological features and fish assemblages in the design of marsh restoration projects. We studied temporal variations in, and the effects of creek geomorphological features on, the estuarine tidal creek fish community. Using modified channel nets, we sampled fish monthly from March 2007 to February 2008 from seven tidal creeks along an intertidal channel system in Chongming Dongtan National Nature Reserve. Fourteen creek geomorphological variables were measured or derived to characterize intertidal creek geomorphological features. The Gobiidae, with 10 species, was the most species-rich family. The most abundant fish species were *Liza affinis*, *Chelon haematocheilus*, and *Lateolabrax maculatus*. The fish community was dominated by juvenile marine transients, which comprised about 80% of the total catch. The highest abundance of fish occurred in June and July, and the highest biomass occurred in December. Canonical redundancy analyses demonstrated that depth, steepness, cross-sectional area, and volume significantly affected the fish species assemblage. *L. affinis* favored small creeks with high elevations. *Synechogobius ommaturus*, *Acanthogobius luridus*, and *Carassius auratus* preferred deep, steep creeks with a large cross-sectional area and volume. These findings indicate that the geomorphological features of tidal creeks should be considered in the conservation and sustainable management of fish species and in the restoration of salt marshes.

Keyword: intertidal environment; habitat selection; geomorphology; restoration; salt marshes; Changjiang (Yangtze) River estuary

1 INTRODUCTION

Tidal marshes are dissected by complex tidal creek systems, which function as periodic links with subtidal habitats. The water exchanged between marshes and adjacent estuaries carries nutrients, particulate organic matter, and invertebrate larvae. It also provides pathways that fish use to move between the marsh and subtidal habitats (Kneib, 1997; Mallin, 2004; Peterson et al., 2008). Tidal creeks provide extensive foraging areas and nursery habitats for many estuarine and marine fish species. Creeks also increase the length of intertidal-subtidal edges, extend inundation time, increase access to marsh surfaces, and are associated with higher fish densities (Peterson et al., 1994; Desmond et al., 2000). In these environments, fish respond rapidly to changes in habitat heterogeneity (Kwak et al., 1997; Able et al., 2003).

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The geomorphology of tidal creeks usually consists of one or more straight, sinuous, or dendritic tidal channels that taper upstream in a negative-exponential fashion and form shoals towards land (Wolanski et al., 1992). Scientists have studied the relationship between tidal flows and tidal marsh channel geometry since the 1960s (Allen, 2000; Williams et al., 2002). Results from early work on the hydraulic geometry of intertidal channels indicate that intertidal channels exhibit an exponential decrease in width in the upstream direction. This change in geometry facilitates greater tidal energy dissipation through the channel network via increased friction (Novakowski, 2004). Pestrong (1965) also recognized that microtopography may control channel initiation by concentrating sheet flow, and that some tributaries may experience predominantly unidirectional flow. Tidal creek networks facilitate marshland inundation and drainage and, to a large extent, control estuary-wide hydrodynamics. Tidal hydraulic geometry characteristics are important for the support of fish and their trophic functions in tidal marshes. Characteristics such as depth, slope, cross-sectional area, and flow have a significant impact on fish distribution patterns within the habitat (Kneib, 2000; Visintainer et al., 2006; Allen et al., 2007; La Peyre and Birdsong, 2008; Larkin et al., 2008). Shallow water depth is beneficial to small fish, because it reduces predation and competition with other aquatic taxa (Bretsch et al., 2006). Creeks with sloped and depositional banks support more fish (McIvor et al., 1988, Allen et al., 2007). Creek length also affects the number of fish supported in the habitat by increasing the length of the marsh edges (Peterson and Turner, 1994; Minello and Rozas, 2002). McIvor and Odum (1988) compared depositional and erosional marsh creek banks and found that the highest fish densities occurred along the depositional banks. The relationship between tidal marsh geomorphology and fish productivity is an important indicator of ecosystem function (Visintainer et al., 2006; Allen et al., 2007). In recent years, intense coastal development worldwide has resulted in a dramatic decline in marsh populations (Peterson et al., 2008). The effects of declining marsh areas highlight the critical relationship between channel geomorphology and fish communities for tidal marsh ecosystem protection and restoration.

The relationships between intertidal creek geomorphological features and fish distribution patterns have been studied in many regions, especially in North America. Most of the studies have considered the effects of only one or a few variables. However, Allen et al. (2007) examined all of the environmental variables that affect the relationship between tidal creek geomorphological features and associated fish use patterns. Water depth, bank slope, tidal flow, and the distance to upland tidal creeks affected how fish use tidal creeks. However, the common features of the estuaries they sampled are different from the features present in other estuaries. Along much of the Atlantic coast of the southeastern USA, semi-diurnal tides with amplitudes that exceed 1.5 m inundate most of the vegetated intertidal marsh once or twice daily, but for relatively short periods (2–4 h) each time (Kneib, 1997, 2000). The Changjiang River estuary tidal marshes are typically open-coast tidal flats that experience mixed semi-diurnal tides (two high and two low tides of differing amplitude per day). The tidal range is mesotidal, with a mean tidal range=2.6 m, mean high water level=3.25 m, and a mean low water level=0.63 m. Questions about the importance of these differences prompted a separate investigation to understand the geomorphological features of the Changjiang River estuary. Previous studies of this estuary have focused on the effects of landscape change on invertebrate and birds (Wu et al., 2002; Fan and Zhang, 2012), but a full understanding of the relationship between fauna assemblage and habitat is critical for the successful implementation of management strategies. In this study, we investigated (1) the structure of the fish assemblage in the oligohaline intertidal creeks of the Changjiang River estuary, and (2) the relationship between creek geomorphological characteristics and fish assemblage.

2 MATERIAL AND METHOD

2.1 Study area

This study was performed in the Dongtan National Nature Reserve in Chongming, Shanghai (121°50′–122°05′E, 31°25′–33°38′N), which is located in the Changjiang River estuary in eastern China (Fig.1). The Dongtan tidal marshes are dominated by two native plant species, *Scirpus mariqueter* (29.53 km^2) and *Phragmites australis* (4.52 km^2), and one invasive species, *Spartina alterniflora* (12.83 km^2) (Huang et al., 2007). In the study area, vegetation was not distributed in the tidal creeks, and the plant species on the marsh surface were mostly *S. mariqueter* and *Scirpus triqueter*. The reserve is affected by the Asian monsoon climate. Dry periods are from November to

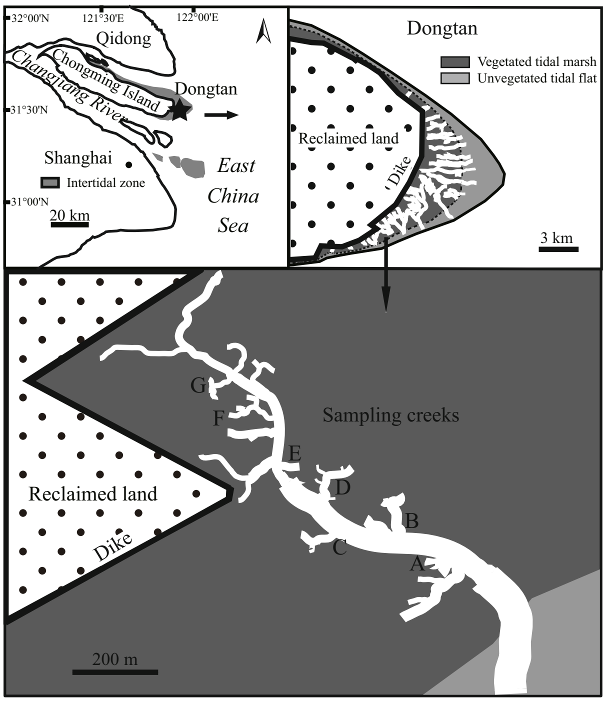

Fig.1 Location of seven sampling sites (A–G) in the Changjiang River estuarine marsh at the Dongtan National Nature Reserve

April, and wet periods are from May to October. Mean annual water temperature and precipitation are 15.3°C and 1 022 mm, respectively. Mean tidal range=2.6 m, and intertidal zones are flooded by semidiurnal meso-tides with a pronounced neap-spring inequality. The marshes consist of a well-developed system of tidal creeks (>20 intertidal channel systems) (Xie et al., 2006) with variable geomorphology; creek length ranges from 100 to 3 500 m (Xu and Zhao, 2005). Owing to the effects of tidal currents and human disturbance, the number of tidal creeks decreases gradually from the south to north (He et al., 2004).

2.2 Fish sampling

Modified channel nets were used to sample fish populations (Shenker et al., 1979) in seven small tidal creeks located within one intertidal creek in the Dongtan marshes (Fig.1). The sampling occurred during an 8-month period between March 2007 and February 2008. Fish were sampled during the day, between the spring and neap tide cycles, when the marsh surface was not flooded by high water. One net (15 m long×2 m high, 4-mm mesh) was suspended across each tidal creek during slack high tide, and fish were captured when they exited the creek with the ebbing tide. Fish were immediately preserved in 10% formalin solution. After transfer to the laboratory, all fish species were identified following the nomenclature used in Fishbase (Froese and Pauly, 2009). The standard length (SL) of each fish was measured to the nearest 0.1 mm, and the wet weight was measured to the nearest 0.1 g after removal of excess water.

2.3 Environmental variables

The major physical variables of the creek (Allen et al., 2007) included 14 parameters: length (m), width (m), depth (m), bottom area (m^2), cross-sectional area (m^2), volume, elevation, location, branches, slope, tributary dominance, steepness, flow, and split. Creek length was measured along centerlines, and was defined as the total length of the main creek plus all tributaries (Allen et al., 2007). Creek width was defined as the mean distance between banks. Measurements were made every 10 m from the mouth to the end of the main creek (Allen et al., 2007). Depth was the mean depth of the main creek at the bank full stage. Vertical distances between the surface of the bank full water surface and the creek bottom were measured every 10 m and were used to calculate the mean depth (Allen et al., 2007). The bottom area was defined as the total area of the bottom of the main creek and all tributaries and was measured using 1-m^2 quadrants and a tape measure (Allen et al., 2007). The cross-sectional area was the cross-sectional area of the creek mouth (Allen et al., 2007). Calculation of the volume, including tributaries, was based on survey measurements of the creek length, width, depth, and cross-sectional area at bank full stage. During low tide, the relative elevation of the sampling creek mouth related to Creek A was surveyed using a leveling rod and an optical level (SUGUANG DSZ3). During slack high tide periods, the elevation at the mouth of Creek A was calculated from the difference between predicted water height (Shanghai Maritime Safety Administration tide table) and water depth. Elevations of the other six creeks were then calculated from the relative elevation and elevation of Creek A (Jin et al., 2010). The location variable was defined as the shortest linear distance from the sampling creek mouth to the mouth of the big channel and was estimated from a high-resolution aerial photograph taken in 2006 using ERDAS IMAGINE 9.1 software (Leica Geosystems; Atlanta, GA, USA). Branches were defined as the number of tributaries extending from the main creek. The creek slope was defined as the slope of the regression line on the bottom elevation at 10 m intervals from the mouth to the end of the

Table 1 Measured and derived geomorphological variables for seven intertidal creeks

Variables	Creeks						
	A	B	C	D	E	F	G
Length (m)	118	209	122	253	47	238	172
Depth (m)	0.99	1.19	0.98	1.52	0.76	0.74	0.81
Width (m)	3.9	4.94	3.93	4.39	2.2	4.45	4.06
Cross-sectional area (m^2)	4.4	10.1	5.8	13.4	2.6	1.3	3.3
Volume (m^3)	194.8	718.7	215.3	672.2	60.4	206.8	158.8
Bottom area (m^2)	418.4	1 203.4	464.3	979.8	197.8	637.6	429.6
Elevation (m)	2.3	2.1	2.9	2.5	3.1	3.1	3.2
Location (m)	185	331	467	535	687	784	933
Branches (number)	2	3	1	5	0	2	2
Slope (regression)	0.013	0.006	0.007	0.009	0.004	0.007	0.006
Tributaries dominance (ratio)	0.372	0.275	0.374	0.831	0	0.758	0.607
Steepness (ratio)	0.466	0.597	0.464	0.686	0.305	0.324	0.37
Flow (ratio)	0.023	0.014	0.027	0.02	0.043	0.006	0.021
Split (ratio)	0.023	0.018	0.011	0.036	0	0.015	0.019

main creek. Values for the four remaining variables were derived from the previous variables. Tributary dominance was the ratio of the combined total length of all tributaries to the length of the main creek axis. Steepness was the ratio of the total volume of water at the bank full stage to the total bottom area. Flow was the ratio of the cross-sectional area at the mouth to the total volume of water at the bank full stage. Split was the ratio of branch number to the length of the main creek axis.

2.4 Data analysis

To standardize captures among creeks, the bottom area adjusted density (individuals/m^2) and standing stock (g/10 m^2) were used in all analyses. The dominant species were determined using the index of relative importance (IRI) (Tofe et al., 2007; Selleslagh et al., 2009). To avoid sample size bias, we normalized the calculation of % total IRI=(% numerical composition+ % gravimetric composition)×% frequency of occurrence. To compare the functional structure of the fish community, species were classified into five estuarine use functional groups (EUFG): estuarine species, marine migrants, freshwater species, anadromous species, and catadromous species (Franco et al., 2006).

Principal components analyses (PCA) were used to find correlation patterns among creek geomorphological variables. Spearman correlation analyses were used to examine the relationships among creek geomorphological variables. The effects of creek characteristics on fish species richness, density, and standing stock were analyzed using non-parametric analysis of variance (ANOVA; Kruskal-Wallis test), for each month. $P<0.05$ was considered to be statistically significant. PCA and correlation analyses were performed using Statistica 6.0 (StatSoftInc; Tulsa, OK, USA).

Canonical redundancy analysis (RDA) was used to evaluate the relationship between fish assemblage and creek geomorphological variables. For each data set, the following analytical options in CANOCO software (version 4.56, Wageningen UR; Wageningen, the Netherlands) were used: direct gradient analysis, species scores divided by the standard deviation, diagram-optimized interspecies distances, log(x+1) transformation of all abundance data, and rare species (<100 individuals for the total catch) were excluded from the analyses. A Monte Carlo test was used on all canonical axes as a test of significance of the species-environment relationships.

3 RESULT

3.1 Creek physical variables

Among the seven sampled creeks, Creek D was the longest, Creek B had the largest width, volume, and bottom area, and Creek E was the smallest (Table 1). Creek elevation increased as the distance to the mouth of the main channel increased. Creeks at lower elevations were deeper and had greater steepness. Steepness was

Table 2 Relationships among 14 geomorphological features in seven sampled creeks

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Length	-													
2. Depth	0.32	-												
3. Width	0.86*	0.25	-											
4. Cross sectional	0.36	0.96*	0.29	-										
5. Volume	0.68	0.68	0.75	0.75	-									
6. Bottom area	0.86*	0.50	0.93*	0.57	0.93*	-								
7. Elevation	-0.13	-0.77*	-0.27	-0.70	-0.70	-0.47	-							
8. Location	0.21	-0.64	0.07	-0.57	-0.46	-0.14	0.92*	-						
9. Branches	0.82*	0.70	0.74	0.63	0.70	0.78*	-0.50	-0.19	-					
10. Slope	0.29	0.44	0.04	0.35	0.33	0.16	-0.43	-0.47	0.42	-				
11. Tributaries dominance	0.79*	0.11	0.43	0.14	0.29	0.43	0.23	0.39	0.52	0.53	-			
12. Steepness	0.50	0.96*	0.43	0.93*	0.79*	0.64	-0.77*	-0.61	0.82*	0.56	0.29	-		
13. Flow	-0.86*	-0.11	-0.93*	-0.07	-0.57	-0.79*	0.18	-0.14	-0.74	-0.20	-0.54	-0.32	-	
14. Split	0.50	0.68	0.29	0.54	0.32	0.32	-0.36	-0.21	0.82*	0.65	0.54	0.75	-0.39	-

Spearman's correlation analysis (*R* values). $P<0.05$ represent statistical significance and are noted with an asterisk (*).

Table 3 Factor loadings and percentage of the variance for 14 geomorphological variables in the first four principal component axes

Variables	Principal component			
	1	2	3	4
Length	0.27	0.35*	0.06	-0.07
Depth	0.30*	-0.19	0.14	0.29
Width	0.28	0.22	-0.09	-0.37*
Cross-sectional area	0.29	-0.20	0.27	0.21
Volume	0.31*	-0.09	0.29	-0.12
Bottom area	0.31*	0.02	0.26	-0.30*
Elevation	-0.25	0.35*	0.13	0.29
Location	-0.14	0.46*	0.32*	0.26
Branches	0.32*	0.09	0.03	0.23
Slope	0.15	-0.13	-0.71*	0.15
Tributaries dominance	0.20	0.44*	-0.17	0.30*
Steepness	0.31*	-0.20	0.11	0.14
Flow	-0.21	-0.38*	0.19	0.42*
Split	0.30*	0.08	-0.22	0.34*
% Variance explained	60.90	19.56	10.50	7.59

Strong loadings (≥0.30) are notated with an asterisk (*)

positively correlated with depth, cross-sectional area, volume, and number of branches. Flow was negatively correlated with the other variables. All variables and their cross-correlations are summarized in Table 2.

Examination of the PCA results revealed that for creek depth, the first principal component, volume, bottom area, branches, steepness, and split had high factor loadings; for creek length, the second principal component, elevation, location, tributary dominance, and flow had high factor loadings. The first four principal components accounted for 98.6% of the variance in the 14 physical variables (Table 3).

3.2 Fish composition

A total of 10 432 fish, with a cumulative weight of 46 kg, were caught with the channel nets. They were from eight families and 25 species (Table 4). The most species-rich family was the Gobiidae (eight genera and 10 species). The two most abundant fish species, comprising 81.54% of the total number caught, were the eastern keelback mullet *Liza affinis* (42.84%) and the red lip mullet *Chelon haematocheilus* (38.70%). *L. affinis* and *C. haematocheilus* are important fishery species in the Changjiang River estuary. A total of 12 estuarine species and 10 freshwater species were captured. The estuarine species were the most abundant EUFG and accounted for 91.59% of the total catch. The dominant species (% IRI>0.5) were *L. affinis*, *C. haematocheilus*, *Carassius auratus*, *Synechogobius ommaturus*, *Acanthogobius luridus*, and *Lateolabrax maculatus*. The results of the Kruskal-Wallis test revealed that species richness was significantly different among the seven creeks in February (H=14.42, P=0.04) and May (H=17.58, P=0.01) (Fig.2). In general, more species

Table 4 Fish families and species captured in the Changjiang River estuarine marsh

Species	EUFG	IRI%	Body size (mm)	Abundance								Total abundance	Total biomass (g)
				Feb.	Mar.	Apr.	May	Jun.	Jul.	Sep.	Dec.		
Adrianichthyidae													
Oryzias latipes	F	<0.00	27.0	0	0	1	0	0	0	0	0	1	0.3
Anguillidae													
Anguilla japonica	C	0.24	359.4 (53, 459)	0	0	1	9	1	8	1	0	20	1 835.6
Cyprinidae													
Abbottina rivularis	F	<0.00	41.1 (29.9, 85.5)	0	0	2	0	1	3	0	0	6	21
Acanthorhodeus chankaensis	F	0.01	27.4 (18.5, 36.8)	0	0	0	0	1	21	0	0	22	12.6
Carassius auratus	F	6.44	79.5 (19.2, 172.6)	2	12	76	63	12	79	16	22	282	7 834.7
Chanodichthys erythropterus	F	0.02	49.7 (17.2, 80.9)	0	0	0	0	0	11	15	1	27	50.8
Hemiculter bleekeri	F	0.18	43.8 (18.8, 84.5)	1	0	2	1	0	19	108	0	131	149.8
Pseudobrama simony	F	0.01	75 (61.0, 88.6)	1	0	0	0	0	12	0	0	13	87.2
Pseudorasbora parva	F	0.01	41.9 (33.7, 57.5)	0	0	1	3	3	7	0	0	14	26.4
Rhodeus sinensis	F	<0.00	56.0	1	0	0	0	0	0	0	0	1	3.9
Engraulidae													
Coilia nasus	A	<0.00	41.0 (33.3, 48.6)	0	0	0	0	0	1	1	0	2	0.6
Gobiidae													
Acanthogobius luridus	ES	1.65	46.7 (15.7, 68.5)	6	125	21	5	4	45	1	170	377	742
Boleophthalmus pectinirostris	ES	0.29	69.1 (50.7, 109.7)	0	0	0	1	3	14	67	1	86	667.5
Mugilogobius abei	ES	0.14	25.2 (13.7, 37.6)	1	7	10	23	10	3	0	16	70	29.4
Mugilogobius myxodermus	ES	<0.00	49.5	0	1	0	0	0	0	0	0	1	2.7
Periophthalmus magnuspinnatus	ES	0.02	62.0 (41.9, 76.2)	0	0	0	0	8	1	6	0	15	59
Periophthalmus modestus	ES	0.13	41.9 (18.7, 61)	0	1	0	8	11	14	25	2	61	109.3
Pseudogobius javanicus	ES	0.01	21.6 (16.5, 25.4)	0	0	5	13	0	0	0	0	18	3.4
Scartelaos histophorus	ES	<0.00	44.5 (24.0, 65.0)	0	0	0	0	1	0	0	1	2	3.2
Synechogobius ommaturus	ES	5.15	70.7 (11.4, 181.0)	18	20	7	78	108	118	51	5	405	4 312.3
Tridentiger trigonocephalus	ES	0.01	20.5 (16.9, 57.4)	0	0	2	2	0	10	0	0	14	12.3
Lateolabracidae													
Lateolabrax maculatus	MM	0.73	23.0 (14.0, 88.3)	0	0	180	154	20	0	0	0	354	340.8
Mugilidae													
Chelon haematocheilus	ES	36.77	35.2 (16.0, 261.0)	143	493	242	822	1 064	966	221	86	4 037	11 045.1
Liza affinis	ES	48.18	53.7 (18.1, 148.8)	245	206	9	3	766	1 184	411	1 645	4 469	18 788.9
Poeciliidae													
Gambusia affinis	F	<0.00	20.3 (15.5, 35.3)	0	1	2	0	1	0	0	0	4	1.7
Species richness				9	9	15	14	16	18	12	10		
Total				418	866	561	1 185	2 014	2 516	923	1 949	10 432	46 140.5

EUFG: ecological use function group; ES: estuarine species; MM: marine migrants; F: freshwater species; A: anadromous species; C: catadromous species; IRI: index of relative importance; Body size (mm): mean standard length with minimum and maximum in parentheses.

were captured in creeks with lower elevations. Creek effects were most significant in April and July for fish densities and in July for fish biomass.

In February, *L. affinis* (52%–84% of the density and 44%–89% of the biomass) accounted for the greatest proportion of the catch in creeks B through G and, with *C. haematocheilus*, comprised most of the density and standing stock in Creek A (Fig.3). In

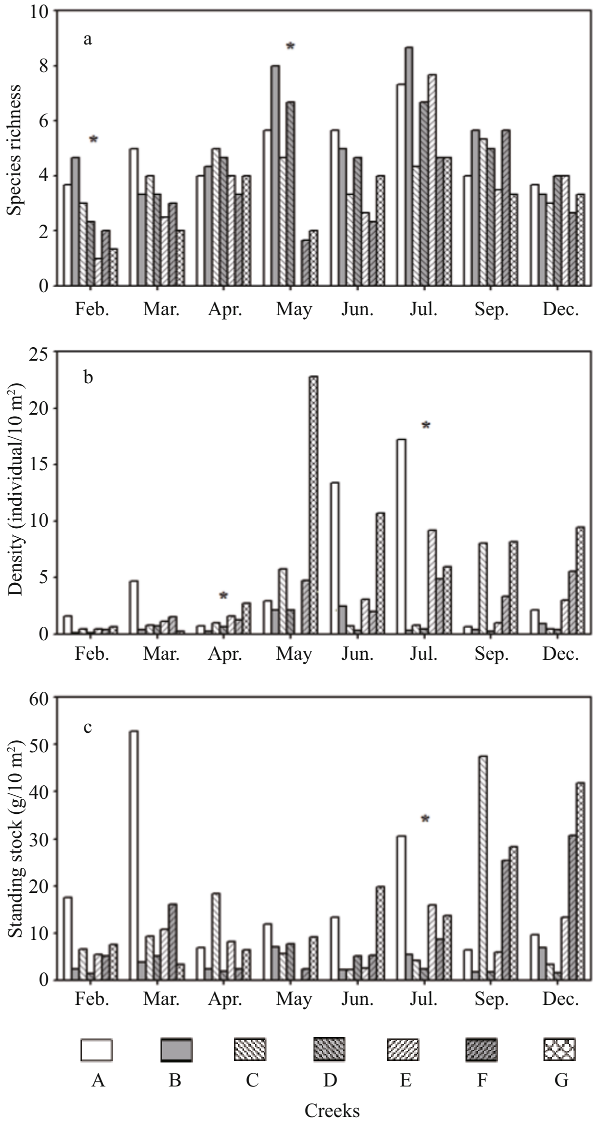

Fig.2 Species richness, density (individuals/10 m^2), and standing stock (g/10 m^2) for seven creeks sampled during the study

Each bar represents one creek (A–G). (*) indicates a significant difference (Kruskal-Wallis test, P<0.05) among the creeks in each sampling month.

April, the fish composition varied among creeks. *L. maculatus*, *C. auratus*, or *C. haematocheilus* were the numerically dominant species. *C. auratus* was most of the standing stock in all creeks except for Creek F. *C. haematocheilus* was the species with the greatest density in May. In July, *L. affinis* and *C. haematocheilus* contributed the most in terms of fish density (Fig.3).

3.3 Effects of physical variables

Axes 1 and 2 from the RDA cumulatively accounted for 84.3% of the total variance (Fig.4). The first axis represented a steepness gradient, depth, cross-sectional area, bottom area, volume, width, and flow. The second axis was determined mainly by slope, split, and branches. The first axis separated Creeks C and D, with large values for steepness, depth, and cross-sectional area, from Creeks F and G, with large values for location, elevation, tributary dominance, and length.

Results of a forward selection of environmental variables test (P<0.05) with a Monte Carlo permutation procedure revealed that depth (P=0.006), steepness (P=0.018), cross-sectional area (P=0.010), and volume (P=0.016) significantly affected the fish assemblage. The presence of *A. luridus* was positively correlated, but the presence of *C. haematocheilus* was negatively correlated, with flow. *S. ommaturus* and *C. auratu* were positively associated with creek steepness, bottom area, and volume. *L. afinis* and *L. maculatus* were negatively associated with these variables (Fig.4).

4 DISCUSSION

This study is the first to investigate the relationship between fish communities and geomorphological characteristics of intertidal creeks in China. These findings add to previous work on the importance of geomorphological characteristics of intertidal creeks on fish use.

4.1 Fish composition

The Gobiidae and Cyprinidae were the most species-rich families in the intertidal creeks. *L. affinis* and *C. haematocheilus* were the dominant species. Using fyke nets, Jin et al. (2007) collected 33 fish species from intertidal creeks in Jiuduansha, approximately 30 km south of Dongtan. They found that Gobiidae was the most species-rich family and that *S. ommaturus*, *C. haematocheilus*, and *L. maculates* were the most abundant fish species. They reported only two species from the family Cyprinidae. These finding support the observation that a few species control most fish assemblages. This general pattern has been reported globally (Shenker et al., 1979; Cattrijsse et al., 1994; Kneib et al., 1994; Rozas, 1995; Desmond et al., 2000; Salgado et al., 2004; Veiga et al., 2006). Three freshwater species were collected from the intertidal creeks in Jiuduansha (Jin et al., 2007), whereas 10 species were collected in Dongtan, probably because of salinity differences between the two systems. Salinity is the most significant factor that affects the composition of fish

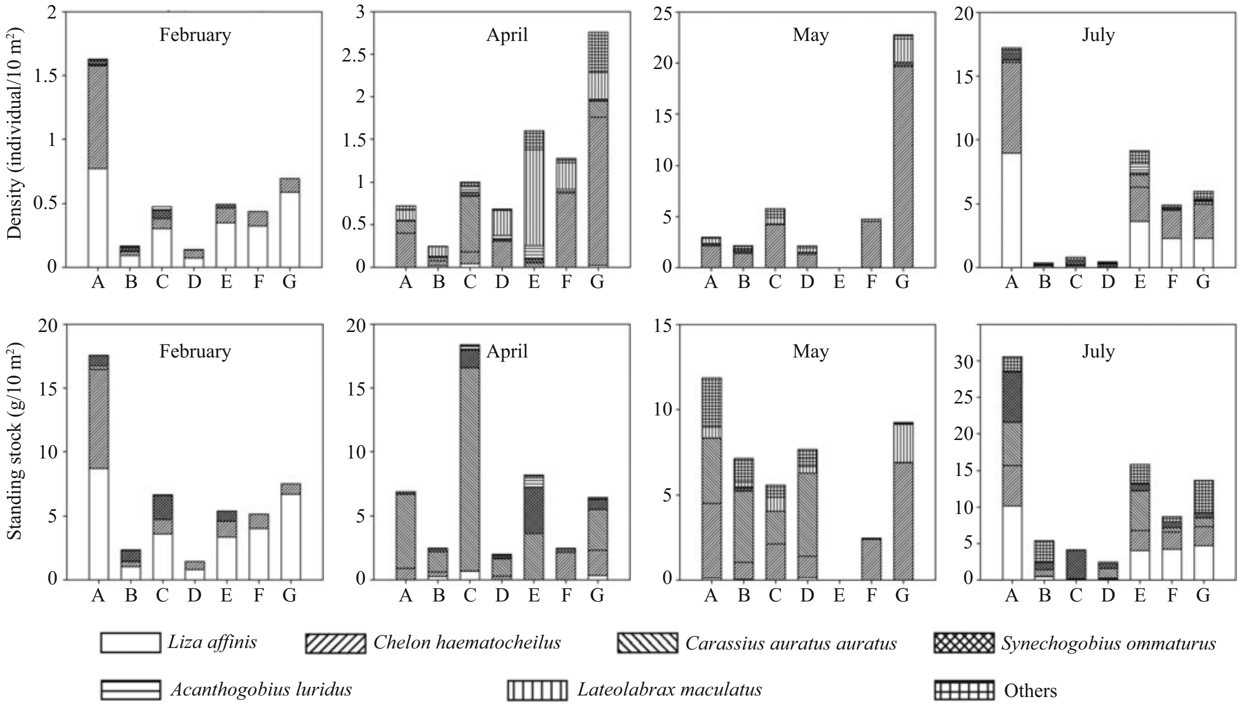

Fig.3 Species composition of the captured fish population in February, April, May, and July 2007

Density (individuals/10 m^2) and standing stock (g/10 m^2) are presented for six dominant fish species and for other species captured from each creek.

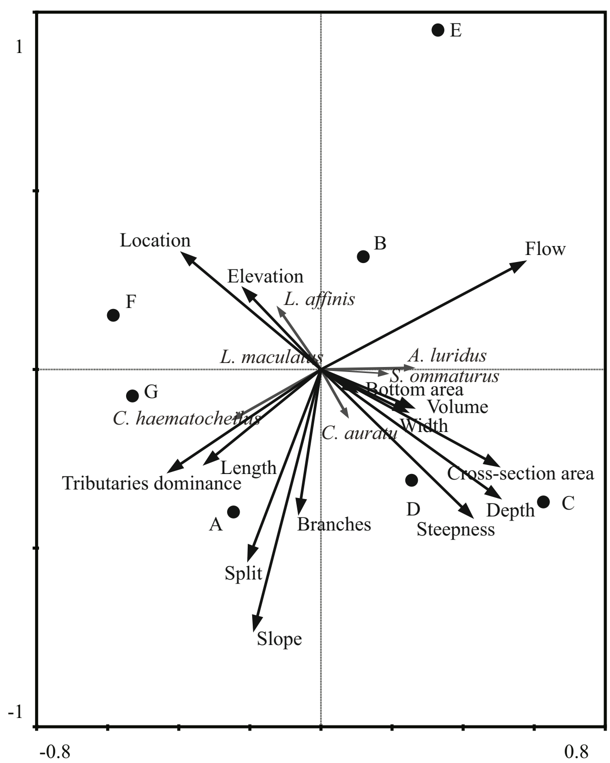

Fig.4 Redundancy analysis (RDA) biplot of fish species, environmental variables, and sampling creeks (A–G)

Species with fewer than 100 individual observations were excluded from the analysis.

communities in estuarine areas (Gunter, 1956; Weinstein et al., 1980; Gelwick et al., 2001; Akin et al., 2005). The results of the Jiuduansha and Dongtan studies indicate that the Changjiang River estuary tidal marshes are important nursery habitats for commercial fish. The importance of the Changjiang River estuary tidal marshes as nursery habitats for commercial fish and the need for further study and conservation of the tidal marsh habitat has been emphasized by this work. Further study of this tidal marsh habitat is critically important so that it can be effectively protected.

4.2 Effects of creek geomorphological variables on fish

Multiple biological and physical factors affect fish distribution within tidal marsh systems (Craig et al., 2000). Creek geomorphological characteristics affect fish distribution patterns (Visintainer et al. 2006; Allen et al., 2007). Allen et al. (2007) found that there is a strong relationship between intertidal creek geomorphological characteristics and some fish species. The highest densities of fish are found in shallow tidal creeks with sloped banks, slow tidal flows, and close proximity to uplands. In this study, fish use of intertidal creeks was strongly associated with depth, creek cross-section area, volume, and steepness. *A. luridus*, *S. ommaturus*, and *C. auratus* were more likely to inhabit large creeks (high water depth, large cross section and volume) with a high degree of steepness. However, *L. affinis*, *L. maculatus*, and *C. haematocheilus* were more abundant in small creeks with a low degree of steepness. Intertidal creeks with a shallower mean depth and a smaller degree of steepness support a greater abundance of fish. Intertidal creeks with shallower banks also support greater numbers of fish, and more fish were captured in the intertidal creeks with small cross-section areas and volumes. These findings were similar to the findings of Allen et al. (2007).

Shallow intertidal creeks are often considered the nursery grounds for juvenile fishes (Shenker et al., 1979; Weinstein, 1979; Rozas et al., 1984). Bretsch and Allen (2006) tested the hypothesis that the depth distribution of nekton was affected by biotic factors. They reported that fish in shallower water might be subject to less predation and competition with other aquatic taxa. Fish may also choose shallow creeks to find more abundant food resources (Kneib, 1997). Allen et al. (2007) reported capturing more nekton in slow flowing (the ratio of cross sectional area to volume) creeks. However, the present results are difficult to explain by flow characteristics. This difference might be due to different intertidal creek systems and related to other potential physical and biological factors. This study was limited to one tidal channel system. It is important to recognize that there are complex relationships between fish assemblages and geomorphological features across multiple sizes and types of tidal channel systems (Visintainer et al., 2006).

A large number of *S. ommaturus* and *C. auratu* were collected in the large intertidal creeks (deep water, large cross-sectional area, and correspondingly, large volume) with steeply sloped banks. This finding did not agree with the work of Allen et al. (2007). They found that small, shallow creeks, with little steepness, supported more nekton species. However, other published studies have reported results similar to ours. Hettler (1989) found a larger number of species on sites adjacent to deep subtidal microhabitats. La Peyre and Birdsong (2008) examined the relationship between marsh edge physical variations and nekton communities. They found that edges with steeper slopes supported greater species diversity. We hypothesize that large creeks with steep banks may provide refuge for fish as they avoid predators. An alternative hypothesis to explain this pattern is that, compared with small shallow creeks, fish that prefer shallow water depths will be compressed against the shoreline in large creeks with steep banks. This distribution could lead to bias (i.e., artifact) if the entire creek is not sampled (Toft et al., 2007). In this study, the largest creeks were deeper at the mouth, and thus there was earlier and greater accessibility for fish entering on flood tides, and increased abundance in these areas.

Location was related to creek elevation, and both factors were important variables affecting *L. affinis* and *L. maculaus* use of intertidal creeks. Previous studies reported that, compared with downstream locations, fish abundance was greater in the upper reaches of tidal creeks (Rozas et al., 1987; Desmond et al., 2000; Webb et al., 2002). The habitat in the interior of marshes may provide food sources suitable to adult transient fish species (Peterson et al., 1994).

Similar to the results of Allen et al. (2007), creek length was not an important variable relating to fish use of intertidal creeks in the Changjiang River estuary. In studies from North America, intertidal creeks were considered to be edges of marshes, and fish densities were higher in the edge habitats than in the adjacent mudflat and inner marshes (Rozas et al., 2000; Webb et al., 2002; Kneib, 2003). Comparative research conducted in different geographical regions will help to explain these differences.

In conclusion, the dendritic intertidal channels and creeks are dominant features of tidal marshes in the Changjiang River estuary. They are important nursery habitats for the fish community. Population of tidal creeks by fish assemblages is related to multiple geomorphological variables, and many of the features of intertidal channels are important for the conservation, sustainable management, and restoration of fish habitats.

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