

Effects of hypoxia on community structure of macrobenthos in the Zhujiang River Estuary

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Abstract

Macrobenthos can serve as an indicator of hypoxia in the estuarine ecosystem. This comparative study surveyed macrobenthos from hypoxic and non-hypoxic areas of the Zhujiang (Pearl) River Estuary (PRE), and explores the effects of environmental factor on the macrobenthos community structure. In July 2020, 49 macrobenthos species were collected from the hypoxic area, contrasting with 91 species found in the non-hypoxic area. July 2021 recorded 51 species in the hypoxic area and 76 in the non-hypoxic area. Analysis of similarities (ANOSIM) and non-metric multidimensional scaling (NMDS) showed no significant difference in the macrobenthos community structure between the two areas. However, Polychaeta displays higher species richness, abundance, and biomass in the hypoxic zone, negatively correlating to dissolved oxygen (DO). Canonical correspondence analysis (CCA) also showed that the abundance of Polychaeta was negatively correlated with that of Crustacea. Interestingly, despite the differences in Polychaeta, macrobenthos community structure remains stable between hypoxic and non-hypoxic samples. This study suggests Polychaeta's potential adaptation to hypoxic conditions in the PRE's hypoxic area. Finally, Spearman correlation analysis showed that DO have a significant negative correlation with total phosphorus (TP), total nitrogen (TN) and total organic carbon (TOC) in the PRE, indicating that water eutrophication would exacerbate the occurrence of hypoxia.

Key words hypoxia, macrobenthos, community structure, Zhujiang River Estuary

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1 Introduction

Hypoxia occurs when dissolved oxygen (DO) concentration fall below 2.0 mg/L, posing a significant challenge to ecosystems in estuaries and coastal waters (Ni et al., 2023). Estuarine hypoxia is influenced by both natural and anthropogenic process (Eby and Crowder, 2002). The species density and diversity in the hypoxic area are relatively low, leading to simplified community structures. Dominant species may shift from foundational species that stabilize communities to opportunistic species characterized by short life cycles and small body sizes (Chu and Tunnicliffe, 2015).

Macrobenthos, which lives on or within sediments for most or all their life, plays a substantial role as primary and secondary consumers in aquatic ecosystems. They exhibit low mobility, strong regional preference and vulnerability to environmental changes. Changes in species composition, diversity and temporal-spatial community dynamics could not only reflect the environmental conditions but also serve as indicators in pollution monitoring and environmental quality assessment (Taft and Haig, 2005). According to the composition of different faunas, macrobenthos can be classified into Polychaeta, Crustacea, Mollusca, Echinodermata and others (Benke and Huryn, 2010).

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The Zhujiang (Pearl) River Estuary (PRE) has unique geographical and hydrological characteristics, along with rich biodiversity. However, rapid economic development, urbanization and population explosion in the Zhujiang River Delta have led to increasing sewage discharge into the PRE over the years (He et al., 2014; Li et al., 2018, 2020). This, coupled with combined impact of global climate change and human activities, has significantly disturbed the PRE ecosystem. Some areas of the PRE have suffered serious pollution, intensifying hypoxia and expanding the hypoxic area. As a result, the PRE is facing severe environmental pressures and ecological security risks, emerging as a prominent example of a coastal ecological fragile area in the world (He et al., 2014; Li et al., 2018; Luo et al., 2021).

To explore the impact of hypoxia on the macrobenthic community structure in the PRE, macrobenthos were collected from the PRE in July 2020 and July 2021. The study also examined the influence of DO and other environmental factors on the macrobenthic community structure. The aims were to explore the distribution of macrobenthos in the PRE and the succession direction of community structure under hypoxic conditions. This research aims to enhance conservation efforts for macrobenthos in the PRE and the ecosystem. Furthermore, the findings contribute to a deeper understanding of macrobenthic communities in the PRE and provide foundational data for developing ecological and environmental protection strategies in the PRE.

2 Materials and methods

2.1 Study area

The Zhujiang (Pearl) River has a total length of 2 320 km and a drainage area of 453 690 km². In recent years, hypoxia has occurred frequently in the PRE, mainly in

summer and was concentrated in the shallow waters of middle and western Lingdingyang Bay, as well as the subestuary outside Modaomen (Zhou et al., 2014; Li et al., 2018).

2.2 Sampling

In this study, macrobenthos in the PRE were investigated in July 2020 (at 33 stations) and July 2021 (at 22 stations). The spatial distribution of sampling stations is shown in Fig. 1. Among all surveyed stations, 7 stations were hypoxic in both 2020 and 2021.

At each station, mud samples were collected using a 0.1 m² dredger with 3 replicates. The sediment was then sieved through a 0.5 mm mesh sieve to recover macrobenthos. Seabird conductivity-temperature-depth (CTD) multi-functional temperature salt depth meter and Yellow Springs Instruments (YSI) multi parameter water quality detector were used to measure the environmental factors at the bottom water, including depth (Z), water temperature (T), salinity (S), turbidity (F), chlorophyll concentration (C_{Chl}), pH and DO. In July 2021, 5 cm surface sediment samples were collected from each station. The samples were analyzed by Perkin Elmer 2400 element analyzer to determine total nitrogen (TN), total phosphorus (TP) and total organic carbon (TOC) in the sediments.

2.3 Data analysis

Specimens were identified to the lowest possible taxonomic level, and the differences in community characteristics of macrobenthos between hypoxic area and non-hypoxic area were analyzed. In this study, the stations with bottom seawater DO ≤ 3 mg/L were taken as the hypoxic (Castrillón-Cifuentes et al., 2023). Species composition, abundance (ind./m²) and biomass (g/m²) of the main taxa were calculated. Dominant species of macrobenthos were identified using the species hierarchy analysis, with calculations based on Berger and Parker (1970):

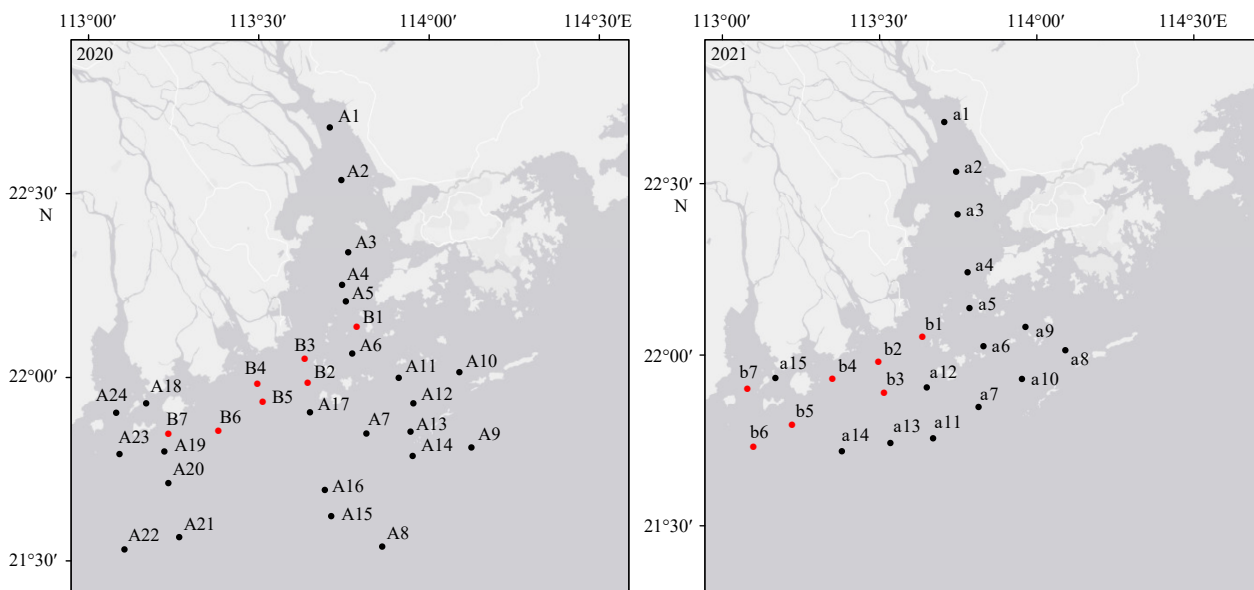


Fig. 1. Distribution of macrobenthos sampling sites in the Zhujiang River Estuary (Note: red sites are hypoxic sites).

$$Y = (n_i/N) \cdot f_i, \quad (1)$$

where Y is the dominance value, N is the total number, n_i is the number of individuals of the i -th species, and f_i is the frequency of occurrence of the species at each station. When $Y > 0.02$, it is regarded as the dominant species.

Three diversity indices of the community were calculated, including the Shannon-Wiener diversity (H'), Pielou's evenness (J') and Margalef's index (D) (Shannon and Weaver, 1949; Pielou, 1975; Margalef, 1958).

Shannon-Wiener diversity (H'):

$$H' = - \sum_i^s P_i \log_2 P_i, \quad (2)$$

where P_i is the density ratio of the i -th species in the sample.

Pielou's evenness (J'):

$$J' = H' / \log_2 S, \quad (3)$$

where S is the number of species.

Margalef's index (D):

$$D = (S - 1) / \log_2 \rho, \quad (4)$$

where ρ is the density (unit: ind./m²).

SPSS statistics was used for Spearman correlation analysis to examine the relationship between environmental factors and macrobenthos. Canonical correspondence analysis (CCA) was conducted in R language with the package PRIMER version 6 to analyze the relationship between the abundance of macrobenthos and environmental factors. Non-parametric multivariate techniques were used to compare assemblage composition between hypoxic

and non-hypoxic areas. To mitigate the impact of outliers and account for the varying weights of rare and dominant species, macrobenthos community structure was evaluated using a Bray-Curtis similarity matrix to the fourth root transformed biomass (g/m²) data (Bray and Curtis, 1957). Assemblage differences were further analyzed using analysis of similarities (ANOSIM), cluster analysis (Cluster), non-metric multidimensional scaling (NMDS) and similarity percentages (SIMPER) (Clarke and Warwick, 1994). These multivariate analyses were performed using the software package PRIMER v6.0.

3 Result

3.1 Species composition

The species composition of macrobenthos is shown in Fig. 2. In July 2020, 49 species of macrobenthos were collected in the hypoxic area, with Polychaeta has the highest count at 21 species, followed by 4 species of Mollusca, 15 species of Crustacea, 3 species of Echinodermata and 6 species of other animals. In contrast, 91 species were collected in non-hypoxic area, with Polychaeta also highest in number at 33 species, accompanied by 17 species of Mollusca, 23 species of Crustacea, 7 species of Echinodermata and 11 species of others. The proportion of Polychaeta was higher in hypoxic than that in non-hypoxic areas, whereas Mollusca species were less abundant in non-hypoxic areas.

In July 2021, 51 species of macrobenthos were collected in the hypoxic area, 29 of which were Polychaeta. There were also 3 species of Mollusca, 6 species of Crustacea, 4 species of Echinodermata and 9 species of others. In the 76 species collected from non-hypoxic area, Polychaeta is also the most abundant, where 44 species were

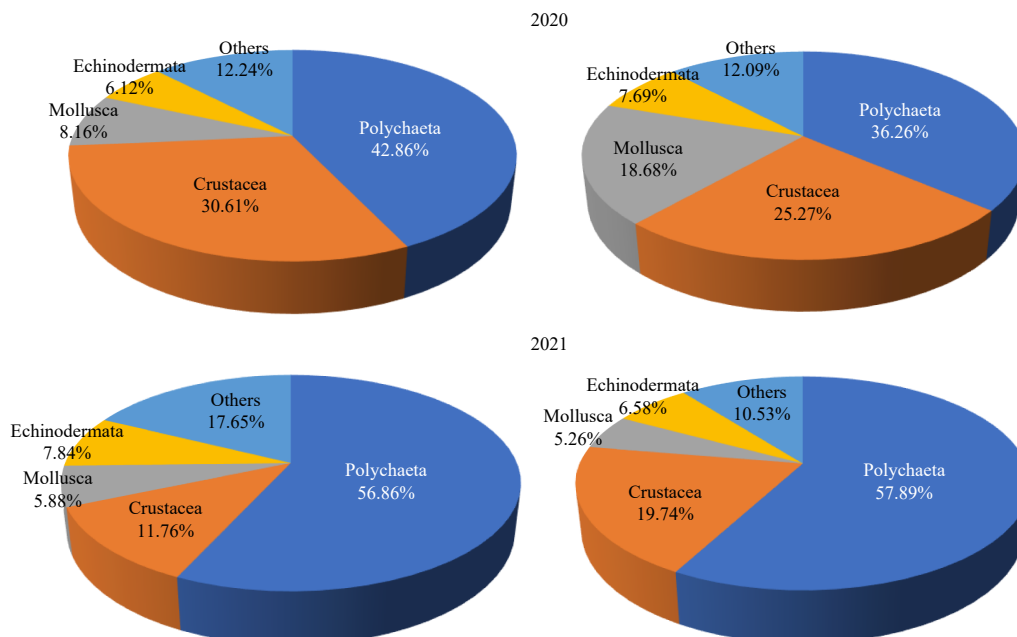


Fig. 2. Species composition of macrobenthos in 2020 and 2021 (left: hypoxic area; right: non-hypoxic area).

identified. Additionally, there were 4 species of Mollusca, 15 species of Crustacea, 5 species of Echinodermata and 8 species of others were.

3.2 Abundance and biomass of macrobenthos

In July 2020, the average abundance and biomass of macrobenthos in hypoxic area were 257.14 ind./m² and 75.98 g/m², while in non-hypoxic area they were 122.10 ind./m² and 20.22 g/m², respectively. In July 2021, the average abundance and biomass of macrobenthos in hypoxic area were 310.71 ind./m² and 66.86 g/m², and in non-hypoxic area were 408.33 ind./m² and 29.48 g/m², respectively. Notably, Polychaeta has the highest average abundance in both hypoxic and non-hypoxic area. Furthermore, the average abundance and biomass of Polychaeta in hypoxic area were higher compared to non-hypoxic area.

3.3 Dominant species of macrobenthos

In July 2020 and July 2021, Polychaeta species have the highest dominance in hypoxic area, whereas Crustacea species display highest dominance in non-hypoxic area. It is worth noting that *Neotrypaea japonica* was one of the most dominant species in both hypoxic and non-hypoxic areas (Table 1). These results also suggest that Polychaeta might prefer habitats with low oxygen levels.

3.4 Species diversity of macrobenthos

In July 2020, the species diversity indices of mac-

robenthos in the hypoxic area varied: Margalef's index ranged from 1.21 to 3.22, Shannon-Wiener diversity ranged from 1.62 to 2.72, and Pielou's evenness index ranged from 0.81 to 0.92. In non-hypoxic area during the same survey, Margalef's index ranged from 0.31 to 2.97, Shannon-Wiener diversity ranged from 0.64 to 2.65, and for Pielou's evenness index ranged from 0.81 to 1.00.

In July 2021, the hypoxic area exhibited Margalef's index ranging from 0.50 to 4.36, Shannon-Wiener diversity ranging from 1.00 to 2.88, and Pielou's evenness index ranging from 0.45 to 0.96. Meanwhile, in non-hypoxic area from the same survey, Margalef's index ranged from 0.79 to 4.55, Shannon-Wiener diversity ranged from 0.85 to 3.00, and Pielou's evenness index ranged from 0.26 to 0.98.

Overall, there was no significant difference in species diversity indices between hypoxic and non-hypoxic area in both surveys, suggesting that hypoxia did not have a significant impact on these species diversity indices.

3.5 Correlation between environmental factors

The water depth (Z) showed a significant negative correlation with T , F , C_{Chl} , TP and TOC, and a significant positive correlation with DO and S . WT was positively correlated with F , C_{Chl} and TOC, and negatively correlated with Sal. DO exhibited a negatively correlation with F , TP, TN and TOC, and a positive correlation with pH. F was negatively correlated with S and positively correlated with TOC. TN was positively correlated with TP and

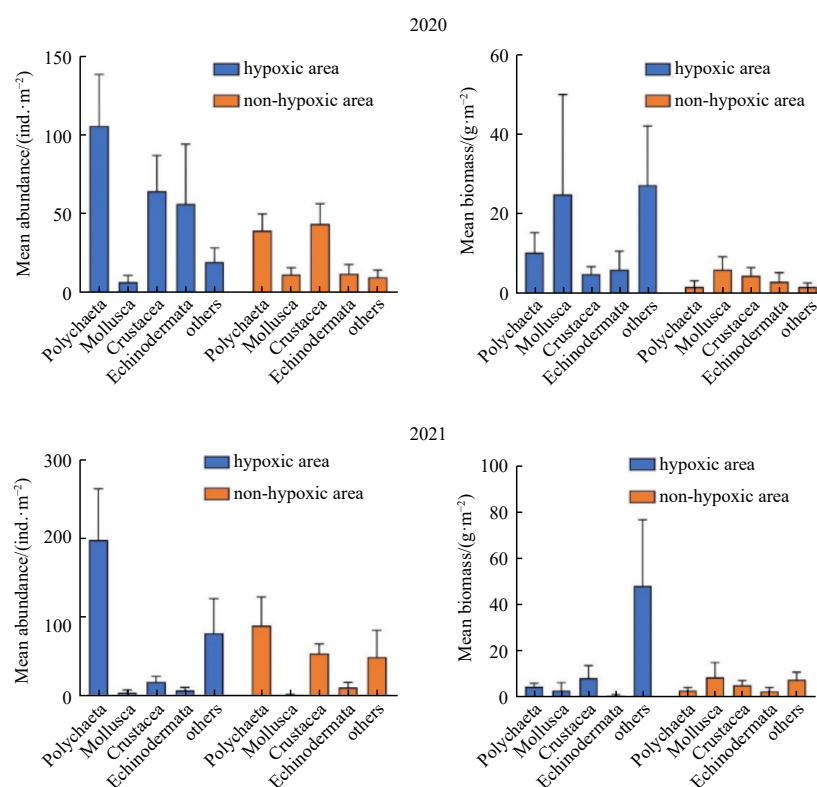


Fig. 3. Mean abundance and biomass of different macrobenthos faunas in hypoxic region and non-hypoxic region in 2020 and 2021.

Table 1. Dominant macrobenthos species in hypoxic area and non-hypoxic area

Date	region	Species	Dominance (Y)
July 2020	hypoxic area	<i>Cossurella dimorpha</i>	0.096
		<i>Sternaspis sculata</i>	0.058
		<i>Neotrypaea japonica</i>	0.052
		<i>Amphioplus sinicus</i>	0.021
July 2021	non-hypoxic area	<i>Neotrypaea japonica</i>	0.027
	hypoxic area	<i>Paraprionospio pinnata</i>	0.190
		<i>Lintriolobus brevirostris</i>	0.057
		<i>Neotrypaea japonica</i>	0.027
<i>Apionsoma trichocephala</i>		0.026	
	non-hypoxic area	<i>Nephtys oligobranchia</i>	0.021
		<i>Linopherus ambigua</i>	0.021
		<i>Neotrypaea japonica</i>	0.094
		<i>Lintriolobus brevirostris</i>	0.041
		<i>Paraprionospio pinnata</i>	0.041

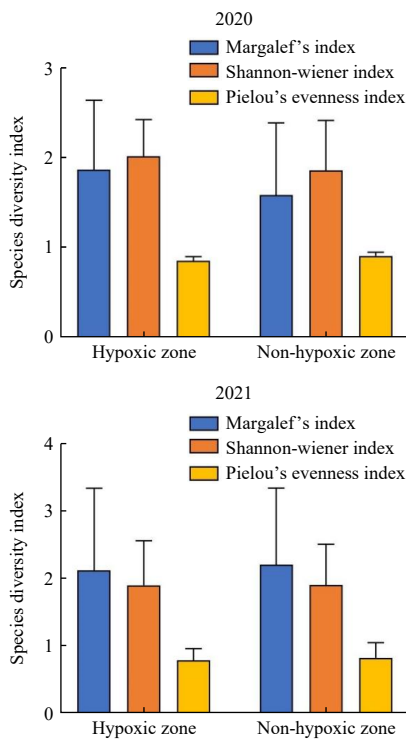


Fig. 4. Mean species diversity index of macrobenthos in hypoxic and non-hypoxic area in 2020 and 2021.

TOC (Table 2).

3.6 Effects of environmental factors on the macrobenthos community

Spearman correlation analysis indicated that DO had a significant negative correlation with the abundance and biomass of macrobenthos, and a significant positive correlation with the evenness index. The correlation between other environmental factors and macrobenthos was not significant, indicating that DO had the strongest association with macrobenthos. Specifically, the average abundance and biomass of Polychaeta were higher in the hypoxic area compared to non-hypoxic area, and DO was significantly negatively correlated only with the abundance and biomass of Polychaeta (Table 3).

CCA results for July 2020 indicated that the first axis (CCA1) was positively correlated with *T*, *C_{Chl}* and *F*, and negatively correlated with *Z*, *S* and DO. CCA1 and CCA2 together explained 90.91% of the variation in macrobenthos community composition. In the results for July 2021, CCA1 was positively correlated with *Z*, pH, DO and *S*, and negatively correlated with *T*, *F*, TP and TOC. CCA1 and CCA2 explained 90.38% of the variation in macrobenthos community composition. The abundance of

Table 2. Spearman correlation analysis between environmental factors

	<i>Z</i>	<i>T</i>	DO	<i>F</i>	<i>C_{Chl}</i>	<i>S</i>	pH	TN	TP	TOC
<i>Z</i>	1.000									
<i>T</i>	-0.702**	1.000								
DO	0.431**	-0.138	1.000							
<i>F</i>	-0.742**	0.429**	-0.482**	1.000						
<i>C_{Chl}</i>	-0.473**	0.432**	0.031	0.273	1.000					
<i>S</i>	0.763**	-0.840**	0.132	-0.512**	-0.378*	1.000				
pH	0.239	-0.134	0.658**	-0.121	-0.464	0.364	1.000			
TN	-0.164	0.151	-0.456*	0.218	-0.393	-0.083	-0.106	1.000		
TP	-0.522*	0.388	-0.797**	0.429	0.179	-0.256	-0.419	0.768**	1.000	
TOC	-0.526*	0.505*	-0.474*	0.571**	-0.214	-0.535*	-0.183	0.723**	0.708**	1.000

Note: ** correlation is significant with $p < 0.01$; * correlation is significant with $p < 0.05$.

Table 3. Spearman correlation analysis between environmental factors and macrobenthos

	Z	T	DO	F	C _{Chl}	S	pH	TN	TP	TOC
Number of species	-0.226	0.028	-0.213	0.106	-0.059	0.005	0.270	-0.121	-0.006	0.409
Total abundance	-0.174	-0.029	-0.386**	0.112	-0.169	0.098	0.103	-0.248	-0.059	0.023
Total biomass	-0.073	-0.232	-0.292*	0.031	-0.091	0.112	0.170	-0.084	-0.025	-0.111
Margalef's index	0.053	-0.082	-0.001	-0.077	0.007	0.237	0.403	-0.419	-0.400	-0.158
Shannon-Wiener index	0.115	-0.253	-0.025	-0.106	0.050	0.290	0.048	-0.285	-0.247	-0.363
Pielou's evenness index	0.254	-0.082	0.349*	-0.134	0.043	-0.124	-0.096	-0.029	-0.116	-0.033
Abundance of Polychaeta	-0.267	0.236	-0.364*	0.175	0.266	-0.129	-0.150	-0.097	0.200	0.276
Biomass of Polychaeta	-0.171	0.062	-0.470**	0.109	0.036	0.017	0.034	-0.241	0.053	0.201
Abundance of Mollusca	0.341	-0.046	0.258	-0.251	0.232	0.116	-0.338	-0.135	-0.439	-0.507
Biomass of Mollusca	0.239	-0.062	0.110	0.036	-0.158	-0.131	0.314	-0.829*	-0.371	0.086
Abundance of Crustacea	0.256	-0.249	0.125	-0.084	-0.088	0.292	0.624**	-0.334	-0.388	0.169
Biomass of Crustacea	-0.161	-0.096	-0.108	-0.148	0.030	0.087	0.176	-0.262	-0.235	0.150
Abundance of Echinodermata	-0.279	-0.112	-0.213	0.135	-0.090	0.227	0.342	-0.439	-0.586	-0.024
Biomass of Echinodermata	-0.122	-0.018	0.033	-0.105	0.316	0.099	0.405	-0.095	-0.357	-0.238
Abundance of others	0.022	-0.079	-0.229	0.060	0.065	0.151	0.160	0.076	0.091	-0.131
Biomass of others	0.012	-0.223	-0.141	0.054	-0.221	0.245	0.300	0.214	0.250	-0.032

Note: ** the correlation is significant with $p < 0.01$; * the correlation is significant with $p < 0.05$.

Polychaeta in July 2020 was positively correlated with F , T and C_{Chl} , but showed an inverse relationship with Z and DO . In contrast, Crustacea was positively correlated with Z and DO . Mollusca, which was positively associated with high T , C_{Chl} and DO , differs from Echinodermata and other faunas that seem to prefer environment with high F and S .

In July 2021, Polychaeta were positively correlated with F , T , TP and TOC , and negatively correlated with Z , pH and DO . Crustacea tended to inhabit environments with higher pH , Z and DO . Mollusca showed preference to environments with higher T , S , TP , TN and TOC . Echinodermata tended to prefer environments with higher S , Z , pH and DO , while other taxa tended to occur in environments with higher S and TN (Fig. 5).

3.7 Non-parametric multivariate analysis

ANOSIM analysis revealed no significant distinction in macrobenthos community structure between hypoxic and non-hypoxic areas for both the July 2020 ($R = -0.223$, $P = 0.996$), and July 2021 ($R = 0.044$, $P = 0.316$) datasets. This finding was further supported by cluster and NMDS analysis, as shown in Figs 6 and 7.

4 Discussion

Environmental factors have significant influences on the community structure of macrobenthos. These factors including Z , T , C_{Chl} , S , F , DO , various nutrients, organic matter, and sediment types (Lu, 2005). Macrobenthic communities and feeding guilds are closely correlated with environmental factors like bottom water chlorophyll a , nutrients, and sediment total TOC (Liao et al., 2019). Salinity can restrict the physiological functions of macrobenthos, necessitating adjustments in ion concentration in body fluid to regulate osmotic pressure (Cognetti and Maltagliati, 2000; Ritter et al., 2005). Water depth deter-

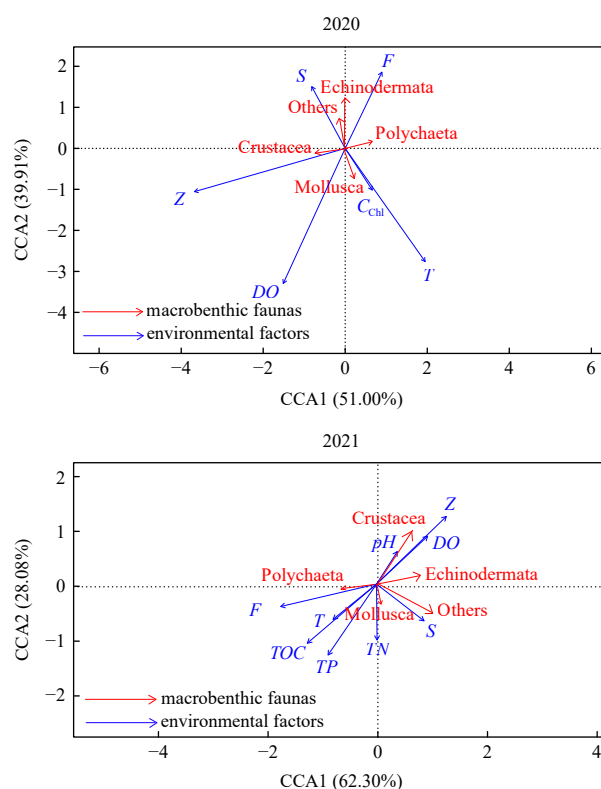


Fig. 5. Canonical correspondence analysis of different macrobenthos faunas and environmental factors in 2020 and 2021.

mines water pressure, thereby impacting the distribution of macrobenthos (Mutlu et al., 2010). Sediment pollution shifts benthic macrofauna species composition, favoring smaller sub-surface dwellers in innermost location and large mid to deep burrowers in outer locations (Ryu et al., 2011). Nutrients and organic matter provide material and energy for organisms, but excessive amount can lead to eutrophication and hypoxia (Kennish, 1997; Galic et al., 2019).

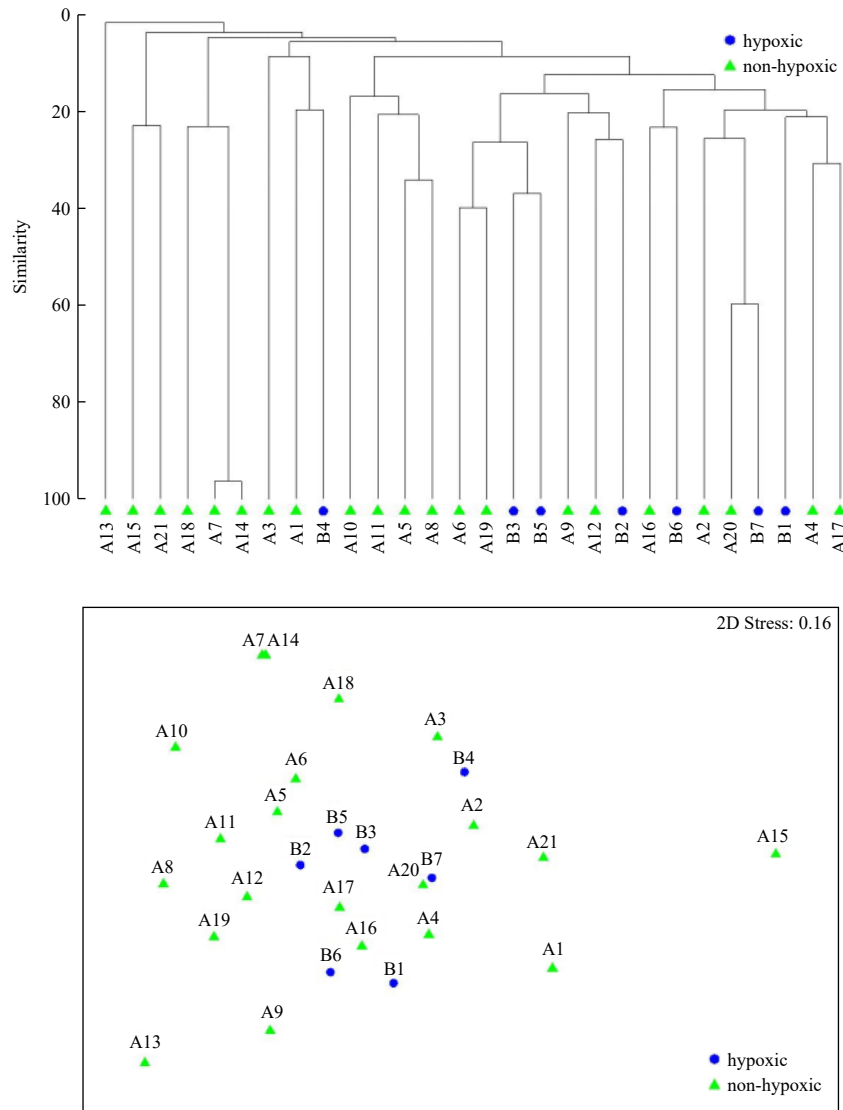


Fig. 6. Cluster and NMDS analysis of macrobenthos community structure in 2020. 2D Stress = 0.16. This suggests that when the original data was reduced to two-dimensional space for display through MDS, the distance relationships among data points are well-preserved. That is, the relative positions of different samples (represented by blue dots and green triangles) in the graph can accurately reflect their distance relationships in the original high-dimensional data space, indicating that this two-dimensional ordination plot is quite representative and reliable.

The availability of DO varies across different regions within water bodies. In Mississippi Bight, DO conditions beneath the freshwater cap are spatially and temporally variable, resulting in areas of hypoxia and near-hypoxic conditions over portions of the shelf (Dzwonkowski et al., 2018). In another study, DO in the surface layer is closely related to the photosynthesis of phytoplankton and the process of atmospheric reoxygenation, whereas in the bottom layer it mainly comes from the exchange of water body, physiological activities of aquatic organisms and the mineralization of bottom organic matter (Wei et al., 2007). Hypoxia occurs when DO is at a very low level. Sluggish water exchange hinders oxygen circulation, thereby fostering formation of hypoxic environment in some water bodies (Ueda, 2013). However, the continuous intensification and expansion of hypoxia in estuarine areas are primarily results from eutrophication of water

bodies and the impact of global climate change (Karatajev et al., 2018). The growth and reproduction of macrobenthos are closely tied to DO levels; hypoxic environment disrupt their normal activities, alter their community function and structure, and reduce community secondary productivity and maturity (Rakocinski and Menke, 2016; Fajardo et al., 2018; Galic et al., 2019).

In recent years, global occurrence of hypoxia have raised concerns due to their potential impacts on organisms at physiological, individual and community levels (Shivarudrappa et al., 2019; Rabalais and Baustian, 2020; Pandiya rajan et al., 2021). Numerous studies have investigated the effects of hypoxia on benthic communities. For example, Dauer (1993) investigated macrobenthos in Chesapeake Bay and found that low oxygen in the estuary can reduce the community biomass and species richness, while promoting the biomass of some opportunistic

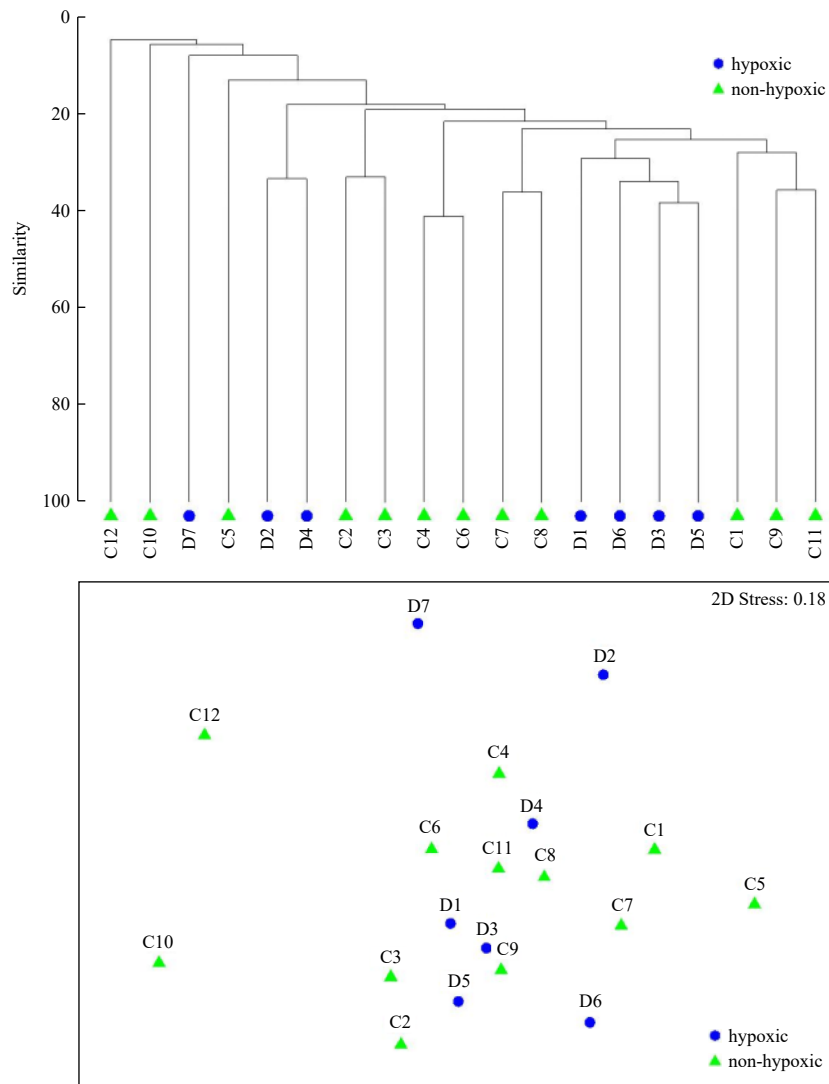


Fig. 7. Cluster and NMDS analysis of macrobenthos community structure in 2021. 2D Stress=0.18. This suggests that when the original data was reduced to two-dimensional space for display through MDS, the distance relationships among data points are well-preserved. That is, the relative positions of different samples (represented by blue dots and green triangles) in the graph can accurately reflect their distance relationships in the original high-dimensional data space, indicating that this two-dimensional ordination plot is quite representative and reliable.

species tolerant to low oxygen environments. In the Gulf of Pomerania in the southern Baltic Sea, [Powilleit and Kube \(1999\)](#) found that severe hypoxia changed the structure of macrobenthos community, leading to significant decrease in the species richness, total abundance and biomass of macrobenthos, alongside an increase in opportunistic species. [Chu and Tunnicliffe \(2015\)](#) found that hypoxia induces significant changes in the community structure of macrobenthos, simplifying it over time and favoring small opportunistic species with short life history ([Maury and Poggiale, 2013](#)). In this study, correlations between the environmental factors were found in the investigated area. The significant negative correlation of DO with *F*, TP, TN and TOC indicates that water eutrophication exacerbates hypoxia, consistent with previous findings ([Friedrich et al., 2014](#); [Coffin et al., 2018](#)). The correlation analysis between environmental factors and macrobenthos found that only DO significantly impacts the

macrobenthos community, particularly showing a significant negative correlation with the abundance and biomass of Polychaeta.

Comparative analysis between hypoxic and non-hypoxic areas revealed notable differences in benthic community composition. In hypoxic areas, there was a higher percentage of Polychaeta species compared to non-hypoxic areas, while the proportions of Mollusca and Crustacea were lower. Additionally, the average abundance and biomass of Polychaeta were higher in hypoxic areas, whereas Crustaceans showed lower abundance and biomass. Dominance patterns also differed, with Polychaeta being predominant in hypoxic areas and Crustacea dominating non-hypoxic areas. These findings suggest that hypoxic conditions favor Polychaeta habitats, and Polychaeta exhibit greater tolerance to hypoxia compared to Crustacea. Numerous studies have highlighted mechanisms by which some Polychaeta species adapt to hypox-

ic environments, such as expanding respiratory surface area through increased gill number and volume (Lamont and Gage, 2000; Hourdez et al., 2002; Castellano et al., 2020). This adaptation strategy likely contributes to the observed higher abundance and biomass of Polychaeta in hypoxic environments, reflecting their physiological resilience to low oxygen conditions compared to Crustacea.

It is generally believed that hypoxia can reduce the abundance, biomass and species richness of macrobenthos community. However, in this study, ANOSIM analysis indicated no significant difference in the macrobenthos community structure between hypoxic and non-hypoxic areas, which was corroborated by cluster and NMDS analysis results. This outcome suggests that Polychaeta species may have adapted to the hypoxic conditions, potentially increased in abundance, biomass and species diversity in hypoxic area. Therefore, it appears that hypoxia has not significantly diminished the macrobenthos communities in the PRE. Instead, they are adapting to the occurrence of hypoxic environments. This adaptation implies that the impact of hypoxia on the macrobenthos community structure in the PRE remained within a self-regulation range, where certain taxa like Polychaeta thrive under hypoxic conditions, thereby maintaining overall community stability despite the challenging environmental conditions.

5 Conclusions

In this survey, the DO in the PRE was significantly negatively correlated with TP, TN and total TOC, indicating that water eutrophication would aggravates hypoxia. The negative correlation between DO and the abundance and biomass of Polychaeta suggests that Polychaeta thrive in hypoxic areas. Polychaeta distribution showed a negative correlation with Crustacea, with Polychaeta favoring hypoxic environments while Crustacea tended to inhabit areas with higher DO concentrations. The significant impact of hypoxia on Polychaeta abundance contrasts with its lack of impact on the overall community structure of macrobenthos. This is likely due to Polychaeta's adaptation to the hypoxic environment, allowing them to increase the species diversity, abundance and biomass within the hypoxic areas.

References

- Benke A C, Huryn A D. 2010. Benthic invertebrate production—facilitating answers to ecological riddles in freshwater ecosystems. *Journal of the North American Benthological Society*, 29(1): 264–285, doi: [10.1899/08-075.1](https://doi.org/10.1899/08-075.1)
- Berger W H, Parker F L. 1970. Diversity of planktonic foraminifera in deep-sea sediments. *Science*, 168(3937): 1345–1347, doi: [10.1126/science.168.3937.1345](https://doi.org/10.1126/science.168.3937.1345)
- Bray J R, Curtis J T. 1957. An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs*, 27(4): 325–349, doi: [10.2307/1942268](https://doi.org/10.2307/1942268)
- Castellano G C, da Cunha Lana P, Freire C A. 2020. Euryhalinity of subtropical marine and estuarine polychaetes evaluated through carbonic anhydrase activity and cell volume regulation. *Journal of Experimental Zoology. Part A. Ecological and Integrative Physiology*, 333(5): 316–324, doi: [10.1002/jez.2357](https://doi.org/10.1002/jez.2357)
- Castrillón-Cifuentes A L, Zapata F A, Giraldo A, et al. 2023. Spatiotemporal variability of oxygen concentration in coral reefs of Gorgona Island (Eastern Tropical Pacific) and its effect on the coral *Pocillopora capitata*. *PeerJ*, 11: e14586, doi: [10.7717/peerj.14586](https://doi.org/10.7717/peerj.14586)
- Chu J W F, Tunnicliffe V. 2015. Oxygen limitations on marine animal distributions and the collapse of epibenthic community structure during shoaling hypoxia. *Global Change Biology*, 21(8): 2989–3004, doi: [10.1111/gcb.12898](https://doi.org/10.1111/gcb.12898)
- Clarke K. R. and Warwick, R. M. 1994. Similarity-based testing for community pattern: The 2-way layout with no replication. *Marine Biology*, 118: 167–176, doi: [10.1007/BF00699231](https://doi.org/10.1007/BF00699231)
- Coffin M R S, Courtenay S C, Pater C C, et al. 2018. An empirical model using dissolved oxygen as an indicator for eutrophication at a regional scale. *Marine Pollution Bulletin*, 133: 261–270, doi: [10.1016/j.marpolbul.2018.05.041](https://doi.org/10.1016/j.marpolbul.2018.05.041)
- Cognetti G, Maltagliati F. 2000. Biodiversity and adaptive mechanisms in brackish water fauna. *Marine Pollution Bulletin*, 40(1): 7–14, doi: [10.1016/S0025-326X\(99\)00173-3](https://doi.org/10.1016/S0025-326X(99)00173-3)
- Dauer D M. 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. *Marine Pollution Bulletin*, 26(5): 249–257, doi: [10.1016/0025-326X\(93\)90063-P](https://doi.org/10.1016/0025-326X(93)90063-P)
- Dzwonkowski B, Fournier S, Reager J T, et al. 2018. Tracking sea surface salinity and dissolved oxygen on a river-influenced, seasonally stratified shelf, Mississippi Bight, northern Gulf of Mexico. *Continental Shelf Research*, 169: 25–33, doi: [10.1016/J.CSR.2018.09.009](https://doi.org/10.1016/J.CSR.2018.09.009)
- Eby L A, Crowder L B. 2002. Hypoxia-based habitat compression in the Neuse River Estuary: context-dependent shifts in behavioral avoidance thresholds. *Canadian Journal of Fisheries and Aquatic Sciences*, 59(6): 952–965, doi: [10.1139/F02-067](https://doi.org/10.1139/F02-067)
- Fajardo M, Andrade D, Bonicelli J, et al. 2018. Macrobenthic communities in a shallow normoxia to hypoxia gradient in the Humboldt upwelling ecosystem. *PLoS One*, 13(7): e0200349, doi: [10.1371/journal.pone.0200349](https://doi.org/10.1371/journal.pone.0200349)
- Friedrich J, Janssen F, Aleynik D, et al. 2014. Investigating hypoxia in aquatic environments: diverse approaches to addressing a complex phenomenon. *Biogeosciences*, 11(4): 1215–1259, doi: [10.5194/BG-11-1215-2014](https://doi.org/10.5194/BG-11-1215-2014)
- Galic N, Hawkins T, Forbes V E. 2019. Adverse impacts of hypoxia on aquatic invertebrates: a meta-analysis. *Science of the Total Environment*, 652: 736–743, doi: [10.1016/j.scitotenv.2018.10.225](https://doi.org/10.1016/j.scitotenv.2018.10.225)
- He Biyan, Dai Minhan, Zhai Weidong, et al. 2014. Hypoxia in the upper reaches of the Pearl River Estuary and its maintenance mechanisms: a synthesis based on multiple year observations during 2000–2008. *Marine Chemistry*, 167:

- 13–24, doi: [10.1016/J.MARCHEM.2014.07.003](https://doi.org/10.1016/J.MARCHEM.2014.07.003)
- Hourdez S, Weber R F, Green B N, et al. 2002. Respiratory adaptations in a deep-sea orbiniid polychaete from Gulf of Mexico brine pool NR-1: metabolic rates and hemoglobin structure/function relationships. *Journal of Experimental Biology*, 205(11): 1669–1681, doi: [10.1242/jeb.205.11.1669](https://doi.org/10.1242/jeb.205.11.1669)
- Karatayev A Y, Burlakova L E, Mehler K, et al. 2018. Biomonitoring using invasive species in a large lake: *Dreissena* distribution maps hypoxic zones. *Journal of Great Lakes Research*, 44(4): 639–649, doi: [10.1016/j.jglr.2017.08.001](https://doi.org/10.1016/j.jglr.2017.08.001)
- Kennish M J. 1997. *Pollution Impacts on Marine Biotic Communities*. Boca Raton: CRC Press.
- Lamont P A, Gage J D. 2000. Morphological responses of macrobenthic polychaetes to low oxygen on the Oman continental slope, NW Arabian Sea. *Deep-Sea Research Part II: Topical Studies in Oceanography*, 47(1–2): 9–24, doi: [10.1016/S0967-0645\(99\)00102-2](https://doi.org/10.1016/S0967-0645(99)00102-2)
- Li Gang, Liu Jiaying, Diao Zenghui, et al. 2018. Subsurface low dissolved oxygen occurred at fresh- and saline-water intersection of the Pearl River Estuary during the summer period. *Marine Pollution Bulletin*, 126: 585–591, doi: [10.1016/j.marpolbul.2017.09.061](https://doi.org/10.1016/j.marpolbul.2017.09.061)
- Li Xiuqin, Lu Chuqian, Zhang Yafeng, et al. 2020. Low dissolved oxygen in the Pearl River estuary in summer: long-term spatio-temporal patterns, trends, and regulating factors. *Marine Pollution Bulletin*, 151: 110814, doi: [10.1016/j.marpolbul.2019.110814](https://doi.org/10.1016/j.marpolbul.2019.110814)
- Liao Y B, Shou L, Jiang Z B, et al. 2019. Effects of fish cage culture and suspended oyster culture on macrobenthic communities in Xiangshan Bay, a semi-enclosed subtropical bay in eastern China. *Marine Pollution Bulletin*, 142: 475–483, doi: [10.1016/J.MARPOLBUL.2019.03.065](https://doi.org/10.1016/J.MARPOLBUL.2019.03.065)
- Lu Lin. 2005. The relationship between soft-bottom macrobenthic communities and environmental variables in Singaporean waters. *Marine Pollution Bulletin*, 51(8–12): 1034–1040, doi: [10.1016/j.marpolbul.2005.02.013](https://doi.org/10.1016/j.marpolbul.2005.02.013)
- Luo Chen, Routh J, Luo Dinggui, et al. 2021. Arsenic in the Pearl River Delta and its related waterbody, South China: occurrence and sources, a review. *Geoscience Letters*, 8(1): 12., doi: [10.1186/s40562-021-00185-9](https://doi.org/10.1186/s40562-021-00185-9)
- Margalef R. 1958. Information theory in biology. *General System*, 3: 36–71
- Maury O, Poggiale J C. 2013. From individuals to populations to communities: a dynamic energy budget model of marine ecosystem size-spectrum including life history diversity. *Journal of Theoretical Biology*, 324: 52–71, doi: [10.1016/j.jtbi.2013.01.018](https://doi.org/10.1016/j.jtbi.2013.01.018)
- Mutlu E, Çınar M E, Ergev M B. 2010. Distribution of soft-bottom polychaetes of the Levantine coast of Turkey, eastern Mediterranean Sea. *Journal of Marine Systems*, 79(1–2): 23–35, doi: [10.1016/j.jmarsys.2009.06.003](https://doi.org/10.1016/j.jmarsys.2009.06.003)
- Ni Xiaobo, Zhou Feng, Zeng Dingyong, et al. 2023. Long-term observations of hypoxia off the Yangtze River Estuary: toward prediction and operational application. *Frontiers in Ocean Observing*, 36(S1): 40–41, doi: [10.5670/oceanog.2023.s1.13](https://doi.org/10.5670/oceanog.2023.s1.13)
- Pandiya rajan R S, Jyothibabu R, Arunpandi N, et al. 2021. Macrobenthos community response to the seasonal hypoxia associated with coastal upwelling off Kochi, along the Southwest coast of India. *Continental Shelf Research*, 224: 104450, doi: [10.1016/j.csr.2021.104450](https://doi.org/10.1016/j.csr.2021.104450)
- Pielou E C. 1975. *Ecological Diversity*. New York: Wiley, 1–165.
- Powilleit M, Kube J. 1999. Effects of severe oxygen depletion on macrobenthos in the Pomeranian Bay (southern Baltic Sea): a case study in a shallow, sublittoral habitat characterised by low species richness. *Journal of Sea Research*, 42(3): 221–234, doi: [10.1016/S1385-1101\(99\)00032-5](https://doi.org/10.1016/S1385-1101(99)00032-5)
- Rabalais N N, Baustian M M. 2020. Historical shifts in benthic infaunal diversity in the northern Gulf of Mexico since the appearance of seasonally severe hypoxia. *Diversity*, 12(2): 49, doi: [10.3390/d12020049](https://doi.org/10.3390/d12020049)
- Rakocinski C F, Menke D P. 2016. Seasonal hypoxia regulates macrobenthic function and structure in the Mississippi Bight. *Marine Pollution Bulletin*, 105(1): 299–309, doi: [10.1016/j.marpolbul.2016.02.006](https://doi.org/10.1016/j.marpolbul.2016.02.006)
- Ritter C, Montagna P A, Applebaum S. 2005. Short-term succession dynamics of macrobenthos in a salinity-stressed estuary. *Journal of Experimental Marine Biology and Ecology*, 323(1): 57–69, doi: [10.1016/j.jembe.2005.02.018](https://doi.org/10.1016/j.jembe.2005.02.018)
- Ryu J, Khim J S, Kang S G, et al. 2011. The impact of heavy metal pollution gradients in sediments on benthic macrofauna at population and community levels. *Environmental Pollution*, 159(10): 2622–2629, doi: [10.1016/j.envpol.2011.05.034](https://doi.org/10.1016/j.envpol.2011.05.034)
- Shannon C E, Weaver W. 1949. *The Mathematical Theory of Communication*. Urbana: University of Illinois Press, 1–144.
- Shivarudrappa S K, Rakocinski C F, Briggs K B. 2019. Vertical distribution of macrobenthos in hypoxia-affected sediments of the northern Gulf of Mexico: applying functional metrics. *Estuaries and Coasts*, 42(1): 250–263, doi: [10.1007/s12237-018-0446-z](https://doi.org/10.1007/s12237-018-0446-z)
- Taft O W, Haig S M. 2005. The value of agricultural wetlands as invertebrate resources for wintering shorebirds. *Agriculture, Ecosystems & Environment*, 110(3–4): 249–256, doi: [10.1016/j.agee.2005.04.012](https://doi.org/10.1016/j.agee.2005.04.012)
- Ueda K. 2013. Modeling of dissolved oxygen concentration recovery in water bodies and application to hypoxic water bodies. *World Environment*, 3(2): 52–59
- Wei Hao, He Yunchang, Li Qingji, et al. 2007. Summer hypoxia adjacent to the Changjiang Estuary. *Journal of Marine Systems*, 67(3–4): 292–303, doi: [10.1016/j.jmarsys.2006.04.014](https://doi.org/10.1016/j.jmarsys.2006.04.014)
- Zhou Weihua, Yuan Xiangcheng, Long Aimin, et al. 2014. Different hydrodynamic processes regulated on water quality (nutrients, dissolved oxygen, and phytoplankton biomass) in three contrasting waters of Hong Kong. *Environmental Monitoring and Assessment*, 186(3): 1705–1718, doi: [10.1007/s10661-013-3487-6](https://doi.org/10.1007/s10661-013-3487-6)