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Environmental factors affecting nematode community structure in the Changjiang Estuary and its adjacent waters

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This paper describes the major features of nematode assemblages collected at 18 stations in the Changjiang River estuary and its adjacent waters and identifies dominant species within communities in relation to environmental parameters. Meiofauna from the Changjiang Estuary and its adjacent waters comprised 21 major taxa of higher categories. Subsamples of nematodes were extracted and identified to the species level. In general, the nematode community structure was similar to that of muddy sublittoral areas world-wide. The most abundant genera were Daptonema, Cobbia, Sabatieria, Dorylaimopsis *and* Terschellingia, *accounting for 50.0%. The studied area exhibited high nematode abundance and high species biodiversity. Measurements of environmental factors were made, including grain size, salinity, temperature, sediment organic matter content, Chl-*a *and Phaeo-*a*. Different combinations of environmental variables are responsible for the meiofauna and nematode communities' structures. However, BIOENV results indicate that water depth, salinity, Chl-*a*, Phaeo-*a *and silt–clay content were more closely linked to variation in meiofauna (mainly nematode) community structure in the studied area. Among these, water depth, salinity, Chl-*a *and Phaeo-*a *were most responsible for nematode assemblage discrimination in the studied area.*

Keywords: environmental factors, nematodes, community structure, Chiangjiang Estuary, People's Republic of China

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INTRODUCTION

The analysis of benthic community structure is a useful tool for describing changes in the state of marine systems (Heip *et al.*, 1992). Most studies on marine nematodes and meiofauna communities are either focused on the intertidal, sublittoral or in deep-sea sites. A considerable number of studies show the importance of environmental effects on meiofauna communities, nematodes in particular (Heip *et al.*, 1985; Giere, 1993, for reviews). Besides structural aspects of standing stock and community composition (family, genus and species), functional approaches, based on feeding type, may give alternative insights on the impact of the environmental parameters (Vanhove *et al.*, 2004).

Meiofauna has been extensively studied in the Bohai Sea (Zhang *et al.*, 1989, 1990, 2001a; Mu *et al.*, 2001; Guo *et al.*, 2002; Zhou *et al.*, 2007) and the Huanghai Sea (Zhang *et al.*, 2001b; Liu *et al.*, 2005a; Huang *et al.*, 2006; Liu *et al.*, 2007) in China. In the East China Sea, several studies on meiofauna and free-living nematodes in some Changjiang (Yangtze River) Estuary areas (Zhang *et al.*, 2004; Lin *et al.*, 2004; Hua *et al.*, 2006) have been carried out. However, there are few studies on the meiofauna community structure and the controlling factors in the Changjiang Estuary and its adjacent waters. In recent years considerable attention has been directed towards the physical, chemical and biological dynamics of this area.

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The Changjiang Estuary and its adjacent area is a complex area since it is influenced by fresh water invasion, a high sedimentation rate, the Taiwan warm currents and coastal water from the north. Sand, nutrients and pollutants brought by Changjiang runoff, coastal upwelling and human activities settle quickly and stimulate phytoplankton blooms (Zhou *et al.*, 2004). The resulting higher primary production can act as a bottom-up stimulus to production at successively higher trophic levels and can thereby increase total system production in estuarine and marine systems (Elmgren, 1989). In turn, those factors are determined by the hydrodynamic features of the estuary. All the complex and related environmental variables influence the meiobenthos in this area. Salinity is one of the most important environmental variables affecting the distribution and abundance of benthic animals in estuaries (Warwick *et al.*, 1991). Several other sediment variables such as grain size, organic content, Chl-*a* and Phaeo-*a* concentrations are also important factors (Levin *et al.*, 1991). The purpose of the present study was to determine the nematode community structure and function at sublittoral muddy sites in Changjiang Estuary and its adjacent waters, and to measure the natural variability of the community in relation to environmental characteristics.

MATERIALS AND METHODS

Study area and sampling method

Sediment samples were collected from Changjiang (Yangtze River) Estuary and its adjacent waters in the East China Sea during a cruise on the RV 'No.2 Dongfanghong' in June 2003. A grid of 18 stations was located at 28°22′~31°45′N and 121°54′~123°00′E (Figure 1).

Three replicate samples were collected with a modified 0.1 m² Gray–O'Hara box corer. From each box, two sub-samples, one for meiofauna and one for chlorophyll-*a* (Chl-*a*) and phaeophytin-*a* (Phaeo-*a*) analysis, were collected with a sawn-off syringe with a 2.9 cm inner diameter and immediately sectioned vertically in fractions of 0–2, 2–5 and 5–8 cm. To avoid the core-compression, the hypodermic syringe was first pushed slowly into the sediment to a certain depth. The syringe with its plunger was then withdrawn carefully from the sediment. Many previous subtidal studies have indicated that most meiofauna individuals (nematodes in particular) are distributed in the top 0–5 cm layer which accounts for over 80–90% of the total meiofauna. In addition, one further sub-sample was taken from one replicate sample to a depth of 5 cm for analysis of grain size and organic matter. All meiofauna samples were fixed on board with 5% formalin solution buffered in seawater. Samples for grain size, organic matter, Chl-*a* and Phaeo-*a* were deep-frozen at −20°C for future laboratory analysis. Conductivity/temperature/depth (CTD) profiles were made for water depth, water column salinity and temperature.

Determination of environmental variables

MEASUREMENTS OF ABIOTIC CHARACTERISTICS

Samples for grain size analysis were collected from surface sediments. Sieving and sedimentation were jointly used for grain size analysis. The sieving method was used to analyse particles over 63 μm and the sedimentation method was used to analyse particles smaller than 63 μm.

MEASUREMENT OF BIOTIC CHARACTERISTICS

The organic matter content of the sediment was measured by the chromic acid method (Higgins & Thiel, 1988).

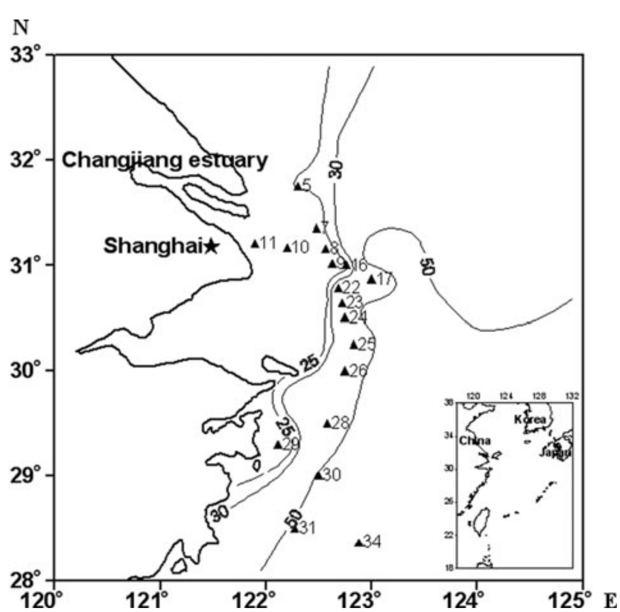

Fig. 1. Sampling stations of the Changjiang Estuary waters and isolines of water depths (m) (omit the '03' before the station number).

In the present study, Chl-*a* and Phaeo-*a* contents were determined by the fluorometric method of Lorenzen & Jeffrey (1980) and modified by Liu *et al.* (1998) for wet sediment.

Meiofauna sample processing in laboratory

Meiofauna is defined here as metazoans that pass through a 0.5-mm mesh sieve, but are retained on a 0.031-mm mesh sieve. The samples were stained with Rose Bengal for more than 24 hours and then washed through 0.5 and 0.031 mm sieves. The meiofauna was extracted using the Ludox centrifugation technique (Heip *et al.*, 1985; Zhang *et al.*, 1989). All meiofauna individuals were sorted into major groups and counted under a stereoscopic microscope.

Nematodes were placed in anhydrous glycerol, mounted on permanent slides (Zhang & Platt, 1983), and identified to genus (or to species wherever possible) using a compound microscope (Olympus BH2-NIC) with differential interference contrast.

Nematode feeding type was measured as a nematode functional aspect. Free-living marine nematodes display high diversity in the structure of their buccal cavity. Wieser (1953) devised a classification of feeding types consisting of four types. Although various authors have later revised and modified this classification (Jensen, 1987; Moens & Vincx, 1997), nevertheless nematode genera in this study were assigned according to Wieser's classification as this is the only scheme available that considers free-living marine nematodes from a variety of habitats (Schratzberger *et al.*, 2007).

Data analyses

In order to assess interrelationships among the meiofauna abundance, expressed as individuals per 10 cm² sediment, and sediment characteristics, Pearson correlation analysis was performed. One-way analysis of variance (ANOVA) was performed to test differences of meiofauna abundance and nematode community diversity among different stations. Levene's test was used to test for homogeneity of variance before differences in univariate indices were explored using ANOVA. Where Levene's test indicated non-homogeneity of variances, data were log-transformed and Levene's test was repeated to confirm that variance was homogeneous following transformation. Following the detection of significant differences ($P \leq 0.05$) among stations, the Tukey HSD multiple comparisons test was used. The above analyses were carried out using SPSS 11.0.

The univariate measures were computed in the PRIMER 5.0 (Plymouth Routines in Multivariate Ecological Research) software package: nematode community biodiversity (Shannon–Wiener diversity index H′), evenness (as Pielou's *J*′), species richness (d), and Simpson dominance index (λ) (Zhang *et al.*, 2000, 2001c).

Principal components analysis (PCA), BIOENV, non-metric multi-dimensional scaling (MDS) analyses were performed using the PRIMER 5.0 software package.

RESULTS

Environmental variables

Various measurements of environmental factors were made, including sediment grain size, salinity, temperature, sediment

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organic matter content, Chl-*a* and Phaeo-*a*. CTD profiles indicated that at the studied sites, temperature decreased from about 22°C at the surface to ~18°C on the bottom. Vertical profiles of salinity indicated a superficial thin layer of low salinity water (23.8‰, affected by Changjiang runoffs), followed by a relatively high salinity (31.7) layer. Most of the sediment studied consisted of poorly sorted silty-clay (TY) and clayey-silt (YT) with a generally high silt–clay fraction (higher than 90%; Table 1).

MDS and PCA ordination of environmental variables showed a clear separation of the studied stations (Figure 2). The first two components shown in Figure 2 accounted for 66.9% of the total variance of the data, being responsible for the differences among the studied stations. Concerning the first component, the coastal stations (Station 0305-0311 and Station 0329) were clearly separated from the other stations. Higher negative values along the first component were related to sediment SK_{Φ} and QD_{Φ}, whilst higher positive scores were due to MD_{Φ}, clay content and Phaeo-*a* concentration (Figure 2). The separation of stations along the second principal component was less pronounced. High positive value along PC2 was related to silt content, while high negative values were related to sand content, water depth (WD) and bottom-water salinity (BWS). The results of PCA ordination suggested that environmental variables of the Changjiang Estuary and its adjacent waters were heterogeneous, mainly because of sediment granulometric variation. A relatively close relationship among sediment granularity and biotic characteristics was apparent (Pearson's $P < 0.05$). This result confirmed that sediment granularity was the major influencing factor of benthic environment in the studied area.

Meiofauna major distribution patterns

A total of 21 meiofauna groups were identified in this study. Meiofauna abundance ranged from 76 ± 44 ind10 cm^{-2} at Station 0311 to 5510 ± 2497 ind10 cm^{-2} at Station 0316. Nematodes dominated the samples at all stations, ranging from 61.3% (Station 11) to 96.8% (Station 16) of total meiofauna (Figure 3).

Results from the one-way ANOVA revealed significant differences between sampling stations in terms of meiofauna abundance (log, $F = 30.117$, $P < 0.001$), nematode abundance (log, $F = 28.041$, $P < 0.001$) and dominance (Kruskal–Wallis ANOVA, $P = 0.008$). Harpacticoid copepods were the next numerically important group at the studied stations, accounting for 4.2% of total meiofauna on average (Table 2). Results from ANOSIM confirmed that meiofauna assemblages at all stations from the studied area were significantly different from each other (Global $R = 0.635$, $P < 0.01$). From applying a multidimensional scaling ordination (MDS) plot of square-root transformed meiofauna abundance, differences between stations can be detected (Figure 4A). Apparently, the meiofauna assemblages of Stations 0310, 0311 and 0329 differed from those of the other stations.

Nematodes community structure

NEMATODES SPECIES COMPOSITION AND BIODIVERSITY

A total of 263 nematode species or morpho-species belonging to 119 genera and 29 families was recorded at the studied stations. Xyalidae (34.8%), Comesomatidae (16.9%), Linhomoeidae (14.8%), Axonolaimidae (6.7%) and Chromadoridae (4.6%) were the most abundant nematode families at all stations, accounting for 77.8% of the total nematode fauna. The most abundant genera were *Daptonema*, *Cobbia*, *Sabatieria*, *Dorylaimopsis* and *Terschellingia*, accounting for 50.0%. The ten most abundant species were *Cobbia* sp. 1, *Dorylaimopsis rabalaisi*, *Daptonema* sp. 3, *Filitonchus* sp. 2, *Parodontophora marina*, *Microlaimus* sp. 2, *Daptonema* sp. 5, *Cobbia* sp. 3, *Axonolaimus* sp. 1 and *Spilophorella* sp. 2, accounting for 52.8%.

MDS of square-root transformed nematodes abundance data showed a similar pattern to that of meiofauna abundance (Figure 4B). The differences between stations can be seen in

Table 1. Environmental variables of the studied stations.

Station	East longitude	North latitude	Depth (m)	BWT (°)	BWS	Chl-*a* (mg/kg) Means ± STD	Phaeo-*a* (mg/kg) Means ± STD	Silt–clay (%) Means ± STD	MD_{Φ} Means ± STD	OM (%)
0305	122.30	31.75	27.25	17.25	31.67	2.08 ± 0.34	2.40 ± 0.16	92.74 ± 3.58	5.86 ± 0.21	4.86
0307	122.48	31.35	22.19	17.18	31.59	0.53 ± 0.03	1.84 ± 0.17	71.22 ± 6.89	6.13 ± 1.77	6.49
0308	122.56	31.15	21.56	17.44	31.09	4.44 ± 1.00	5.54 ± 0.45	98.31 ± 0.93	7.48 ± 0.78	12.56
0309	122.63	31.02	20.06	18.63	29.86	3.77 ± 0.38	4.33 ± 0.19	99.43 ± 0.23	8.22 ± 0.33	12.04
0310	122.20	31.17	12.44	21.13	15.51	1.37 ± 0.19	2.84 ± 1.32	82.11 ± 8.83	6.63 ± 0.81	6.58
0311	121.89	31.21	10.75	21.79	13.12	0.33 ± 0.16	1.04 ± 0.21	94.24 ± 4.99	7.17 ± 0.29	6.04
0316	122.76	31.00	20.81	19.08	30.78	6.26 ± 1.26	10.17 ± 1.59	98.56 ± 1.72	7.65 ± 0.34	8.93
0317	123.00	30.86	31.19	18.91	34.10	1.83 ± 0.16	4.82 ± 0.73	64.35 ± 8.54	5.95 ± 0.76	9.46
0322	122.68	30.78	37.63	18.94	32.08	3.14 ± 0.59	7.10 ± 0.32	99.73 ± 0.06	8.16 ± 0.54	7.46
0323	122.72	30.64	41.31	18.85	32.33	3.02 ± 0.25	9.22 ± 0.56	99.81 ± 0.01	8.25 ± 0.13	6.90
0324	122.75	30.50	42.50	18.75	33.68	1.47 ± 0.05	4.95 ± 0.29	99.58 ± 0.10	8.63 ± 0.16	7.10
0325	122.83	30.25	33.56	19.49	32.42	5.34 ± 0.10	9.44 ± 1.21	99.80 ± 0.06	7.57 ± 1.54	8.39
0326	122.75	30.00	41.81	19.06	33.70	1.84 ± 0.01	7.42 ± 0.42	99.68 ± 0.16	8.49 ± 0.04	9.12
0328	122.58	29.50	40.56	18.47	33.56	1.29 ± 0.01	5.39 ± 0.09	99.19 ± 0.23	8.51 ± 0.14	8.29
0329	122.11	29.30	13.63	21.26	27.25	1.85 ± 0.42	2.74 ± 0.43	99.17 ± 0.25	7.15 ± 0.66	5.37
0330	122.50	29.00	52.19	18.18	24.42	2.01 ± 0.02	9.17 ± 0.08	99.82 ± 0.21	8.99 ± 0.77	9.65
0331	122.27	28.50	52.50	18.50	34.33	2.48 ± 0.50	7.69 ± 0.71	99.80 ± 0.11	8.92 ± 0.08	7.70
0334	122.88	28.37	78.69	18.85	34.44	1.42 ± 0.08	5.70 ± 0.15	82.75 ± 3.44	7.86 ± 0.41	8.76

BWT, bottom-water temperature; BWS, bottom-water salinity; OM, organic matter content.

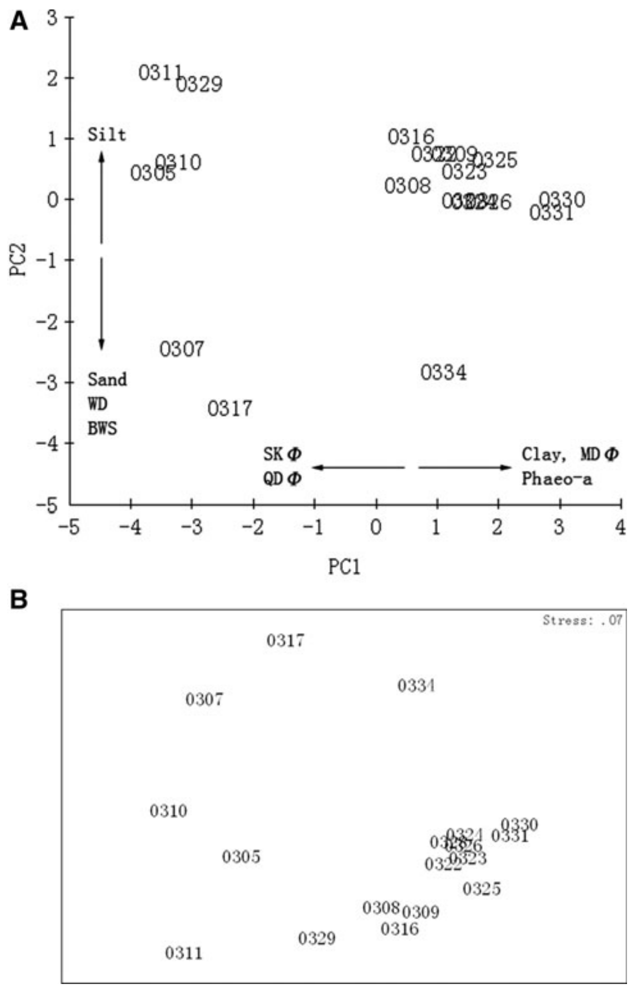

Fig. 2. PCA (A) and MDS (B) ordination on the environmental variables of the different stations.

the MDS plot: most of them showed aggregation except for Stations 0334, 0330 and 0329. In addition, results from the MDS revealed that the nematodes species assemblages of Stations 0310 and 0311 differed significantly from those of the other stations.

Biodiversity indices Shannon H′, species richness d, and evenness index *J*′ were low at stations near the Changjiang Estuary (such as Stations 0310 and 0311) and Simpson dominance index λ was high at these stations. At other stations the indices differed little and showed a similar biodiversity level (Figure 5).

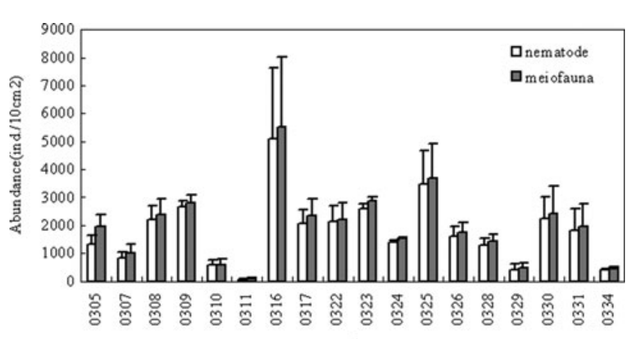

Fig. 3. Meiofauna and nematode abundance at sampling stations (the error bars refer to standard deviations).

FUNCTIONAL ASPECTS OF THE NEMATODE COMMUNITY

The analysis of the trophic structure of the nematode community from the studied area showed a dominance of epigrowth feeder types (2A) constituting 45.3 ± 10.4% of nematode abundance. In particular, 2A dominance was prominent at Station 0311 (73.3% of nematode abundance), and lowest at Station 0310 (27.1% of nematode abundance). Selective feeder types (1A) and non-selective feeder types (1B), taken together, made up 52.5 ± 22.8% of nematode abundance. However, 1B showed complete dominance, comprising 65.9% of nematode abundance at Station 0310. At Station 0334, 1B comprised only 10% of nematode abundance while 1A predominated, comprising 45.0% of nematode abundance. Predators were 2.2 ± 1.3%. The ratio 1B to 2A was different among stations ranging from 0.24 (Station 0334) to 2.43 (Station 0310). There was a weak gradient from stations near the Changjiang Estuary to the more distant stations. Only in the furthest away Stations 0330 and 0334, the ratio was less than 0.5 and much lower than that of other stations. In other stations, the ratio was high and the highest ratio was observed in the coastal Stations 0310, 0317 and 0329 (1B/2A larger than 1). This indicated that organic detritus was abundant in most coastal stations.

Correlation analysis with environmental variables

Correlation analysis of the meiofauna numbers and environmental variables indicated that total meiofauna abundance and nematode abundance had highly significant correlations with bottom-water temperature (Pearson's $r = -0.602$ and -0.571, $P < 0.01$), bottom-water salinity (Pearson's $r = 0.688$ and 0.691, $P < 0.01$), Chl-*a* (Pearson's $r = 0.824$ and 0.839, $P < 0.01$), Phaeo-*a* (Pearson's $r = 0.777$ and 0.806, $P < 0.01$), and organic matter content (Pearson's $r = 0.471$ and 0.499, $P < 0.05$). MDS plots based on meiofauna and nematodes assemblages generally agreed with those of environmental variables. BIOENV was used to determine the subsets of environmental variables, which provide the closest matches with the meiofauna community structure. The results showed that no single variable was highly correlated with the variation in meiofauna or nematode community structure (Table 3).

Variation in the meiofauna community structure across stations was most highly correlated with five variables (Spearman's $\rho = 0.692$), namely water depth, BWT, BWS, Phaeo-*a* and QD_{Φ}. Among these, water depth and BWS were included in all the ten best combinations of environmental variables. Sediment variables and Phaeo-*a* were included in most combinations.

The data treatment indicates that nematode community structure variation (Spearman's $\rho = 0.832$) is influenced by five variables: water depth, BWT, BWS, Phaeo-*a* and silt–clay content. Among these, water depth, BWS and silt–clay content were included in all the ten best combinations. Nematode trophic structure was influenced by water depth, bottom-water salinity, Chl-*a* and Phaeo-*a* (Spearman's $\rho = 0.72$). The correlation analysis of

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Table 2. Mean abundance and relative abundance (%) of meiofauna groups.

	Abundance (ind/10 cm²)	RA%			Abundance (ind/10 cm²)	RA%	
	Means ± STD	Max	Min		Means ± STD	Max	Min
Nematoda	1784.98 ± 493.68	96.82	61.36	Gastropoda	0.62 ± 0.87	0.60	0.00
Copepoda	83.09 ± 35.02	25.35	1.34	Gastrotricha	0.11 ± 0.1	0.10	0.00
Polychaeta	28.4 ± 10.65	5.55	0.00	Halacaroidea	0.15 ± 0.25	0.04	0.00
Kinorhyncha	33.09 ± 19.16	6.86	0.00	Oligochaeta	1.25 ± 1.07	0.74	0.00
Bivalvia	2.59 ± 1.99	2.00	0.00	Holothuroidea	0.59 ± 0.56	0.18	0.00
Ostracoda	0.39 ± 0.61	0.15	0.00	Actiniaria	0.08 ± 0.15	0.02	0.00
Amphipoda	0.17 ± 0.23	0.67	0.00	Rotifera	0.11 ± 0.19	0.04	0.00
Tanaidacea	0.06 ± 0.10	0.23	0.00	Nemertina	0.31 ± 0.42	0.15	0.00
Isopoda	0.08 ± 0.15	0.34	0.00	Tardigrada	0.03 ± 0.05	0.03	0.00
Cumacea	0.20 ± 0.13	0.21	0.00	Others	33.96 ± 18.21	12.03	0.05
Turbellaria	0.28 ± 0.28	0.67	0.00	Total	1970.56 ± 583.85	100.00	100.00

Max, maximum; Min, minimum.

nematode trophic structure with environmental variables showed that all the nematode feeder types abundances were positively correlated with BWS, Chl-*a*, and Phaeo-*a* (all $P < 0.01$). In addition, types 1A and 2A were negatively correlated with BWT (Pearson's $r = -0.677$ and -0.547, $P < 0.05$). Types 2A and 2B were correlated positively with organic matter content (Pearson's $r = 0.47$ and 0.537, $P < 0.01$) and negatively with QD_{Φ} (Pearson's $r = -0.588$ and 0.48, $P < 0.01$).

DISCUSSION

Benthic environment

The studied area is located in the inshore area of the continental shelf. The dominant sediment types of the sampling stations are silty-clay (TY) and clayey-silt (YT) and the attenuated currents allow fine sand and mud to be deposited (Giere, 1993). In addition, the studied area receives deposits

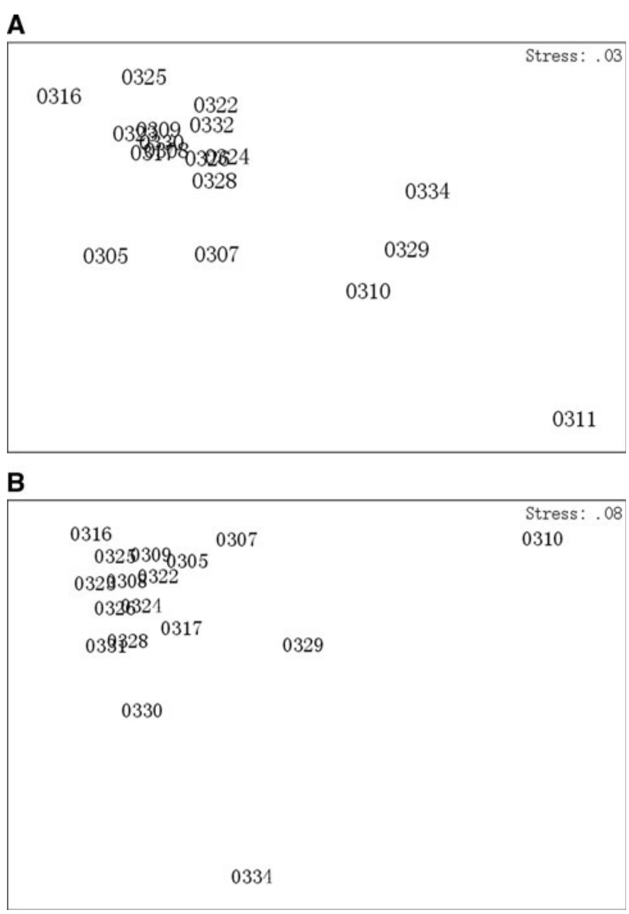

Fig. 4. MDS ordination on square-root transformed absolute abundance data of meiofauna taxa (A) and nematodes (B).

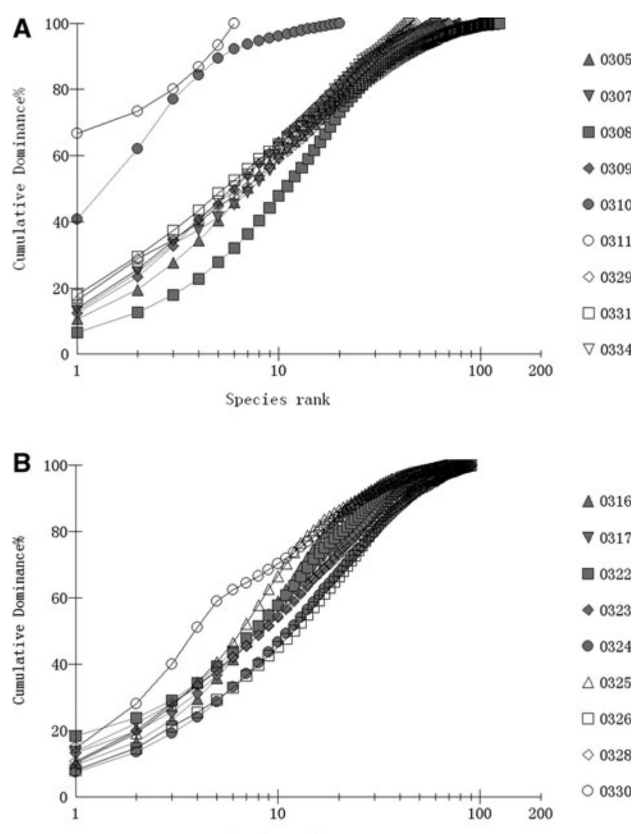

Fig. 5. K-dominance curves of nematode species at the different stations of this study.

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Table 3. Summary of BIOENV results. Environmental variables (√) contributing to subsets providing the ten 'best' matches (ρ = Spearman's rank correlation) with nematode and meiofauna abundances across sites.

ρ	Depth	BWT	BWS	Chl-*a*	Phaeo-*a*	Silt–clay	MD_{Φ}	QD_{Φ}	SK_{Φ}	OM
Major taxa										
0.692	√	√	√		√			√		
0.688	√	√	√		√					
0.685	√	√	√		√		√			
0.684	√	√	√					√		
0.682	√	√	√				√	√		
0.680	√		√		√					
0.677	√		√		√		√	√		
0.677	√	√	√					√		√
0.677	√		√		√			√		
0.675	√	√	√							
Nematode										
0.832	√	√	√		√	√				
0.828	√	√	√	√		√				
0.827	√		√		√	√				
0.826	√		√	√	√	√				
0.823	√		√	√		√				
0.821	√		√	√		√		√		
0.819	√		√		√	√		√		
0.814	√		√	√				√		
0.813	√	√	√			√				
0.813	√		√	√		√	√			

BWT, bottom-water temperature; BWS, bottom-water salinity; OM, organic matter content.

from Changjiang runoffs. This area received run-offs from the Changjiang River, which transports mud and sand from the land. The gradual sedimentation of the discharges may result in the actual sediment composition in the studied area. Due to anthropogenic activities (estuarine training engineering, aquaculture, sewage discharge and pollution, etc.), sediment chloroplastic pigments and organic matter accumulated in the benthic environment. Sediment chloroplastic pigments and organic matter content were higher than those of the Bohai Sea (Guo *et al.*, 2002) and the southern Yellow Sea (Liu *et al.*, 2007). In the studied area, the proportion of carbon originating from the terrestrial environment was high (Liu *et al.*, 2005b). This is the main reason why the studied area had higher organic matter content than other adjacent seas of China. A relatively close relationship among sediment granularity and sediment biotic factors confirmed that the environmental variables of the studied area were heterogeneous, mainly because of sediment grain size variation.

Relationship between nematode assemblages and their habitat

The densities of total meiofauna and the important meiofauna groups reported here are broadly in line with those reported in marine sediments from a variety of studied locations (Zhang *et al.*, 1989, 2004; Mu *et al.*, 2001; Liu *et al.*, 2005a). The predominant nematode genera *Daptonema*, *Cobbia*, *Sabatieria*, *Dorylaimopsis* and *Terschellingia* are also dominant in the sublittoral of other areas, albeit in different proportions (Somerfield *et al.*, 2003; Huang *et al.*, 2006). In addition, the genera found in the Changjiang Estuary and its adjacent waters are also found in other sediments world-wide (Lambshead *et al.*, 2003; Schratzberger *et al.*, 2004). In the light of these facts there is no evidence that the nematode communities in the Changjiang adjacent waters are very different to those already studied in the other sublittoral areas of the world, and therefore they should be expected to respond to changes in environmental conditions in similar ways.

In general, the studied nematode communities exhibited high nematode abundance and high species diversity. According to the location and habitat heterogeneity, nematode assemblages showed differences reflecting a weak influence of the Changjiang runoff, which was considered to have a potential impact on benthos. Apart from differences that might have resulted from stochastic causes, environmental variation may explain, to a certain extent, the observed similarities or differences in composition among the studied sites. Different combinations of environmental variables can be considered as responsible for the meiofauna and nematode communities' structures (Coull, 1999). In the present study, the main factors governing the meiofauna (with emphasis on nematodes) community assemblage, diversity and functional aspect were: water depth, salinity, Chl-*a*, Phaeo-*a*, and silt–clay content, as reported in other studies (Vincx *et al.*, 1990; Danovaro & Gambi, 2002). The present study also showed that water depth, salinity, Chl-*a* and Phaeo-*a* were mostly responsible for nematode assemblages' discriminations in the studied area, as they control or affect nematode communities to different extents.

The presence of Chl-*a* and Phaeo-*a* is essential for nematode density and distribution. Sand, nutrients and pollutants brought by Changjiang runoff settled in the studied area. The silty-clay sediment texture indicates a low energy and reduced sedimentation rate with large amounts of fine particles where land-source organic matter and detritus settle. The ratio of non-selective deposit feeders and epigrowth feeders (1B/2A) was used to indicate the alteration of nematode trophic characteristics and the amount of organic detritus in the substrate (Lambshead, 1986). In the present study, the 1B/2A ratio value of nematodes decreased from the stations near the coast to more distant stations. The low value along the gradient indicates that organic detritus is abundant in most coastal stations. In addition, the significant coastal upwelling increased the density, production and biodiversity of phytoplankton resulting in the phytodetritus sinking to the bottom (González *et al.*, 2007; Montero *et al.*, 2007). These rich food sources, represented by high values of Chl-*a* and Phaeo-*a*, may support an abundant meiofauna community as has been reported by Levin *et al.* (1991), Zhang *et al.* (2004) and Liu *et al.* (2005a). The highest meiofauna standing stocks have generally been observed in areas with high phytodetritus deposition, such as upwelling regions (West Africa) and frontal areas (Pfannkuche, 1985). Deposit feeders become abundant with the increase of available food resources in the sediment. At most stations, considerable quantities of microplankton settle, benefiting from coastal upwelling and fresh water intrusion. Epigrowth feeders also increase with the presence of benthic or recently settled diatoms, as is the case in the studied area which is dominated by epigrowth feeders, indicative of increased food supply.

The salinity effect becomes noticeable at Stations 0310 and 0311 where nematode assemblages are very different from each other as well as different from the other stations. *Metalinhomoeus* sp. 1 was dominatant at Station 0311 and *Daptonema* sp. 1 at Station 0310. These two nematode assemblages exhibit low abundance, few species and low biodiversity. These two stations are the sites closest to the Changjiang Estuary where the low salinity (13.1–15.5‰) becomes one of the distinguishing features differentiating nematode assemblages from others ($P < 0.01$). Warwick *et al.* (1991) stated that the most important environmental variables controlling or affecting the distribution and abundance of benthic animals in estuaries are salinity and several interrelated sediment variables (grain size and organic content), which in turn are determined by the hydrodynamic features of the estuary. The present results are very much in line with the findings of this study and of Yu *et al.* (2004), in which he shows that tides, currents, runoff and fresh water invasion are the main hydrodynamic features in the studied area. Suspended sand is brought by the Changjiang runoff and resuspended sediment from the low transparency turbid zone just beyond the estuary is carried in by tidal action. The turbid water impedes the assimilation and absorption of surplus nutrient brought by the Changjiang runoff, and is responsible for the markedly lower abundance of organisms in the estuary in comparison with other water bodies (Zhang *et al.*, 1989; Wang *et al.*, 2004). The high turbidity and low salinity not only decrease meiofauna biodiversity (positive correlation with BWS, $P < 0.01$), but also affect the trophic structure of nematode communities. Deposit feeders (1A,B) are more abundant than epigrowth feeders (2A) that feed on benthic or recently settled diatoms. Epigrowth feeders seemed more sensitive to low BWS (Pearson's $r = 0.661$, $P < 0.01$). However, 2A dominance was prominent at the lowest salinity Station 0311. This however may be a sporadic occurrence, since the nematode abundance is very low.

Water depth was potentially important in influencing benthic assemblage structure, most likely because it determines other factors such as the amount and quality of phytoplankton-derived carbon reaching the sea-floor (Schratzberger *et al.*, 2004). With the increase in water depth, nematode abundance and biodiversity at Stations 0330, 0331 and 0334 decrease. As stated by Coull (1999), Soltwedel (2000) and many others, meiofauna abundance and density decrease with increasing water depth. Although the water depth variations within the studied stations are not significant, nevertheless meiofauna abundance decreased with increasing water depth while differences in meiofauna community structure related to water depth were also evident.

In the present study, the assemblages of both major taxa and nematodes species provide evidence that water depth, salinity, Chl-*a*, Phaeo-*a*, and silt–clay content are important determinants of community structure. However, Changjiang runoff, tides, currents, Zhejiang coastal upwelling etc are essential abiotic environments for the area studied. Together they interacted, to determine the conditions which shaped the meiofauna community structure in the Changjiang Estuary and its adjacent waters.

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REFERENCES

Coull B.C. (1999) Role of meiofauna in estuarine soft-bottom habitats. *Australian Journal of Ecology* 24, 327–343.

Danovaro R. and Gambi C. (2002) Biodiversity and trophic structure of nematode assemblages in seagrass systems: evidence for a coupling with changes in food availability. *Marine Biology* 141, 667–677.

Elmgren R. (1989) Man's impact on the ecosystem of the Baltic Sea: flows today and at the turn of the century. *Ambio* 18, 322–326.

Giere O. (1993) *Meiobenthology. The microscopic fauna in aquatic sediments*. Berlin, Heidelberg: Springer.

González H.E., Menschel E., Aparicio C. and Barría C. (2007) Spatial and temporal variability of microplankton and detritus, and their export to the shelf sediments in the upwelling area off Concepción, Chile (~36°S), during 2002–2005. *Progress in Oceanography* 75, 435–451.

Guo Y.Q., Zhang Z.N. and Mu F.H. (2002) Large-scale patterns of meiofaunal abundance in the Bohai Sea. *Acta Ecologica Sinica* 22, 1463–1469. [In Chinese with English abstract.]

Heip C., Huys R. and Alkemade R. (1992) Community structure and functional roles of meiofauna in the North Sea. *Netherlands Journal of Aquatic Ecology* 26, 31–41.

Heip C., Vincx M. and Vranken G. (1985) The ecology of marine nematodes. *Oceanography and Marine Biology: an Annual Review* 23, 399–489.

Higgins R.P. and Thiel H. (eds) (1988) *Introduction to the study of meiofauna*. Washington, DC: Smithsonian Institution Press.

Hua E., Zhang Z.N. and Zhang Y. (2006) Meiofauna distributions at the oxygen minimum zone in Changjiang (Yangtze) River Estuary waters. *Acta Oceanologica Sinica* 25, 120–134.

Huang Y., Zhang Z.N., Liu X.S. and Zhang Y. (2006) Studies on the species composition and biodiversity of free-living marine nematodes in the southern Huanghai Sea. *Acta Oceanologica Sinica* 25, 87–98.

Jensen P. (1987) Feeding ecology of free-living marine nematodes. *Marine Ecology Progress Series* 35, 187–196.

Lambshead P.J.D. (1986) Sub-catastrophic sewage and industrial waste contamination as revealed by marine nematode faunal analysis. *Marine Ecology Progress Series* 29, 247–260.

Lambshead P.J.D., Brown C.J., Ferrero T.J., Hawkins L.E., Smith C.R. and Mitchell N.J. (2003) Biodiversity of nematode assemblages from the region of the Clarion–Clipperton Fracture Zone, an area of commercial mining interest. *BMC Ecology* 3, 1–12.

Levin L.A., Huggett C.L. and Wishner K.F. (1991) Control of deep-sea benthic community structure by oxygen and organic-matter gradient in the eastern Pacific Ocean. *Journal of Marine Research* 49, 763–800.

Lin K.X., Zhang Z.N. and Wang R.Z. (2004) Research on biomass size spectra of macro- and meiofauna at typical stations in the East China Sea and Yellow Sea. *Acta Ecologica Sinica* 24, 241–245. [In Chinese with English abstract.]

Liu H., Wu Y.P., Gao S.D. and Zhang Z.N. (1998) The variations of chlorophyll-*a* and phaeophytin in the sediment of Jimo shrimp pond before the outbreak of shrimp disease. *Transactions of Oceanology and Limnology* 1, 65–69. [In Chinese with English abstract.]

Liu X.S., Zhang Z.N. and Huang Y. (2005a) Abundance and biomass of meiobenthos in the spawning ground of anchovy (*Engraulis japonicus*) in the southern Huanghai Sea. *Acta Oceanologica Sinica* 24, 94–104.

Liu X.X., Zhai S.K. and Niu L.F. (2005b) Study on the c/n ratios of organic matters in the core sediments of the Yangtze river estuary. *Environmental Chemistry* 24, 255–259. [In Chinese.]

Liu X.S., Zhang Z.N. and Huang Y. (2007) Sublittoral meiofauna with particular reference to nematodes in the southern Yellow Sea, China. *Estuarine, Coastal and Shelf Science* 71, 616–628.

Lorenzen C.J. and Jeffrey S.W. (1980) Determination of chlorophyll in seawater. *Unesco Technical Papers in Marine Science* 35, 1–20.

Moens T. and Vincx M. (1997) Observations on the feeding ecology of estuarine nematodes. *Journal of the Marine Biological Association of the United Kingdom* 77, 211–227.

Montero P., Daneri G., Cuevas L.A., González H.E., Jacob B., Lizárraga L. and Menschel E. (2007) Productivity cycles in the coastal upwelling area off Concepción: the importance of diatoms and bacterioplankton in the organic carbon flux. *Progress in Oceanography* 75, 518–530.

Mu F.H., Zhang Z.N. and Guo Y.Q. (2001) Abundance and biomass of the benthic meiofauna in the Bohai Sea. *Journal of the Ocean University of Qingdao* 30, 897–905. [In Chinese with English abstract.]

Pfannkuche O. (1985) The deep-sea meiofauna of the Porcupine seabight and abyssal plain (NE Atlantic): population structure, distribution, standing stocks. *Oceanologica Acta* 8, 343–353.

Schratzberger M., Warr K. and Rogers S.I. (2007) Functional diversity of nematode communities in the southwestern North Sea. *Marine Environmental Research* 63, 368–389.

Schratzberger M., Whomersley P., Kilbride R. and Rees H.L. (2004) Structure and taxonomic composition of subtidal nematode and macrofauna assemblages at four stations around the UK coast. *Journal of the Marine Biological Association of the United Kingdom* 84, 315–322.

Soltwedel T. (2000) Metazoan meiobenthos along continental margins: a review. *Progress in Oceanography* 46, 59–84.

Somerfield P.J., Fonsêca-Genevois V.G., Rodrigues A.C.L., Castro F.J.V. and Santos G.A.P. (2003) Factors affecting meiofaunal community structure in Pina Basin, an urbanized embayment on the coast of Pernambuco, Brazil. *Journal of the Marine Biological Association of the United Kingdom* 83, 1209–1213.

Vincx M., Meire P. and Heip C. (1990) The distribution of nematodes communities in the Southern Bight of the North Sea. *Cahiers de Biologie Marine* 31, 107–129.

Wang J.H., Huang X.Q., Liu A.C. and Zhang Y.F. (2004) Tendency of the biodiversity variation nearby Changjiang Estuary. *Marine Science Bulletin* 23, 32–39. [In Chinese with English abstract.]

Warwick R.M., Goss-Custard J.D., Kirby R., George C.L., Pope N.D. and Rowden A.A. (1991) Static and dynamic environmental factors determining the community structure of estuarine macrobenthos in SW Britain: why is the Severn estuary different? *Journal of Applied Ecology* 28, 329–345.

Wieser W. (1953) Die Beziehung zwischen Mundhöhlengestalt, Ernährungsweise und Vorkommen bei freilebenden marinen Nematoden. Eine skologisen-morphologische studie. *Arkiv für Zoologie* 4, 439–484.

Yu D.S., Tian C. and Yan Y.X. (2004) An analysis of current characteristics at the Yangtze River Estuary. *Port and Waterway Engineering* 360, 49–53.

Zhang Z.N., Zhou H., Guo Y.Q., Mu F.H., Yu Z.S., Han J. and Zhou Y. (2000) A comparative study on nematode biodiversity in the Bohai Sea. *Chinese Science Abstracts* 6, 93–95. [In Chinese with English abstract.]

Zhang Z.N. and Platt H.M. (1983) New species of marine nematodes from Qingdao, China. *Bulletin of the British Museum of Natural History (Zoology)* 45, 253–261.

Zhang Z.N., Gu F. and Yu Z.S. (1990) A study on spatial pattern of marine nematodes in the subaqueous delta of the Huanghe River. *Oceanologia et Limnologia Sinica* 20, 11–18. [In Chinese with English abstract.]

Zhang Z.N., Li Y.G., Tu L.H. and Yu Z.S. (1989) A preliminary study of meiobenthos in the submarine delta of Huanghe River estuary and its adjacent waters. *Oceanologia et Limnologia Sinica* 20, 197–207. [In Chinese with English abstract.]

Zhang Z.N., Lin K.X., Zhou H., Han J., Wang R.Z. and Tian S.Y. (2004) Abundance and biomass of meiobenthos in autumn and spring in the East China Sea. *Acta Ecologica Sinica* 24, 997–1005. [In Chinese with English abstract.]

Zhang Z.N., Zhou H., Guo Y.Q. and Mu F.H. (2001a) Comparative study of the nematode community structure in the submarine delta of Huanghe River estuary and its adjacent waters. *Oceanologia et Limnologia Sinica* 32, 436–444. [in Chinese with English abstract.]

Zhang Z.N., Zhou H., Yu Z.S. and Han J. (2001b) Abundance and biomass of the benthic meiofauna in the northern soft-bottom of the Jiaozhou Bay. *Oceanologia et Limnologia Sinica* 32, 139–147. [In Chinese with English abstract.]

Zhang Z.N., Zhou H. and Mu F.H. (2001c) Biodiversity and neutral model analyses on nematode community in Bohai Sea, China. *Acta Ecologica Sinica* 21, 1808–1814. [In Chinese with English abstract.]

Zhou H., Zhang Z.N., Liu X.S., Tu L.H. and Yu Z.S. (2007) Changes in the shelf macrobenthic community over large temporal and spatial scales in the Bohai Sea, China. *Journal of Marine Systems* 67, 312–321.

and

Zhou W.H., Yuan X.C., Hou W.Y. and Yin K.D. (2004) Distribution of chlorophyll *a* and primary productivity in the adjacent sea area of Changjiang River Estuary. *Acta Oceanologica Sinica* 26, 143–150.

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