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Distribution pattern of meiofauna assemblages along an environment gradient on the coast of the Yellow and Bohai Seas☆

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ABSTRACT

This study investigated the influence of both natural and anthropogenic factors on meiofauna assemblages along the coasts of the Yellow Sea (YS) and Bohai Sea (BS). Over 300 abiotic and biotic samples were collected from 101 sites, categorized by land use (agricultural, industrial, municipal, no use), region (southern, central, northern China, and Korea), and habitat (fresh, brackish, saline). Meiofauna densities and assemblage structures varied significantly across all regions, habitats, and land-use types, while diversity differed mainly by region. A distance-based linear model identified key environmental drivers—grain size, heavy metals, total nitrogen, pH, δ15N, salinity, and dissolved oxygen—that collectively explained approximately 26 % of the variation in meiofauna distribution. These findings enhance understanding of how environmental gradients and human impacts shape benthic ecosystems. The study provides essential ecological information for assessing sediment quality and informs strategies for mitigating marine pollution in the YS and BS regions.

1. Introduction

The Yellow Sea (YS) and Bohai Sea (BS) are marginal seas in the Western Pacific Ocean that are semi-enclosed by China and Korea. The coastlines of the YS and BS are approximately 960 km long and bordered by massive industrial and municipal development (Khim et al., 2018). The YS and BS coasts are part of the Yellow Sea Large Marine Ecosystem (YSLME), which comprises 66 large marine ecosystems (LMEs) worldwide. Among the 66 LMEs, the YSLME is affected by the strongest anthropogenic pressure, including industrial activities that produce persistent toxic substances (PTSs) pollution (Yoon et al., 2020; Kim et al., 2024). As a result of human activities, many studies have revealed that various anthropogenic pollutants, including heavy metals and PTSs, accumulate in sediments along the YS and BS coasts (Hong et al., 2012; Yoon et al., 2020). The majority of previous studies, however, have either only focused on the distribution of pollutants (Yoon et al., 2020) or reported some PTSs (Hong et al., 2012; Meng et al., 2017) on the coast of YS and BS, whereas only a few studies have addressed ecological responses related to chemical pollutants on the coast of YS and BS (Khim et al., 2018). According to previous research, integrated assessment considering multiple benthic quality elements were useful tools to evaluate overall quality of sediment and were also consistent with chemical-, species-, or site-dependent pollution of sediments in the Bohai and Yellow Seas (Khim et al., 2018).

Benthic organisms are locally situated and can thus be affected by localized pollution, such as heavy metals and PTSs (Engle et al., 1994; Khim et al., 2018; Ryu et al., 2011; Warwick et al., 1990). Therefore, the variability of benthic communities could be a useful tool for assessing the sediment quality in coastal marine ecosystems (Khim et al., 2018; Ryu et al., 2011; Warwick et al., 1990). Therefore, multiple local-scale studies have confirmed the relationship between abiotic variables, including pollutants, and different types of assemblages in the YS and BS (Choi et al., 2010; Li et al., 2022; Ni et al., 2019; Xu et al., 2021). Regional-scale studies, however, are less common, particularly

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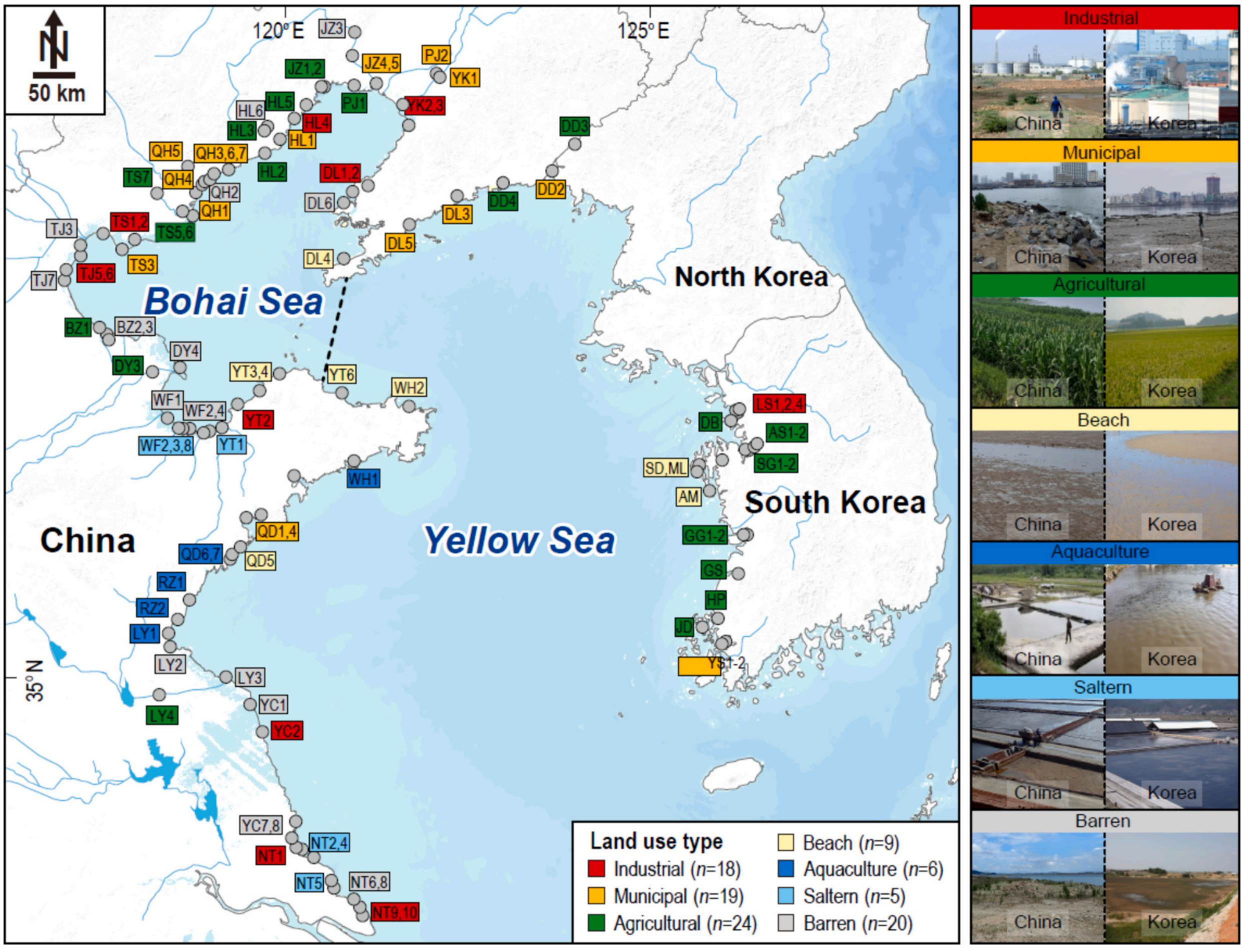

Fig. 1. Map showing the sampling areas along the coast of Yellow and Bohai Seas. The images on the right depict typical land-use types in South Korea and China; the land-use types are based on surrounding dominant activities. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

meiofauna assemblages in the YS and BS (Khim et al., 2018; Liu et al., 2018).

Meiofauna are also useful indicators for determining sediment quality and the biological impact of anthropogenic activities due to their high abundance, ubiquitous distribution, and high diversity across intertidal to subtidal regions (Higgins and Thiel, 1988; Schmidt-Rhaesa, 2020). Many studies have revealed that the variability of meiofauna assemblages has been linked to natural and anthropogenic factors, such as sediment grain size (Alves et al., 2013; Kim et al., 2020; Semprucci et al., 2010), depth (Armenteros et al., 2009), salinity (Shimanaga et al., 2015), bottom water temperature (Gao and Liu, 2018), heavy metals (Somerfield et al., 1994), and PTSs (Moreno et al., 2008). However, few studies have been conducted on the coasts of the YS and BS to investigate the natural and anthropogenic impacts on benthic communities (Khim et al., 2018). The response of meiofauna communities can be complex in time and space due to the different sets of natural (or altered) environmental factors (Kim et al., 2020) and the variation of meiofaunal communities offers valuable insights into the influence of land use, geographical setting, and habitat type on sediment contamination (Khim et al., 2018). Moreover, the wide distribution of meiofauna communities in relation to the local-regional environment along the coasts of the YS and BS has never been reported.

In this study, we focused on the relationship between a combination of natural and anthropogenic drivers and the distribution of meiofauna assemblages on the coasts of the YS and BS. We hypothesized that (1) site-specific environmental factors, including grain size and surface seawater temperature, may play a dominant role in shaping the variability of meiofaunal assemblages, and (2) while natural environmental conditions influence these assemblages, their spatial distribution patterns may also reflect sediment contamination associated with land use. Furthermore, the findings of this study are expected to serve as a reference point for future assessments of benthic environmental quality.

2. Materials and methods

2.1. Sampling design and laboratory analyses

The BS and YS are located in the Western Pacific Ocean and encompass many development areas. Several megapolitan cities with large-scale ports are situated along the coastlines of South Korea (Seoul, Incheon, Asan, Gunsan, and Mokpo) and China (Beijing, Tianjin, Dalian, Huludao, Qinhuangdao, Weifang, Yantai, Qingdao, and Nantong). >300 million people currently live along the coastlines of both seas, and population growth has consistently increased (National Bureau of Statistics, 2018; KOSIS, 2018). Because of high population activities, a large number of organic contaminants are transported to coastal waters (Jeon et al., 2017; Wang et al., 2015; Yoon et al., 2020).

A total of 101 sites along the coast of both seas were selected to identify the spatial patterns of meiofauna assemblages in relation to organic contaminants (Fig. 1). We conducted a comprehensive field survey by collecting freshwater and marine sediments from major rivers, estuaries, and selected intertidal zones along the entire coasts of the Yellow Sea (YS) and Bohai Sea (BS) to examine the distribution patterns of meiofaunal assemblages. Table S1 shows the specific locations and geographical information of each site. The sampling design of the present study considered the type of habitat (freshwater, brackish water, and saline water), region (North, Central, South coast of China, and West coast of Korea), and land use (industrial, municipal, agricultural, aquaculture, saltern, barren, and beach) to identify variables that determine the spatial variation of meiofauna assemblages. In brief, 32 fresh sites, 39 brackish sites, 30 saline sites, 38 North China sites, 29 Central China sites, 16 South China sites, 18 West Korean sites for regions, 24 agricultural sites, 18 industrial sites, 19 municipal sites, five saltern sites, six aquaculture sites, nine beach sites, and 20 barren sites for types of land use were collected along the coast of both seas. The types of land use were categorized based on the dominant surrounding activities at the time of sampling and were based on previous studies that provided information on land-use types at the same locations (Hong et al., 2012; Yoon et al., 2020). At each site, surface sediment samples were collected for both abiotic and biotic analyses using stainless steel devices (from the top 2 cm) from June to July 2018 in both China and South Korea. The samples were then gently brought to the laboratory on dry ice for further analyses. All samples were subsequently frozen to preserve them for further processing in the laboratory and were analyzed within 30 days.

In terms of environmental variables, we analyzed 24 environmental variables with reference to data from previous studies at the same locations (Yoon et al., 2020). Bottom seawater quality parameters were measured in situ before sediment core sampling using a multiprobe (YSI 556 MPS). Other environmental variables, such as median grain size and nutrients, were analyzed using methods described elsewhere (Yoon et al., 2020). In terms of meiofauna samples, the pooled meiofauna samples were fixed with 5 % formaldehyde solution and separated from sediment by decantation (Heip et al., 1985) and centrifugation method (Burgess, 2001) using a colloidal silica solution (LudoxHS-40, Aldrich Chemical Company). This procedure was repeated more than three times to ensure that all organisms were removed from the sediment. All meiofauna individuals were identified at the highest taxonomic level following Higgins and Thiel (1988) and counted under a stereo microscope (Leica M205c).

2.2. Statistical analysis

Uni-and multivariate data analysis was performed using Primer 6.0.2 (Clarke and Gorley, 2006) with permutational analysis of variance (PERMANOVA) (Anderson et al., 2008). The data for the abundance of each meiofauna assemblage were square root transformed. The means of the transformed abundance for each site were used to construct a Bray-Curtis similarity matrix, which was then subjected to group-averaged hierarchical cluster analysis and non-metric multidimensional scaling (nMDS) ordination. Three-way PERMANOVA tests were used to determine the factor (habitat, region, and land use) differences in density, diversity, and taxon composition of meiofauna along the coast of both seas. Estimates of components of variation were calculated using a PERMANOVA test to identify the variability in meiofauna composition among sites. The test of homogeneity of dispersion (PERMDISP) was used to test the PERMANOVA assumption on the homogeneity of multivariate dispersion and to identify the nature of the effect of the factor of interest. When PERMANOVA detected significant differences among the groups, similarity percentages (SIMPER) were used to determine the species that typified those groups and the species that distinguished each group from other groups.

The distance-based linear model (DistLM) routine (Anderson et al., 2008; Anderson, 2001; McArdle and Anderson, 2001) was used to explore the relationship between meiofauna assemblage composition and environmental variables to address the factors determining benthic meiofauna assemblage patterns. The correlation between the environmental variables was checked using a Draftsman plot to avoid collinearity. All variables with >0.7 correlation were excluded from the final analysis. A forward stepwise selection procedure was applied to select

Table 1
Data statistics of the meiofauna community structure observed along the coast of Yellow and Bohai Seas (2018). Minimum, maximum, and mean values of benthic community structure indices provided.

	All			Region Mean (± SD)				Habitat Mean (± SD)			Land use Mean (± SD)						
	Min	Max	Mean (± SD)	1	2	3	4	Fresh	Brackish	Saline	Agricul.	Indust.	Munici.	Saltern	Aquacul.	Beach	Barren
Number of taxa	1	7	3.3 (± 1.6)	2.7 (± 1.5)	3.5 (± 1.8)	4.1 (± 1.5)	3.6 (± 1.5)	2.8 (± 1.4)	3.6 (± 1.6)	3.5 (± 1.8)	2.9 (± 1.4)	3.6 (± 1.5)	3.1 (± 1.6)	4.0 (± 1.6)	4.5 (± 2.1)	3.0 (± 1.9)	3.5 (± 1.7)
Density (ind. m^{-2})	2	2620	262.5 (± 402.3)	152.7 (± 143.8)	135.8 (± 161.4)	813.9 (± 728.2)	208.3 (±228.7)	147.2 (± 218.3)	244.1 (± 329.4)	409.5 (± 572.2)	155.1 (± 111.1)	439.2 (± 628.1)	187.0 (± 256.4)	190.0 (± 337.2)	361.7 (± 188.5)	51.4 (± 47.4)	387.6 (± 543.4)
Dominant taxa[a]																	
1st	Ne			Ne	Ne	Ne	Ne	Ne	Ne	Ne	Ne	Ne	Ne	Ne	Ne	Ne	Ne
2nd	Co			Co	Co	Co	Co	Co	Co	Co	Co	Co	Co	Ost	Co	Co	Co
3rd	Iso			Iso	Ost	Nau	Ost	Iso	Ost	Iso	Ost	Po	Iso	Co	Bi	Nau	Nau
Ecological indices																	
Diversity (H)	0.0	1.2	0.4 (± 0.3)	0.3 (± 0.4)	0.4 (± 0.3)	0.2 (± 0.2)	0.5 (± 0.3)	0.3 (± 0.3)	0.4 (± 0.3)	0.3 (± 0.3)	0.3 (± 0.3)	0.4 (± 0.3)	0.3 (± 0.3)	0.5 (± 0.4)	0.3 (± 0.3)	0.5 (± 0.4)	0.3 (± 0.3)
Evenness (J)	0.0	1.0	0.3 (± 0.3)	0.3 (± 0.3)	0.4 (± 0.3)	0.1 (± 0.1)	0.4 (± 0.2)	0.4 (± 0.3)	0.4 (± 0.2)	0.3 (± 0.2)	0.3 (± 0.2)	0.3 (± 0.3)	0.3 (± 0.2)	0.5 (± 0.3)	0.2 (± 0.2)	0.5 (± 0.1)	0.4 (± 0.3)
Richness (R)	0.0	1.8	0.5 (± 0.3)	0.4 (± 0.3)	0.7 (± 0.4)	0.5 (± 0.2)	0.5 (± 0.3)	0.4 (± 0.3)	0.6 (± 0.4)	0.4 (± 0.3)	0.4 (± 0.3)	0.5 (± 0.3)	0.4 (± 0.3)	0.9 (± 0.4)	0.6 (± 0.4)	0.5 (± 0.4)	0.6 (± 0.4)
Dominance (D)	0.7	1	1.0 (± 0.1)	1.0 (± 0.1)	1.0 (± 0.1)	1.0 (± 0.0)	1.0 (± 0.0)	1.0 (± 0.0)	1.0 (± 0.1)	1.0 (± 0.0)	1.0 (± 0.0)	1.0 (± 0.0)	1.0 (± 0.1)	0.9 (± 0.1)	1.0 (± 0.0)	1.0 (± 0.0)	1.0 (± 0.1)

[a] Ne: Nematoda; Co: Copepod; Iso: Isopoda; Ost: Ostracoda; Nau: Naurplius; Po: Polychaeta; Bi: Bivalvia.

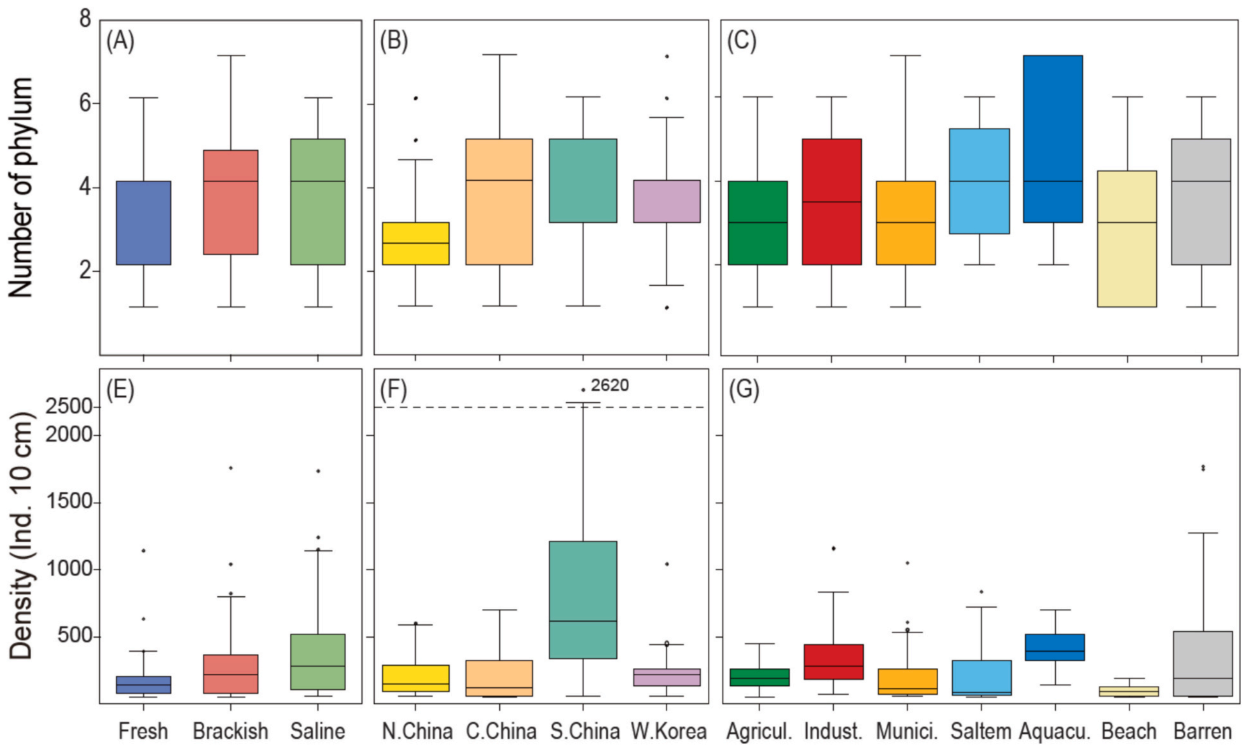

Fig. 2. Box plot of density and number of phylum of meiofauna assemblages relative to three habitat (fresh, brackish, and saline), four regional (North, Central, South China, and West Korea), and seven land-use types (industrial, municipal, agriculture, beach, saltern, barren and aquaculture).

significant explanatory variables for the multivariate regression, with the best model selected based on the Akaike information criterion (AIC) method to choose the most parsimonious model (Chambers and Hastie, 2017; Schwarz, 1978). Distance-based redundancy analysis (dbRDA) was used to visualize the results of DistLM. The dbRDA routine was used to perform constrained ordination of the meiofauna assemblages using the DistLM model.

3. Results

3.1. Spatial patterns of environmental variables

A total of twenty-four environment variables were measured along the coast of both the Bohai and Yellow Seas (Table S2). Table S3 summarizes the statistics on the key environmental variables, including water quality parameters (e.g., water temperature and salinity),

Table 2
Summary of PERMANOVA and PERMDISP test based on taxon composition, diversity and density data. Ha: Habitat; Re: Region; La: Land use; df: degree of freedom; MS: mean squares; P-F: Pseudo-F; ECV: Estimate Components of Variation; Sqrt: square root of ECV; Bold values: $p < 0.05$.

		PERMANOVA					PERMDISP	
Target	Term	*df*	P-F	ECV	Sqrt	*p*	P-F	*p*
Taxon diversity	Ha	2	1.29	2.40	1.55	0.29	1.61	0.30
	Re	3	4.19	42.85	6.54	**0.005**	1.05	0.53
	La	6	0.90	−1.60	−1.26	0.48	1.16	0.57
	Ha × Re	6	1.95	55.62	7.45	0.07		
	Ha × La	8	1.64	38.99	6.24	0.13		
	Re × La	8	0.54	−32.20	−5.67	0.82		
	Ha × Re × La	3	0.28	−69.19	−8.31	0.85		
	Res	61		181.35	13.46			
Density	Ha	2	3.46	71.96	8.48	**0.01**	0.61	0.72
	Re	3	6.36	259.14	16.09	**0.001**	5.35	**0.02**
	La	6	3.77	164.15	12.81	**0.001**	6.06	**0.001**
	Ha × Re	6	2.86	391.08	19.77	**0.005**		
	Ha × La	8	1.24	52.69	7.25	0.24		
	Re × La	8	1.53	136.95	11.7	0.13		
	Ha × Re × La	3	1.53	184.47	13.58	0.18		
	Res	61		652.89	25.55			
Taxon composition	Ha	2	3.1	108.41	10.41	**0.005**	0.43	0.73
	Re	3	4.44	294.07	17.14	**0.001**	4.70	**0.04**
	La	6	2.70	178.2	13.34	**0.001**	6.02	**0.003**
	Ha × Re	6	1.92	343.95	18.54	**0.01**		
	Ha × La	8	0.96	−13.98	−3.73	0.48		
	Re × La	8	1.21	95.32	9.76	0.22		
	Ha × Re × La	3	1.37	227.67	15.08	0.17		
	Res	61		1154.7	33.9			

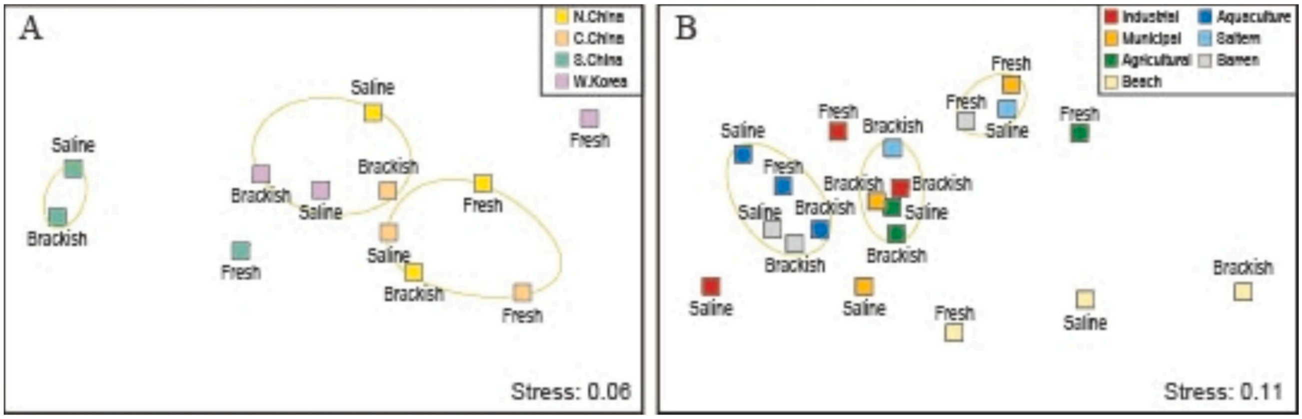

Fig. 3. Non-parametric multi-dimensional scaling (nMDS) based on the average abundance of (A) meiofauna taxa by region (North, Central, South China, and West Korea) and (B) land-use types (industrial, municipal, agriculture, beach, saltern, barren and aquaculture) along the coast of Yellow and Bohai Seas. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

sediment properties (mean grain size, organic matter, etc.), and heavy metals (mercury, copper, etc.). Environmental variables varied significantly among regions, habitats, and land uses. For example, the mean grain size and organic matter were clearly different among regions, whereas the amounts of Zn and As differed among land-use types. In particular, the concentrations of heavy metals was clearly higher in industrial areas, whereas that of organic matter was higher in municipal areas.

3.2. *Spatial patterns of meiofauna assemblages*

A total of 26,514 individuals were identified as belonging to >13 taxa when all samples were pooled. The three-way PERMANOVA test indicated that the taxon diversity of the meiofauna assemblage only differed significantly among regions (df = 3, Pseudo-F = 4.19, $p <$ 0.005). The top three dominant taxa accounted for >95 % of the total meiofauna abundance (Table 1). Although the three dominant taxa were predominant across all sites, the mean number of taxa was clearly different among the regions (Fig. 2). The meiofauna assemblage compositions differed significantly among habitats (df = 2, Pseudo-F = 3.1, $p < 0.005$), regions (df = 3, Pseudo-F = 4.44, $p < 0.001$), land use (df = 6, Pseudo-F = 2.7, $p < 0.001$), and the interaction between habitats and regions (df = 6, Pseudo-F = 1.92, $p < 0.01$).

In contrast to meiofauna diversity, the density of meiofauna assemblages along the coast of The BS and the YS was significantly different among habitats (df = 2, Pseudo-F = 1.29, p < 0.01), regions (df = 3, Pseudo-F = 6.36, $p < 0.001$), land use (df = 6, Pseudo-F = 3.77, $p <$ 0.001), and the interaction between habitats and regions (df = 6, Pseudo-F = 2.86, $p < 0.01$) (Table 2). The highest average density of meiofauna was found in South China, and saline habitat, and whereas the average density at West coast of Korea, and freshwater habitat were smaller than other regions (Fig. 2). The average density of meiofauna was varied across the land-use types following aquaculture, industrial, and barren areas (Fig. 2).

The ordination of samples with the nMDS technique based on meiofauna relative abundance data showed clear differences among regions (Fig. 3), whereas there was no clear difference between land use and habitats, although the PERMANOVA test indicated significant differences among sites along the coast of both the Bohai and Yellow Seas (Table 2). The south coast of China showed significantly different meiofaunal assemblages compared to other regions across all habitat types. The estimate of the component variation test in the PERMANOVA test also indicated that variations among regions were greater than variations across land use and habitats (Table 2). The PERMDISP test showed significant dispersion differences among regions, land use in meiofauna densities, and composition of meiofauna assemblages ($p <$ 0.05), which could be due to heterogeneous variance rather than a real factor effect (Table 2).

Table 3
Results of the DISTLM analysis used to explore the relationship between meiofauna and environmental variables. *p*-Values were obtained using 999 permutations of residuals under the best model (forward selection based on AIC test). Bold values indicate significant value; V: Variables; AIC: Akaike information criterion; P-F: Pseudo-F; Cum: Cumulation; B.S.: Best Solution.

V	AIC	P-F	*p*	Cum.
G-Size	603.83	6.91	**0.001**	0.08
Cd	601.43	3.90	**0.008**	0.12
TN	599.71	3.61	**0.007**	0.16
pH	598.83	2.75	**0.031**	0.19
d15N	598.64	2.05	0.09	0.21
Salinity	598.26	2.21	0.07	0.23
DO	597.61	2.42	**0.042**	0.26

B.S.	AIC	R^2	V
	597.61	0.25	7

3.3. *Environment-meiofauna relationship*

The results of DistLM indicated that grain size, heavy metals (Cd, Pb, Cu, Zn, Cr, Ni, and Hg), TN, pH, d15N, salinity, and DO explained the significant variations in meiofauna assemblage compositions along the coast of the BS and the YS (Table 3). The results of a sequential test based on a stepwise selection procedure revealed that a combination of seven environmental variables significantly contributed to the best explanatory model for meiofauna assemblage compositions (ca. 26 % of total variability was explained). A relatively low level of variability explained by the model may suggest the presence of unmeasured factors, weak associations, or a high level of noise in the data. In brief, variability in grain size contributed to a large part of the total variability observed in the meiofauna assemblages along the coasts of both seas. The contribution of each environmental variable to meiofauna assemblages varied among regions. The dbRDA routine also indicated that the environmental variables of importance were clearly different among the regions (Fig. 4).

4. Discussion

The integration of information on natural and anthropogenic variables with meiofauna assemblages revealed clear spatial variability in

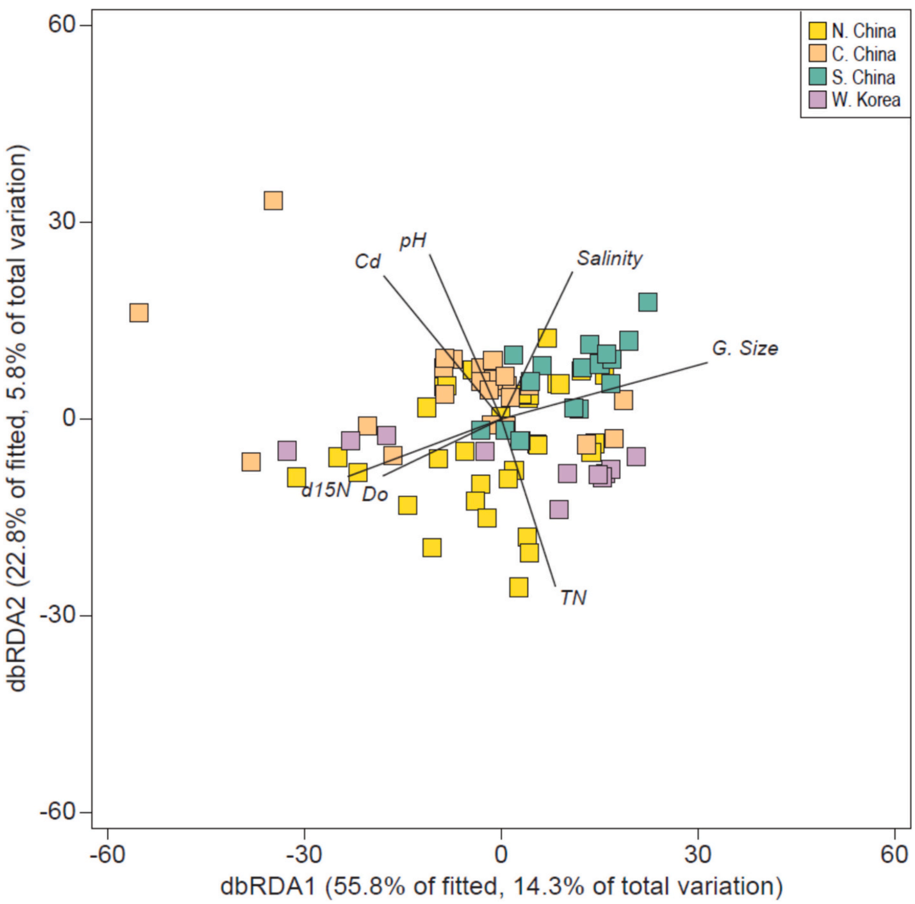

Fig. 4. Distance-based redundancy analysis (dbRDA) ordination displaying the first and second axes, indicating the relationship between environmental variables and the density of meiofauna assemblage data by region (North, Central, South China, and West Korea) along the coast of Yellow and Bohai Seas. Partial correlations of the significant environmental variables are superimposed on the ordination as vectors. The length and direction of environmental vectors indicate the strength and direction of the relationship with meiofauna, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

relation to various geological features. These results also indicate that multivariate patterns of meiofauna assemblages were mainly explained by natural (grain size, salinity, etc.) and anthropogenic (organic matter, heavy metals) factors along the coast of the YS and BS. In our study, the most predominant environmental factors that determined the variability of meiofauna assemblages were sediment properties, including mean grain size and percentage of clay silt. Several previous studies have also reported that natural variables such as regional differences in sediment grain size and salinity are the primary determinants of variability in meiofauna assemblages (Hourston et al., 2009; Kim et al., 2023; Liu et al., 2018). For example, the spatial distribution of nematode assemblages in the Swan River estuary in Australia was clearly correlated with salinity and grain size composition (Hourston et al., 2009). Our results also indicated that the regional and habitat variation in meiofauna composition was higher than the variation in land-use type. This indicates that natural variables can alter the density, diversity, and composition of meiofauna assemblages.

Although meiofauna assemblages were predominantly influenced by natural factors, the variation in meiofauna was also affected by anthropogenic contaminants, such as heavy metals, and a high percentage of TOC and TN. The YSLME coastline is lined by numerous major metropolitan areas in South Korea and China, with approximately 300 million people residing close to the shore. Consequently, human activities are likely to contribute to an increase in coastal pollution (Khim et al., 2018; Yoon et al., 2020). For example, the highest concentration of polycyclic aromatic hydrocarbons (PAHs) was associated with industrial areas and differed from the concentrations in other land-use types in the Yellow and Bohai Seas (Yoon et al., 2020). The concentrations of Polyfluoroalkyl substances (PFASs) also have been reported and varied greatly between different regions along the coastline of YS and BS (Shi et al., 2021). Our study also indicated that the second most dominant environmental factor varied among regions, habitats, and land-use types due to the degree of anthropogenic contaminants (Table 3). Moreover, the density and taxon diversity of the meiofauna assemblage were different among land-use types because of the concentration of pollution contaminants, such as heavy metals and PAHs. The concentration of pollutants in the sediment along the coasts of the Yellow and Bohai Seas in China and South Korea gradually decreased from 2008 to 2018. However, the levels remained elevated and even increased in the sediments of industrializing and urbanizing regions in China, largely due to insufficient enforcement of environmental regulations (Yoon et al., 2020). For instance, PAH concentrations in 2018 were notably elevated compared to 2008 at certain sites, including TS7 (6.9 times higher), QH3 (6.2 times higher), HL4 (24 times higher), and QH5, where levels were 150 times higher. As a result, the rise in pollutant levels in the sediment could be a key factor influencing the density and composition of meiofauna communities, especially in the industrial and urbanizing areas of the Yellow and Bohai Seas.

Benthic diversity and composition play important roles in coastal ecosystem functioning and services in several ways, including bioturbation (Wohlgemuth et al., 2016), enhancement of geochemical processes (Cardinale et al., 2012), and the supply of essential food resources for higher trophic levels (Lee et al., 2021). Therefore, understanding the spatiotemporal variability of benthic organisms is essential for the management and conservation of coastal areas (Kim et al., 2023). In our study, nutrient and heavy metal concentrations contributed to the variability of the meiofauna assemblages (Table 3). Meiofauna assemblages are particularly sensitive to chemical pollution and serve as valuable ecological indicators for assessing sediment quality and biological effects of human activity (Ridall and Ingels, 2021). For example, meiofauna species diversity decreased in heavy metal-enriched sediments, with the dominance of *Monhystera* and *Theristus* colonizer genera (Gyedu-Ababio et al., 1999). Some tolerant nematodes, *Diplolaimella dievengatensis* and *Halomonhystera disjuncta* (Gyedu-Ababio and Baird, 2006; Vranken et al., 1991), and copepods (Burton et al., 2001) can be tolerate high levels of heavy metals. This indicates that eutrophication and heavy metal enrichment conditions can alter the composition of the meiofauna assemblage, leading to an increase in some nematodes and a decrease in other meiofauna taxa (Gyedu-Ababio and Baird, 2006; Vranken et al., 1991). Our results also showed that site-specific anthropogenic influences altered and decreased meiofauna diversity, with an increase in the nematode proportion in total abundance. A previous study in the YS and BS, moreover, reported reduced species diversity in contaminated areas, primarily dominated by nematodes and copepods, with nematodes exhibiting a strong negative correlation with arsenic concentrations. Therefore, meiofauna assemblages can be used as indicators of benthic ecosystem health, particularly those affected by chemical contamination.

5. Conclusion

Our study identified the distribution patterns of meiofauna assemblages in relation to natural and anthropogenic contaminants in various locations, as well as land-use types along the coast of the Yellow and Bohai Seas. High concentrations of contaminants, such as PAHs and heavy metals, in some rivers and coastal areas of China pose significant risks to aquatic ecosystems. The spatial variation in meiofauna assemblages along the coast of the YS and BS was clearly affected by the integrated impacts of natural and anthropogenic factors. Sediment properties, salinity, and dissolved oxygen were found to be key natural variables influencing the spatial (site and region) and habitat differences of the meiofauna assemblages. Anthropogenic factors, such as PAHs and heavy metals, are superimposed on the natural environment, particularly in industrialized areas, resulting in reduced opportunities for less diverse nematode communities. In conclusion, the observed variability of meiofauna assemblages clearly demonstrated their association with pollution and will provide valuable information for sediment quality management and monitoring along the coasts of the YS and BS. Further studies should focus not only on continued management but also on enhancing methodological approaches, such as incorporating molecular techniques, to improve the assessment of meiofaunal responses to marine pollution, thereby aiding in contamination control and addressing potential ecological risks to the marine ecosystems of the Yellow and Bohai Seas.

CRediT authorship contribution statement

Hyeong-Gi Kim: Writing – original draft, Investigation, Formal analysis, Conceptualization. **Seo Joon Yoon:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Junghyun Lee:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Seongjin Hong:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Bong-Oh Kwon:** Project administration, Formal analysis, Data curation. **Wenyou Hu:** Investigation, Formal analysis, Data curation. **Tieyu Wang:** Supervision, Investigation, Funding acquisition. **Jong Seong Khim:** Writing – review & editing, Supervision, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2025.117966.

Data availability

No data was used for the research described in the article.

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<Supplementary Materials>

Distribution pattern of meiofauna assemblages along an environment gradient on the coast of Yellow sea and Bohai seas

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Table of Contents

Supplementary Tables

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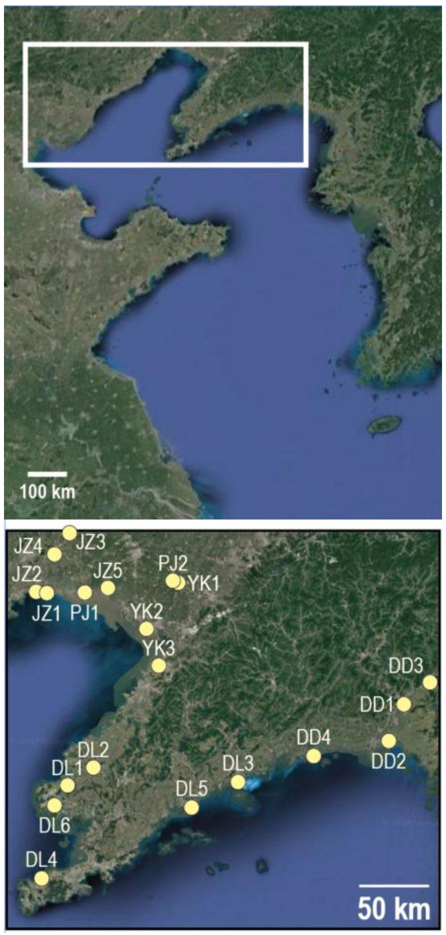
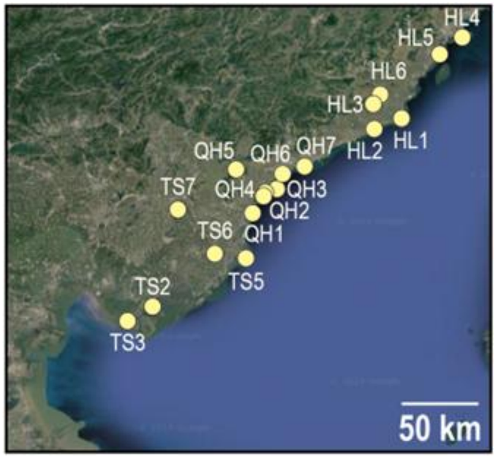
Supplementary Tables

Table S1. Information on sampling stations by each region along the coast of the Bohai and Yellow seas.



Map of sampling locations	Date (yyyymmdd)	Site	Latitude (°N)	Longitude (°E)	Land use type
	Team 1 (N. China)				
	20180701	DL4	38.9844	121.5103	Beach
	20180701	DL6	39.5058	121.4033	Unused land
	20180701	DL1	39.6208	121.5214	Industrial
	20180701	DL2	39.6947	121.740.	Industrial
	20180702	DL5	39.4817	122.5592	Municipal
	20180702	DL3	39.6633	122.9939	Municipal
	20180702	DD4	39.8383	123.6528	Agricultural
	20180703	DD3	40.3122	124.6968	Agricultural
	20180703	DD1	40.1771	124.4567	Industrial
	20180703	DD2	39.9436	124.2828	Unused land
	20180704	YK3	40.425	122.2844	Industrial
	20180704	YK2	40.69	122.1292	Industrial
	20180704	YK1	40.9963	122.4638	Municipal
	20180704	PJ2	41.0238	122.4338	Municipal
	20180705	JZ5	40.9092	121.8192	Industrial
	20180705	PJ1	40.8822	121.5714	Agricultural
	20180705	JZ3	41.4531	121.4594	Unused land
	20180705	JZ4	41.1763	121.3792	Industrial
	20180706	JZ2	40.9181	121.2436	Agricultural
	20180706	JZ1	40.9242	121.1867	Agricultural
	20180706	HL4	40.7469	120.9347	Industrial
	20180706	HL5	40.5919	120.7694	Agricultural
	20180707	HL3	40.3703	120.2583	Agricultural
	20180707	HL6	40.4181	120.2992	Unused land
	20180707	HL1	40.2697	120.4622	Municipal

Table S1. (Continued)



Sampling map	Date	Site	Latitude (°N)	Longitude (°E)	Land use type
	20180707	HL2	40.1747	120.2614	Agricultural
	20180708	QH7	39.9653	119.7694	Municipal
	20180708	QH6	39.9203	119.5667	Municipal
	20180708	QH5	39.9802	119.2126	Municipal
	20180709	QH3	39.8394	119.5133	Municipal
	20180709	QH4	39.8017	119.4419	Municipal
	20180709	QH2	39.7814	119.4136	Unused land
	20180709	QH1	39.6789	119.2911	Municipal
	20180710	TS7	39.6641	118.7881	Agricultural
	20180710	TS6	39.4607	119.1341	Agricultural
	20180710	TS5	39.4308	119.28	Agricultural
	20180710	TS2	39.1522	118.5342	Industrial
	20180710	TS3	39.0436	118.3642	Municipal
	Team 2 (C. China)				
	20180627	RZ1	35.298	119.4482	Aquaculture
	20180627	RZ2	35.0782	119.3033	Aquaculture
	20180628	QD4	36.2353	120.1206	Municipal
	20180628	QD5	35.8568	120.0477	Beach
	20180628	QD6	35.7684	119.9262	Aquaculture
	20180628	QD7	35.7405	119.9111	Aquaculture
	20180629	QD2	36.7802	120.4099	Unused land
	20180629	QD3	36.6637	120.295	Agricultural
	20180630	QD1	36.2609	120.3259	Municipal
	20180701	WH1	36.8266	121.4636	Aquaculture
	20180701	WH3	36.9321	121.8657	Unused land
	20180701	YT5	36.6543	120.7688	Agricultural
	20180702	WH2	37.4296	122.2754	Beach
	20180702	YT4	37.7493	120.5242	Beach
	20180702	YT6	37.5753	121.2966	Beach

Table S1. (Continued)

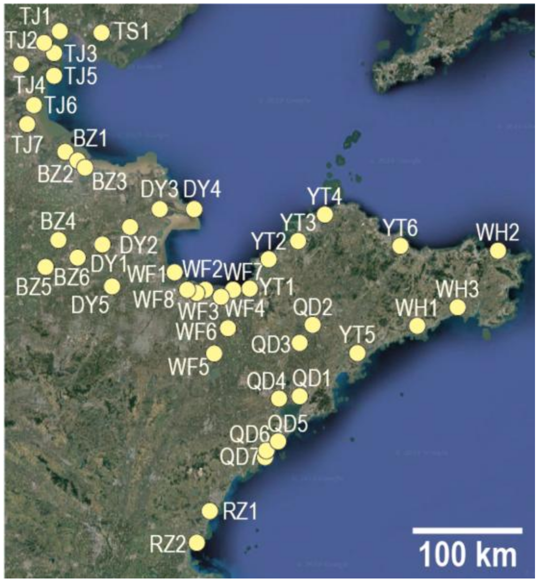
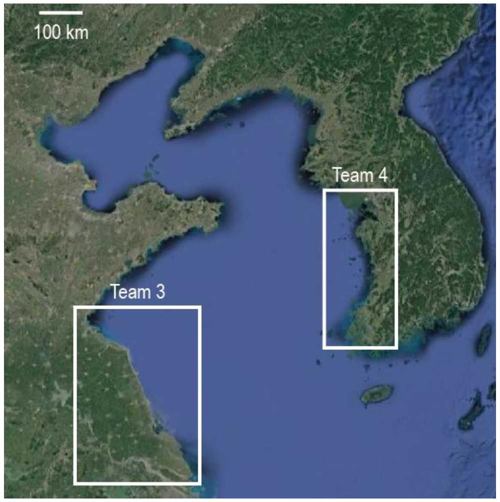
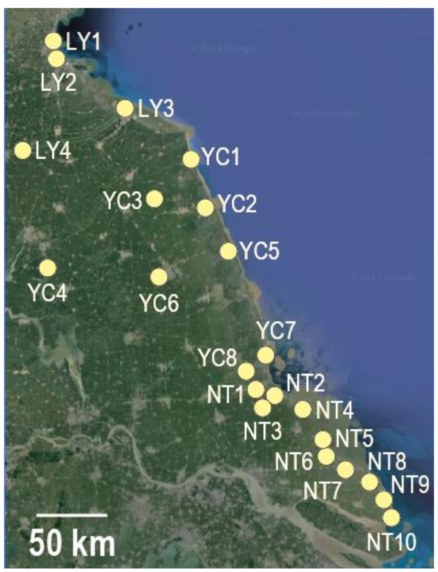
Sampling map	Date	Site	Latitude (°N)	Longitude (°E)	Land use type
	20180703	YT1	37.1286	119.7277	Saltern
	20180703	YT2	37.4017	119.9493	Industrial
	20180703	YT3	37.5518	120.2482	Beach
	20180704	WF4	37.0765	119.4793	Unused land
	20180704	WF5	36.5802	119.3846	Agricultural
	20180704	WF6	36.7421	119.5374	Agricultural
	20180704	WF7	37.0921	119.5599	Unused land
	20180705	WF1	37.2751	118.9848	Unused land
	20180705	WF2	37.1354	119.2870	Saltern
	20180705	WF3	37.1401	119.1434	Saltern
	20180705	WF8	37.1330	119.1860	Saltern
	20180705	DY5	38.1363	118.4322	Industrial
	20180706	DY2	37.6046	118.5384	Agricultural
	20180706	DY3	37.7481	118.8214	Agricultural
	20180706	DY4	37.7615	119.1706	Unused land
	20180707	DY1	37.4851	118.2691	Agricultural
	20180707	BZ4	37.5010	117.8540	Agricultural
	20180707	BZ5	37.2497	117.7231	Agricultural
	20180707	BZ6	37.3350	118.0576	Agricultural
	20180708	BZ1	38.2637	117.8511	Agricultural
	20180708	BZ2	38.2006	118.0047	Unused land
	20180708	BZ3	38.1460	118.0528	Unused land
	20180709	TJ1	39.2000	117.7641	Industrial
	20180709	TJ2	39.1640	117.6623	Unused land
	20180709	TJ3	39.0938	117.7298	Unused land
	20180709	TJ5	38.9695	117.7315	Industrial
	20180710	TJ4	39.0214	117.4955	Agricultural
	20180710	TJ6	38.7667	117.5694	Industrial
	20180710	TJ7	38.6547	117.5447	Unused land

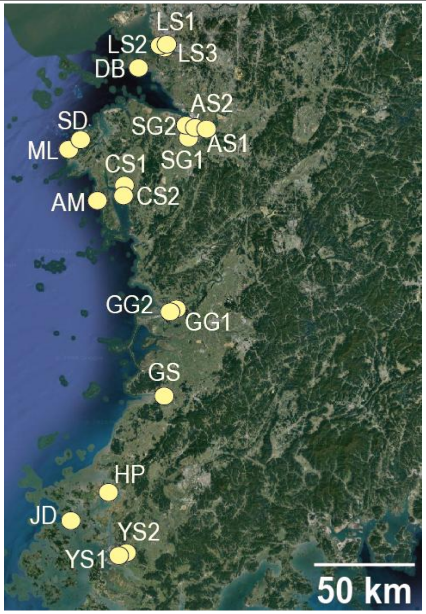
Table S1. (Continued)





Sampling map	Date	Site	Latitude (°N)	Longitude (°E)	Land use type
	20180710	TS1	39.0203	117.4578	Industrial
	Team 3 (S. China)				
	20180630	LY2	34.7963	119.2244	Unused land
	20180701	LY1	34.9023	119.1961	Aquaculture
	20180701	LY3	34.5026	119.7720	Unused land
	20180701	LY4	34.1537	118.8366	Agricultural
	20180702	YC1	34.1128	120.3239	Unused land
	20180702	YC3	33.8934	120.0150	Agricultural
	20180702	YC4	33.4793	119.1460	Municipal
	20180702	YC6	33.3674	120.0770	Industrial
	20180703	YC2	33.8160	120.4768	Industrial
	20180703	YC5	33.7400	120.5499	Unused land
	20180703	YC7	32.8821	120.9646	Unused land
	20180704	YC8	32.6933	120.8959	Unused land
	20180704	NT1	32.6031	120.9437	Industrial
	20180704	NT2	32.5577	121.0457	Unused land
	20180704	NT3	32.5140	120.9660	Agricultural
	20180704	NT4	32.4919	121.2226	Unused land
	20180705	NT5	32.2016	121.3851	Saltern
	20180705	NT6	32.1535	121.4562	Unused land
	20180705	NT7	32.1014	121.6039	Unused land
	20180705	NT8	32.0292	121.7411	Unused land
	20180706	NT9	31.9337	121.8257	Industrial
	20180706	NT10	31.8490	121.8521	Industrial
	Team 4 (W. Korea)				
	20180713	YS1	34.7821	126.4441	Municipal
	20180713	YS2	34.7866	126.4627	Municipal
	20180713	HP	35.0890	126.3538	Agricultural
	20180713	JD	34.9690	126.1662	Agricultural

Table S1. (Continued)



Sampling map	Date	Site	Latitude (°N)	Longitude (°E)	Land use type
	20180714	GS	35.5728	126.6636	Agricultural
	20180714	GG1	36.0225	126.7422	Agricultural
	20180714	GG2	36.0085	126.7353	Agricultural
	20180714	AM	36.5401	126.3265	Beach
	20180714	ML	36.7838	126.1364	Beach
	20180715	SD	36.8385	126.1834	Beach
	20180715	SG1	36.8788	126.8272	Agricultural
	20180715	SG2	36.8951	126.8191	Agricultural
	20180715	AS1	36.8933	126.9123	Agricultural
	20180715	AS2	36.9154	126.9052	Agricultural
	20180716	DB	37.2142	126.5855	Agricultural
	20180716	LS1	37.3348	126.6895	Industrial
	20180716	LS2	37.3257	126.6571	Industrial
	20180716	LS4	37.3249	126.6556	Industrial
	20180723	CS1	36.5981	126.4632	Agricultural
	20180723	CS2	36.2142	126.5355	Agricultural

* N. China: North China; C. China: Center China; S. China: South China; W. Korea: West sea of Korea

Table S2. Environmental bottom water and sediment characteristics, along with sediment PAH, AP, and SO concentrations, at the coast of the Bohai and Yellow seas.

Site	Temp. (°C)	Sal. (‰)	DO (mg L^{-1})	pH	G. Size (Ø)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	TN (%)	TC (%)	δ15N	δ13C	PAHs (ng g^{-1})	APs (ng g-1)	SOs (ng g-1)	Cd (mg kg^{-1})	Pb (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Cr (mg kg^{-1})	Ni (mg kg^{-1})	As (mg kg^{-1})	Hg (mg kg^{-1})
Team 1 (N. China)																								
DL4	26.1	1.2*	9.09	7.82	2.34	0	97.9	2	0.2	0.01	0.06	13.3	-18.4	40	7	0.7	0.07	16.8	7.5	26.3	53.6	6.3	2.3	0.01
DL6	26.4	35.5	8.03	7.89	4.32	0	53.4	40.2	6.4	0.02	0.16	10	-22.8	48	0.6	13.6	0.06	20.5	11.1	35.0	27.3	9.9	2.9	0.01
DL1	25.4	34.9	7.51	7.93	6.09	0	15.2	66.3	18.5	0.07	1.6	8.2	-23.8	467	2.3	11.9	0.11	26.9	23.0	60.7	42.9	22.0	6.5	0.02
DL2	27.9	0.76	9.83	8.59	4.69	0	31.7	63.4	5	0.07	1.55	5.8	-25	1010	2	0.9	0.09	23.4	21.7	75.1	79.5	33.0	3.4	0.01
DL5	24.5	34.6	7.35	7.84	6.11	0	13.7	69.3	17	0.1	0.97	8.2	-21.6	249	1.4	9.5	0.09	34.2	27.3	86.3	69.2	28.1	8.4	0.03
DL3	26.2	31.8	6.09	7.69	6.29	0	8.2	74.7	17.1	0.14	1.53	8.5	-22.1	285	10	1.6	0.13	33.4	23.9	93.3	70.4	29.6	7.5	0.05
DD4	25	9.9*	6.62	8.36	5.04	0	34.7	55.9	9.4	0.09	0.96	7.9	-23	151	2.5	0.9	0.11	31.5	15.0	78.1	66.1	24.4	8.5	0.03
DD3	25	0.24	9.52	8.32	2.48	0	83.2	15.5	1.3	0.08	0.57	6.4	-22	143	22.8	2.7	0.19	25.1	16.3	92.6	77.2	28.9	8.5	0.05
DD1	22.5	0.15	8.9	8.12	-	-	-	-	-	-	-	-	-	351	18.5	8.7	0.41	46.1	34.1	116.0	62.5	26.7	21.4	0.11
DD2	25.1	0.40*	5.61	7.97	6.24	0	10.3	74.4	15.3	0.14	1.8	6.5	-23.9	1351	12.4	14.5	0.29	41.0	34.7	162.0	91.8	37.0	20.5	0.18
YK3	27.9	38.5	4.81	7.82	6.66	0	1.4	83.5	15.1	0.13	1.42	8.6	-21.5	491	2	3.3	0.24	30.8	35.1	113.0	86.7	45.2	16.1	0.08
YK2	29.1	35.3	7.2	8.3	5.45	0	23	64.4	12.6	0.07	0.86	8.8	-23.6	632	3	2.7	0.24	24.8	19.5	69.7	42.6	21.2	7.6	0.05
YK1	30.4	0.64	13.8	8.84	-	-	-	-	-	-	-	-	-	1606	11.7	11.9	0.14	28.8	28.8	106.0	53.6	32.5	7.9	0.09
PJ2	29.5	0.81	4.77	8.11	4.24	0	54.2	39.7	6.2	0.1	0.97	9.8	-23.9	1891	8.8	7.1	0.13	20.0	17.9	64.9	43.8	20.5	4.0	0.04
JZ5	29	36.5	7.41	7.96	6.06	0	9.5	73.3	17.2	0.09	0.87	7.9	-21	288	5.2	3.2	0.18	20.2	16.6	57.6	46.4	20.8	6.3	0.03
PJ1	31.8	0.50*	10.3	8.54	5.78	0	13.4	73.3	13.3	0.09	0.89	7.8	-22.7	291	27	7.5	0.26	26.2	21.9	74.6	68.1	28.4	14.9	0.05
JZ3	27.1	0.71	8.46	8.3	2.53	0	91.2	8.5	0.3	0.01	0.02	10.6	-22.2	56	2	2.5	0.11	19.5	18.1	57.6	80.4	23.0	4.9	0.03
JZ4	28.1	0.76	9.36	8.25	3.17	0	79.3	19.2	1.6	0.03	0.5	9.6	-21.9	270	3.3	12.4	0.18	21.3	19.9	69.6	76.7	21.8	3.3	0.02
JZ2	27.8	39.2	7.59	7.68	5.39	0	16.8	73.2	10	0.04	0.27	6.6	-20.7	176	2	1.9	0.25	20.7	16.7	68.2	59.6	22.5	5.4	0.03
JZ1	28.1	37.5	8.6	8.95	3.61	0	60.8	35.5	3.6	0.02	0.48	10	-20.9	91	2.2	2	0.17	23.0	15.4	67.1	66.6	19.5	4.8	0.02
HL4	30.6	9.1	11.1	7.14	6.3	0	9.8	72.5	17.7	0.34	3.12	4.1	-23	18110	503.7	218.1								
HL5	28.3	7.5	7.44	8.94	4.59	0	38.9	54.7	6.4	0.07	1.05	6.7	-23.6	207	4.9	3.2	0.65	33.6	24.4	106.0	36.2	19.8	7.4	0.09
HL3	25.3	0.43	8.07	7.77	6.66	0	10.2	67	22.9	0.12	1.36	6.3	-21.4	111	2	1.3	0.19	35.3	36.7	99.6	61.6	33.3	11.2	0.06
HL6	26.7	0.54	2.99	7.2	-	-	-	-	-	0.06	0.45	8.9	-20.4	35	2.8	4	0.17	27.6	28.4	78.2	28.3	16.8	4.3	0.03
HL1	26.2	33.7	8.73	8	5.5	0	23.4	64.3	12.3	0.13	2.4	8.2	-22.5	211	3.8	2.2	0.17	34.4	27.2	103.0	46.8	24.3	5.3	0.06
HL2	28.7	0.2	10.8	9.51	6.04	0	12	72.9	15.1	0.18	1.73	6.5	-20.5	396	3.8	6.5	0.26	37.3	28.8	107	46.7	23.3	8.3	0.07
QH7	23.8	22.5	9.18	8.63	2.94	0	69.3	27.2	3.5	0.12	3.39	5.9	-25.9	171	34.4	10.8	0.09	23.7	23.3	71	41.6	13.5	4.8	0.03
QH6	24.8	0.4*	6.28	8.47	5.77	0	21.8	63.3	14.9	0.27	4.67	7.4	-28.1	7644	57.2	100.8	0.34	54.2	49.2	193	62.7	29.7	13.2	0.28
QH5	25.8	0.4	9.88	8.81	3.82	0	59.7	36.3	4.1	0.15	1.99	7.8	-24.8	12012	2.8	29.6	0.17	35.9	42.1	115	75.3	34.1	6.0	0.18
QH3	25	0.5	5.36	7.23	3.23	0	76.2	20.6	3.3	0.12	2.02	5	-24.1	2155	156	22	0.25	24.7	21.0	87	47.3	18.9	5.0	0.27

Table S2. (Continued)

Site	Temp. (°C)	Sal. (‰)	DO (mg L^{-1})	pH	G. Size (Ø)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	TN (%)	TC (%)	δ15N	δ13C	PAHs (ng g^{-1})	APs (ng g^{-1})	SOs (ng g^{-1})	Cd (mg kg^{-1})	Pb (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Cr (mg kg^{-1})	Ni (mg kg^{-1})	As (mg kg^{-1})	Hg (mg kg^{-1})
QH4	26.2	0.3*	3.8	8.07	-	-	-	-	-	0.28	2.48	8.5	-26.2	2591	78.4	11	0.35	96.7	42.6	135	66.2	37.1	5.3	0.75
QH2	25.6	8.1	7.97	7.95	-	-	-	-	-	0	0.04	16.9	-23.3	22	1.6	1.7	0.08	16.8	10.7	42	21.6	10.7	4.2	0.01
QH1	25.2	24.2	6.79	7.93	2.25	0	93.5	5.6	0.9	0.02	0.05	7.2	-22.7	128	1.6	17.9	0.15	20.4	19.4	44	31.4	12.1	4	0.02
TS7	26.6	0.59	5.87	7.5	5.77	0	18.9	68.2	12.9	0.39	6.74	9	-25.6	1887	27.4	30.5	0.4	45.6	70.1	148	66.8	30.5	5.4	0.1
TS6	27	0.73	9.4	8.09	2.47	0	93	6.6	0.4	0.04	0.26	3.7	-18.9	93	9.9	4.7	0.07	17.7	9	41	84.2	15	2.3	0.02
TS5	28.4	35.3	8.37	7.75	3.52	0	67.5	30.4	2.1	0.03	0.43	7.7	-21.8	57	2.5	2.9	0.07	18.6	12.4	45	67.9	16.4	2.8	0.02
TS2	27.7	37.3	6.35	7.82	5.44	0	20.9	68.1	11	0.06	1.01	7.1	-20.8	665	1	4.5	0.1	21.4	15.7	52	52.7	19.7	6.3	0.02
TS3	25.6	38	7.54	7.9	4.1	0	50.9	45.3	3.8	0.05	0.93	8	-20.7	739	9.1	8.5	0.08	20.2	15	46	36.1	15.9	5.3	0.02
Team 2 (C. China)																								
RZ1	31.3	13.8	4.9	7.7	2.7	0	75.3	23.4	1.3	0.02	0.11	6.4	-20.6	35	18.1	4.5	0.1	20.9	18.2	49	65.5	24.3	5	0.04
RZ2	27.2	24.3	4.5	8	-	-	-	-	-	0.03	0.15	7.1	-20.7	125	32.4	4.7	0.08	19.8	12.1	47	36.5	13.8	6.7	0.03
QD4	27.4	18.6	7.1	8	5.88	0	15.8	67.2	17	0.05	2.01	8.5	-22.9	300	6.1	4.9	0.12	26.5	8.3	35	27	12.2	2.9	
QD5	27.4	21.2	13.6	8.5	1.68	0	99.5	0.5	0	0	0.02	12.2	-23	10	15.5	3.7	0.92	60.5	83	380	37.9	22.4	65.9	0.43
QD6	30.1	4.4	7.1	8.1	5.87	0	15.6	70.1	14.3	0.1	1.34	6.5	-28.1	192	45.2	14.2	0.26	37.5	30.6	100	29.7	16.4	7.5	0.05
QD7	29	14.2	3.8	7.7	-	-	-	-	-	0.01	0.32	11	-19.7	24	42.2	5.2	0.06	16.4	9.6	30	33.7	12.4	6.3	0.01
QD2	29.9	0.5	16.7	10.4	-	-	-	-	-	-	-	-	-	38	2.4	3.2	0.1	20.4	4.8	36	28.9	9.7	3.2	
QD3	30	0.3	12	9.3	-	-	-	-	-	-	-	-	-	162	7.7	14.8	0.13	25.8	17	75	57.6	23.1	15.1	0.02
QD1	31.7	18.5	3.83	7.76	6.46	0	4.4	79.4	16.2	0.12	1.83	8.2	-22.9	1565	97.5	17.9	0.09	29.4	15.1	47	39.9	13.3	7.8	0.03
WH1	28.7	19.9	8	7.9	6.16	0	13.7	67.9	18.4	0.16	1.4	5.6	-20.8	172	75	11.7	0.11	18.4	18.5	55	50.7	23.9	10.6	0.02
WH3	27.6	20.9	9.8	8.3	-	-	-	-	-	-	-	-	-	29	11.6	24.3	0.12	19.9	20.2	67	52.1	22.7	5.5	0.1
YT5	26.3	1.8	11.6	9	-	-	-	-	-	-	-	-	-	10	12.5	4.8	0.11	17.6	21.2	61	56.5	21	5.8	0.02
WH2	22.4	26.9	9.2	8.2	2.05	0	98.7	1.3	0	0.01	0.03	20.9	-21.1	18	9.2	5.5	0.1	21	16.9	61	82.3	17.7	7.6	0.04
YT4	26.1	27.8	8.6	8.4	-	-	-	-	-	0	0.02	14	-23.5	14	14.1	16.8	0.19	31.8	33.5	110	89.4	33.7	15.8	0.05
YT6	25.8	28	9.8	8.3	1.83	0	91.9	7.6	0.5	0.01	0.06	3.8	-21.1	24	18.2	10.3	0.13	24.9	37.3	110	85.3	40.9	14.2	0.04
YT1	30.4	28.2	8.5	8.2	3.28	0	81.2	18	0.8	0.01	0.09	5.7	-19	15	8.9	10.8	0.12	26.2	24.6	77.0	38.5	25.4	5.3	0.17
YT2	29.5	27.4	9.4	8.4	-	-	-	-	-	0.03	1.74	7.6	-19.1	273	25.7	23.4	0.06	18.0	9.3	32.4	30.3	12.0	5.9	0.02
YT3	29.5	17.4	9.1	8.5	-	-	-	-	-	0	0.09	12.6	-19.8	12	14.3	5.6	0.11	17.6	17.6	51.1	51.1	22.9	8.8	0.02
WF4	28.8	25.6	7.6	8.2	5.02	0	28.4	63.5	8.1	0.04	0.35	8	-21.5	15	13.2	10.8	0.11	18.5	16.4	48.0	48.4	21.8	8.0	0.03
WF5	31.2	0.8	18.1	9.2	-	-	-	-	-	-	-	-	-	11	10.5	8.8	0.26	22.0	21.8	60.8	57.7	27.4	10.5	0.04
WF6	26.1	1.7	0.3	7.4	-	-	-	-	-	-	-	-	-	116	31.1	13.1	0.16	26.6	25.9	74.7	67.0	31.8	12.8	0.02
WF7	29	33.7	21.8	3.7	3.69	0	73.4	26.1	0.5	0.04	0.2	6.2	-17.8	19	17.3	9.7	0.10	16.5	15.8	52.4	49.3	21.4	11.1	0.01

Table S2. (Continued)

Site	Temp. (°C)	Sal. (‰)	DO (mg L^{-1})	pH	G. Size (Ø)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	TN (%)	TC (%)	δ15N	δ13C	PAHs (ng g^{-1})	APs (ng g^{-1})	SOs (ng g^{-1})	Cd (mg kg^{-1})	Pb (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Cr (mg kg^{-1})	Ni (mg kg^{-1})	As (mg kg^{-1})	Hg (mg kg^{-1})
WF1	30	5.2	4.8	7.9	3.63	0	67.4	30.3	2.3	0.02	0.36	7.6	-21.3	40	19.3	6	0.11	17.9	15.2	44.0	44.6	20.8	7.2	0.02
WF2	29.8	23.5	8.9	8.2	3.53	0	80.7	18.1	1.2	0.03	0.13	7.3	-19.4	22	16.4	19.5	0.09	16.3	12.4	36.4	31.7	17.7	6.1	0.02
WF3	32.1	29.7	12.6	8.8	3.28	0	85.2	13.5	1.3	0.04	0.7	5.9	-16.5	146	36	27.4	0.10	16.7	12.8	34.6	41.4	17.0	5.4	0.01
WF8	31.3	37	9	8.5	3.53	0	78.1	20.7	1.3	0.02	0.11	7.1	-22.3	22	10.8	20.6	0.16	23.2	24.0	72.4	63.8	31.2	14.2	0.04
DY5	30.5	1.6	9.4	8.1	-	-	-	-	-	-	-	-	-	1748	57.5	46.1	0.13	26.8	25.9	114.0	65.5	29.8	7.9	0.07
DY2	30.1	0.3	7.6	8.2	-	-	-	-	-	-	-	-	-	15	17.2	12.7	0.08	31.6	10.7	35.7	27.0	11.5	4.3	0.01
DY3	-	-	-	-	4.14	0	43.6	55.5	0.9	0.01	0.05	10.7	-22.2	6	10	4.9	0.19	41.8	57.6	155.0	109.0	42.4	11.1	0.19
DY4	33.1	0.5	8.4	8.4	5.69	0	5.3	87.1	7.6	0.03	0.19	7.5	-23.4	30	12.1	25.4	0.06	16.4	12.9	37.6	46.4	21.1	2.9	0.01
DY1	29.3	0.5	7.4	8.5	-	-	-	-	-	-	-	-	-	57	11.2	28.4	0.14	28.9	21.0	72.1	61.6	29.0	7.5	0.03
BZ4	32.2	0.8	16.3	8.9	-	-	-	-	-	-	-	-	-	35	26.8	9.5	0.23	28.5	34.1	84.3	64.4	29.8	9.3	0.04
BZ5	30.5	0.4	5.1	8.2	-	-	-	-	-	-	-	-	-	25	11	8.4	0.07	19.3	7.7	31.4	22.3	6.1	4.8	0.01
BZ6	29.9	0.3	7.1	8.5	-	-	-	-	-	-	-	-	-	11	6.9	8.2	0.08	24.5	15.2	42.7	47.2	14.6	3.7	0.01
BZ1	28	31.6	7.3	8.3	4.91	0	25.4	68.5	6.2	0.04	0.49	7.9	-22.2	32	13.3	12.8	0.07	22.3	9.8	48.0	32.0	13.7	3.5	0.01
BZ2	28	33.3	5.3	7.6	5.93	0	8.4	78.6	13	0.08	0.66	6.8	-21.3	22	20.2	8.4	0.08	20.6	11.5	49.4	50.1	16.9	3.3	0.03
BZ3	27.2	15.7	8.4	8.4	5.6	0	13.1	76.9	10	0.04	0.28	8.4	-25	19	16.8	10.4	0.12	31.6	30.3	87.1	70.2	32.0	8.7	0.04
TJ1	-	2.2	9.4	9.5	-	-	-	-	-	-	-	-	-	75	1.8	10.5	0.11	20.9	17.6	96.9	41.7	16.8	3.7	0.03
TJ2	26.8	0.7	10.2	9.3	-	-	-	-	-	-	-	-	-	186	19.1	8.9	0.07	19.5	10.2	33.6	52.5	17.4	3.0	0.01
TJ3	25.8	22	5.8	8.1	4.98	0	40	48.9	11.1	0.07	0.59	9.1	-22.6	92	9.7	28.7	0.07	18.2	15.6	96.9	43.0	16.5	8.5	0.02
TJ5	26.4	15.7	7.7	8.4	2.45	0	84.3	12	3.7	0.02	0.49	11.1	-23	92	9.8	12.6	0.09	20.4	26.9	54.0	46.2	18.8	18.7	0.03
TJ4	27.9	6.2	10.1	9	-	-	-	-	-	-	-	-	-	114	13.1	13.9	0.08	15.2	9.7	32.8	49.4	15.0	7.0	0.01
TJ6	29.3	29.7	8.8	8.3	5.65	0	19.7	67.1	13.2	0.06	0.82	8.2	-21.9	279	22.3	18	0.14	18.2	15.5	48.1	50.3	22.5	8.9	0.02
TJ7	29.1	19.8	6.4	8.2	6.14	0	21.5	55	23.5	0.07	0.48	9.2	-21.9	32	11	7.6	1.79	33.9	56.0	383.0	146.0	41.9	13.2	0.43
TS1	26.9	3.1	6	8.1	7.22	0	0.4	72.3	27.3	0.12	2.38	7.5	-23.8	956	6	6.5	0.25	25.9	30.7	80.6	72.3	35.3	13.3	0.06
Team 3 (S. China)																								
LY2	25.8	30.7	7	7.7	6.97	0	2.4	72.7	24.9	0.13	1.57	8.6	-23	60	11	8.1	0.13	21.8	15.9	54.0	49.6	19.0	5.6	0.02
LY1	28	46.6	7.4	7.8	4.68	0	39.9	52.7	7.4	0.04	0.39	8	-23.7	17	8.3	5.3	0.18	35.2	33.7	99.6	85.6	41.7	17.6	0.05
LY3	28.4	33.7	7.4	7.7	6.77	0	1.6	77	21.4	0.12	0.97	7	-22.4	2	25	4.8	0.17	34.3	34.9	101.0	80.3	39.6	16.3	0.05
LY4	28	0.5	8.1	7.9	6.62	0	9.7	67.2	23.1	0.08	0.75	7.5	-21.8	13	0.5	5.7	0.08	23.9	14.9	40.4	51.2	21.8	7.3	0.02
YC1	25.4	15	7.2	7.8	5.48	0	21.5	66.5	12	0.06	0.35	6.2	-23.4	26	10	5.6	0.09	16.1	12.4	57.8	52.6	21.8	2.8	0.02
YC3	27	0.6	2.1	7.5	-	-	-	-	-	-	-	-	-	173	25.7	25.8	0.11	21.2	23.6	72.7	69.0	30.5	11.0	0.04
YC4	27.1	0.4	8.1	8	-	-	-	-	-	-	-	-	-	1075	23.8	11	0.11	27.3	24.6	78.0	74.8	34.5	11.6	0.04

Table S2. (Continued)

Site	Temp. (°C)	Sal. (‰)	DO (mg L^{-1})	pH	G. Size (Ø)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	TN (%)	TC (%)	δ15N	δ13C	PAHs (ng g^{-1})	APs (ng g^{-1})	SOs (ng g^{-1})	Cd (mg kg^{-1})	Pb (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Cr (mg kg^{-1})	Ni (mg kg^{-1})	As (mg kg^{-1})	Hg (mg kg^{-1})
YC6	27.4	0.6	3.7	7.4	-	-	-	-	-	-	-	-	-	1367	61.7	34.3	0.13	27.0	22.2	85.8	79.1	31.7	10.5	0.04
YC2	27	0.8*	2.4	7.6	6.15	0	9.3	73.2	17.5	0.07	0.63	6.3	-24	144	9	18.4	0.07	13.7	9.6	44.7	71.1	21.1	4.8	0.01
YC5	28	20.2	7.5	7.9	-	-	-	-	-	-	-	-	-	10	9	4.8	0.09	20.6	16.7	67.1	70.5	25.9	7.2	0.03
YC7	28.6	41.7	5.6	7.6	5.13	0	26.4	65.2	8.4	0.06	0.78	6.8	-23	9	13.1	6.1	0.12	24.8	22.8	78.7	74.1	31.7	10.3	0.05
YC8	28.5	4	9.4	8.2	5.93	0	4.6	83.4	12	0.07	0.35	6.7	-23.9	12	7.8	4.5	0.17	58.5	61.4	158	69.6	29.1	7.6	0.04
NT1	29	2.3*	4.7	7.7	6.66	0	1.4	77.8	20.8	0.12	1.6	5.7	-24.8	250	24.6	13.9	0.29	43.6	33.6	137.0	93.0	35.4	11.1	0.04
NT2	31.5	17.2	16.3	8.6	5.46	0	14.6	76.2	9.1	0.07	1.19	3.2	-23.4	45	22.2	7.3	0.10	15.4	17.1	65.2	50.9	23.3	6.1	0.02
NT3	30	1.4	11.7	8.2	-	-	-	-	-	-	-	-	-	121	20.2	9.2	0.13	20.3	18.9	65.0	69.9	26.8	11.3	0.02
NT4	29.4	44.6	7.9	7.9	2.47	0	99.3	0.7	0	0.01	0.08	5.5	-19.1	18	6.7	7.6	0.16	18.2	22.5	86.0	67.5	29.6	10.4	0.05
NT5	28.8	28.1	5.1	7.4	5.91	0	13.2	72	14.8	0.07	1	5.6	-24.1	142	15	11.6	0.16	23.4	23.5	71.4	67.7	30.3	11.8	0.02
NT6	27.7	43.1	6.7	7.7	6.43	0	6.7	73.8	19.5	0.08	1.12	6	-22.4	82	7.8	8.2	0.11	19.0	17.0	55.5	57.5	24.7	8.5	0.02
NT7	27.5	44.6	8.2	8.1	-	-	-	-	-	-	-	-	-	68	7.5	12.4	0.11	19.2	20.4	65.5	61.7	28.5	9.6	0.02
NT8	27	30.8	7.5	8	6.25	0	4.5	80.1	15.4	0.07	0.95	4.8	-21.3	81	17	12.8	0.15	27.1	27.4	88.1	78.3	36.9	12.7	0.03
NT9	26.7	33.3	4.3	7.6	6.2	0	7.6	75.6	16.8	0.07	1.53	4.8	-22.5	12959	66.9	28.8	0.12	18.8	20.4	64.7	56.5	25.5	8.4	0.03
NT10	27.4	2	3.1	7.7	5.41	0	22.8	65.6	11.6	0.07	1.31	4.5	-26.1	65404	56.8	163.6	0.11	21.4	18.5	50.6	55.6	23.7	36.9	0.17
Team 4 (W. Korea)																								
YS1	28.1	26.7	7.3	8.3	6.04	0	4.3	84.3	11.4	0.05	0.98	9.3	-23.3	12	14.8	22	0.09	25.2	6.5	40.0	81.6	23.7	3.3	0.01
YS2	29.2	0.2	5.8	9.2	6.34	0	10.2	72.1	17.7	0.05	1.14	9.2	-26.1	18	9.8	16.8	0.14	27.4	6.9	42.2	87.3	29.7	4.3	0.01
HP	34.8	31.3	4.4	7.7	-	-	-	-	-	0.04	0.82	7.6	-20.4	16	9.6	5.2	-	-	-	-	-	-	-	-
JD	25.3	32.3	7.4	8.2	6.48	0	1.3	83.5	15.2	0.04	1.04	7.7	-20.5	13	6.8	25.9	-	-	-	-	-	-	-	-
GS	33.4	24.9	7.3	7.9	5.76	0	15	72.3	12.7	0.06	0.71	7.1	-21.3	29	12.7	6	-	-	-	-	-	-	-	-
GG1	29.3	0.1	6.7	8.7	6.34	0	7.1	76.5	16.4	0.08	1.31	5.5	-22.6	139	92.3	7.2	0.27	34.1	8.5	42.5	107.1	43.3	5.0	0.05
GG2	35.7	12.7	3.7	7.6	6.3	0	10.6	72.7	16.7	0.1	1.6	8	-22.6	62	24.8	7.6	0.25	27.8	8.8	44.7	85.2	33.3	3.2	0.03
AM	27.1	30.5	6	7.5	2.28	0	100	0	0	0	0.03	18.2	-19.5	10	4.4	5.4	0.01	15.4	4.8	15.0	9.2	4.0	4.2	-
ML	23.1	31.2	7.5	7.6	1.64	0	100	0	0	0	0.02	20.3	-18.7	18	4.5	5.7	0.02	38.0	7.0	18.0	9.6	3.7	7.7	-
SD	21.7	31.3	6.6	7.5	2.11	0	98.2	1.8	0	0.03	0.1	13.9	-24.8	14	6.2	8.2	0.03	28.2	5.6	33.4	36.1	10.5	4.8	-
SG1	36.6	0.2	12	9.7	-	-	-	-	-	0	0.05	7.6	-24.3	7	3.7	6.7	0.04	25.8	7.4	38.1	35.4	15.7	6.3	-
SG2	28.5	27.2	4.4	7.7	5.99	0	13.9	71.2	14.9	0.15	1	8.9	-22.7	66	14.3	7.6	0.12	34.4	24.0	104.0	66.0	30.0	8.3	0.03
AS1	32.8	0.2	10.1	9.1	-	-	-	-	-	0.03	0.02	11.3	-24.9	10	3.2	7.2	0.09	43.4	18.9	89.6	49.4	23.2	7.4	0.01
AS2	29.5	24.9	4.2	7.8	5.44	0	24.4	63.7	11.9	0.11	0.66	8.8	-21.7	61	17.5	33.7	0.09	24.3	21.1	91.8	58.8	28.2	7.8	0.03
DB	26.4	22.5	6.3	7.7	4.99	0	38.7	51.7	9.6	0.11	1.06	8.9	-21	37	20.4	5.2	0.06	35.0	18.3	87.5	67.5	42.0	6.7	0.03
LS1	29.3	22.2	4.6	7.6	5.8	0	16.6	70.6	12.8	0.11	0.8	6.3	-21.6	35	43.2	9	0.08	19.6	16.0	70.2	49.2	20.0	4.3	0.02
LS2	27.2	28.6	6.5	7.7	5.6	0	21.4	66.3	12.3	0.13	1.38	7.3	-21.6	41	41.8	11.6	0.10	24.5	21.2	87.9	59.4	22.4	4.8	0.03
LS4	25.9	28.8	8.5	8.1	3.2	0	69.2	27.4	3.5	0.02	0.13	7.5	-21	11	13	6	0.16	40.6	25.5	113.0	45.0	20.2	5.3	0.03
CS1	33.3	1.5	12.7	9.3	-	-	-	-	-	-	-	-	-	12	3	3	0.03	24.6	10.5	32.5	33.8	9.9	3.3	0.01
CS2	29.9	29.6	7.7	7.5	-	-	-	-	-	-	-	-	-	15	9.2	5.6	0.05	20.8	14.6	62.8	68.4	23.8	6.6	0.02

- Not analyzed

* The sample at these sites were collected at ebb tide time in the estuary (considered to be seawater locations)

** N. China: North China; C. China: Center China; S. China: South China; W. Korea: West sea of Korea

Table 3. Data statistics of the water quality and sediment properties monitored in the subtidal environments of the sampling sites along the coast of the Bohai and Yellow seas. Minimum, maximum, mean values, and standard deviation of environmental variables provided.

	All			Region Mean (± SD)				Habitat Mean (± SD)			Landuse Mean (± SD)						
	Min	Max	Mean(±SD)	1	2	3	4	Fresh	Brackish	Saline	Agricul.	Indust.	Munici.	Saltern	Aquacul.	Beach	Barren
Water																	
pH	3.7	9.5	8.0(±0.6)	8.1(±0.5)	8.0(±1.0)	7.8(±0.3)	7.8(±0.4)	8.1(±0.5)	8.1(±0.4)	7.7(±0.9)	8.06(±0.5)	8.1(±0.5)	8.2(±0.3)	8.2(±0.6)	7.9(±0.2)	7.9(±0.3)	7.7(±1.0)
Temperature (˚C)	21.6	35.7	27.7(±2.4)	26.8(±1.8)	28.8(±2.4)	28.0(±1.5)	27.6(±3.7)	27.7(±2.2)	28.1(±2.8)	27.2(±2.0)	28.4(±3.0)	27.9(±1.6)	26.7(±1.8)	29.5(±2.3)	27.1(±3.8)	26.8(±3.3)	27.8(±1.6)
DO (mg L^{-1})	2.4	21.8	7.5(±2.7)	7.7(±1.6)	8.5(±3.7)	6.9(±3.2)	5.9(±1.5)	7.3(±2.4)	7.6(±2.8)	7.6(±3.0)	7.03(±2.2)	7.5(±2.9)	7.7(±2.2)	9.0(±3.2)	7.3(±1.8)	7.4(±1.7)	7.8(±3.8)
Salinity (psu)	0.0	46.6	20.2(±14.7)	16.4(±17.1)	21.9(±9.7)	23.4(±17.3)	23.6(±9.5)	1.1(±1.5)	21.6(±6.1)	35.8(±4.3)	11.4(±13.3)	26.0(±13.3)	19.6(±15.5)	32.8(±9.2)	22.9(±7.5)	19.9(±13.8)	21.7(±15.7)
Sediment																	
Mean grain size (Ø)	1.6	7.2	4.8(±1.6)	4.7(±1.5)	4.4(±1.6)	5.8(±1.1)	4.5(±1.8)	5.0(±1.6)	4.5(±1.6)	4.9(±1.5)	5.3(±1.4)	5.2(±1.0)	5.1(±1.6)	4.9(±1.6)	4.5(±2.5)	2.9(±1.4)	4.7(±1.5)
Gravel (%)	0	0	0(±0)	0(±0)	0(±0)	0(±0)	0(±0)	0(±0)	0(±0)	0(±0)	0(±0)	0(±0)	0(±0)	0(±0)	0(±0)	0(±0)	0(±0)
Sand (%)	0.4	100	39.4(±33.5)	41.0(±31.2)	49.0(±35.0)	17.8(±24.2)	45.5(±38.6)	35.9(±34.1)	44.5(±32.6)	37.0(±34.3)	28.1(±29.6)	27.3(±19.0)	34.0(±30.1)	40.1(±40.5)	47.6(±46.8)	81.5(±29.0)	44.2(±35.6)
Silt (%)	0	87.1	50.8(±27.1)	49.6(±24.9)	43.6(±29.1)	67.5(±19.3)	45.6(±31.9)	53.4(±27.3)	46.7(±26.8)	52.9(±27.6)	60.5(±24.6)	61.9(±15.2)	54.1(±23.1)	50.3(±32.3)	41.3(±34.7)	16.2(±24.3)	46.8(±28.7)
Clay (%)	0	27.3	9.8(±7.3)	9.4(±7.2)	7.5(±7.2)	14.7(±6.6)	8.9(±6.8)	10.8(±8.1)	8.8(±6.6)	10.1(±7.5)	11.3(±6.0)	10.8(±5.7)	11.9(±7.7)	9.6(±9.2)	11.1(±12.4)	2.3(±4.9)	9.0(±7.8)
TN	0.0	0.4	0.1(±0.1)	0.1(±0.1)	0.1(±0.0)	0.1(±0.0)	0.1(±0.1)	0.1(±0.1)	0.1(±0.0)	0.1(±0.0)	0.1(±0.1)	0.1(±0.0)	0.1(±0.1)	0.1(±0.0)	0.1(±0.1)	0.0(±0.0)	0.0(±0.0)
TC	0.0	6.7	1.0(±1.0)	1.4(±1.4)	0.6(±0.6)	0.9(±0.5)	0.7(±0.6)	1.4(±1.5)	0.8(±0.8)	0.8(±0.6)	1.2(±1.5)	1.0(±0.4)	1.7(±1.2)	0.7(±0.4)	0.8(±0.8)	0.3(±0.5)	0.6(±0.6)
d15N	3.2	21.0	7.9(±3.0)	7.8(±1.8)	8.2(±3.3)	6.1(±1.4)	10.3(±4.9)	7.2(±2.1)	7.9(±3.1)	8.6(±3.5)	7.1(±1.6)	7.0(±1.8)	8.2(±1.5)	6.7(±1.2)	10.4(±7.2)	11.2(±6.1)	7.3(±1.7)
d13C	-28.1	-16.5	-22.3(±2.0)	-22.6(±2.0)	-21.7(±2.3)	-23.1(±1.6)	-21.6(±1.7)	-23.3(±2.4)	-22.1(±1.8)	-21.7(±1.6)	-22.2(±1.4)	-22.4(±1.6)	-23.5(±1.9)	-20.2(±3.2)	-21.4(±1.1)	-21.4(±3.4)	-22.5(±1.9)
pH	6.4	9.0	7.9(±0.5)	7.8(±0.3)	8.2(±0.6)	8.0(±0.2)	7.2(±0.7)	7.9(±0.5)	7.8(±0.7)	7.9(±0.3)	7.6(±0.6)	7.7(±0.5)	7.7(±0.4)	8.5(±0.4)	7.8(±0.3)	8.3(±0.5)	8.1(±0.4)
Organic Matter	1.5	49.7	12.8(±9.7)	15.6(±11.5)	9.2(±8.6)	11.6(±6.8)	13.6(±7.6)	16.6(±13.1)	11.6(±7.8)	10.6(±6.9)	14.9(±11.3)	14.2(±9.5)	17.0(±11.4)	3.5(±2.3)	6.3(±0.5)	10.2(±8.8)	10.4(±7.2)
Heavy Metal																	
Cd	0.1	1.8	0.2(±0.2)	0.2(±0.1)	0.2(±0.4)	0.1(±0.1)	0.1(±0.1)	0.2(±0.1)	0.2(±0.4)	0.1(±0.1)	0.2(±0.1)	0.3(±0.4)	0.2(±0.2)	0.1(±0.0)	0.1(±0.0)	0.1(±0.1)	0.1(±0.1)
Pb	13.7	60.5	26.9(±10.0)	27.5(±8.8)	24.2(±9.9)	26.0(±11.8)	31.8(±10.5)	30.2(±12.9)	26.1(±9.7)	24.7(±6.4)	29.2(±10.2)	25.3(±6.6)	32.4(±12.6)	18.1(±1.2)	20.5(±1.5)	25.6(±8.8)	25.3(±10.8)
Cu	4.8	83.0	22.9(±13.4)	23.8(±12.5)	22.9(±16.9)	24.1(±12.5)	18.3(±9.2)	27.0(±15.8)	23.1(±14.4)	19.0(±8.3)	22.5(±14.0)	23.1(±10.3)	29.7(±18.9)	15.4(±2.3)	17.4(±1.2)	16.6(±12.7)	23.0(±12.0)
Zn	15.0	383.0	82.0(±57.9)	81.5(±36.4)	87.2(±95.3)	78.3(±32.9)	77.6(±38.7)	89.2(±44.9)	92.0(±82.3)	64.8(±25.3)	82.0(±30.6)	94.0(±80.2)	111.2(±88.6)	46.0(±10.6)	54.8(±4.9)	53.0(±37.6)	74.3(±33.2)
Cr	9.2	146.0	58.0(±20.6)	60.0(±17.3)	53.1(±25.5)	66.3(±13.5)	50.4(±24.0)	65.3(±16.7)	55.6(±22.7)	54.1(±20.3)	63.6(±13.0)	63.1(±27.0)	56.8(±18.3)	49.1(±8.1)	62.0(±15.3)	38.4(±24.6)	58.1(±19.4)
Ni	3.7	45.2	24.1(±8.9)	23.8(±8.4)	22.2(±7.9)	28.5(±6.8)	23.1(±13.2)	26.0(±8.1)	23.6(±8.2)	23.0(±10.4)	26.4(±7.9)	26.1(±8.8)	24.7(±7.9)	21.2(±3.9)	21.2(±3.4)	16.0(±12.8)	24.4(±8.9)
As	2.3	65.9	8.9(±8.1)	7.2(±4.3)	10.7(±12.7)	11.2(±7.9)	6.8(±2.4)	9.0(±7.4)	9.6(±11.2)	8.0(±4.2)	7.2(±3.4)	9.5(±8.2)	12.0(±16.3)	7.3(±1.7)	7.2(±2.5)	6.7(±3.6)	9.1(±4.8)
Hg	0.0	0.4	0.1(±0.1)	0.1(±0.1)	0.1(±0.1)	0.0(±0.0)	0.0(±0.0)	0.1(±0.1)	0.1(±0.1)	0.0(±0.0)	0.0(±0.0)	0.1(±0.1)	0.1(±0.1)	0.0(±0.0)	0.0(±0.0)	0.0(±0.1)	0.0(±0.1)

*nd: not detected