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Assessment of Sediment Quality and Benthic Community Structure of the Quanzhou Bay, Fujian Province, China

Xueping Lin [1,2], Linting Zhang [1,2], Degang Jiang [1,2,*], Kunfu Wu [3], Mee Mee Soe [4], Mohammad Saydul Islam Sarkar [5], ShuXia Yang [6] and Fan Yu [1,2]

[1] Island Research Center, Ministry of Natural Resources, Pingtan 350400, China
[2] Fujian Key Laboratory of Island Monitoring and Ecological Development, Pingtan 350400, China
[3] Jinjiang Municipal Forestry and Parks Bureau, Jinjiang 362200, China
[4] Department of Port and Harbour Engineering, Myanmar Maritime University, Yangon 11293, Myanmar
[5] Department of Oceanography, University of Chittagong, Chittagong 4331, Bangladesh
[6] Wuhu Science and Technology Engineering School, Wuhan 241399, China

* Correspondence: jiangdegang123m@163.com

Abstract: The Chinese government is vigorously advancing the initiative of constructing ‘Beautiful Bay’ as part of its broader environmental governance strategy to enhance marine ecological protection and achieve sustainable coastal development. As a fundamental unit and operational carrier for marine ecological and environmental protection efforts, bays play a crucial role in the effective implementation of conservation strategies. The precise management and governance of a bay’s ecological environment are of utmost significance, directly influencing the success of marine conservation initiatives and the overall health of coastal ecosystems.

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This study focuses on Quanzhou Bay as the primary case study site. Sediment quality and benthic community structure were assessed in 2020 at 12 strategically located sampling stations. A comprehensive evaluation of surface sediment characteristics and benthic organisms was conducted using both the single-factor index method and the integrated comprehensive evaluation method. These methodologies facilitated the identification of sediment contamination and enabled a scientific assessment of potential ecological risks using principal component analysis. The findings demonstrated that, with the exception of elevated levels of petroleum hydrocarbons, zinc, cadmium, and lead at stations S3 and S6—which exceeded the first-category criteria outlined in the Marine Sediment Quality manual—all other sediment parameters were in accordance with the first-category standards. Moreover, the comprehensive pollution index for heavy metals across all stations was found to be less than 1, indicating a generally clean sediment status. A total of 88 benthic species were identified across the 12 sampling stations. These species were categorized into four major classes: polychaetes, crustaceans, mollusks, and echinoderms. Of these, polychaetes were the most abundant, with 56 species recorded. The Index of Relative Importance identified *Chaetozone setosa* and *Cossurella dimorpha* as the dominant species. The study revealed that while most sediments in Quanzhou Bay were uncontaminated, elevated levels of zinc, cadmium, lead, and petroleum hydrocarbons were detected at stations S3 and S6, exceeding established environmental standards. The cause of these anomalies was attributed to industrial discharges and anthropogenic activities. Consequently, the implementation of targeted measures to prevent, control, treat, and remediate these localized issues is recommended.

Keywords: Quanzhou Bay; sediment quality assessment; benthic organisms; heavy metals; biological community structure; beautiful bay

1. Introduction

In March of 2018, China initiated a new phase of institutional reform. The Ministry of Ecology and Environment (MEE) has been entrusted with the responsibility of safeguarding marine environmental quality [1–4]. Given the preeminent status of marine pollution as an environmental issue in China, the nation's legal framework and associated management policies have undergone timely revisions [5–14]. In an effort to promote marine environmental protection and sustainable development, governments of various countries—including those of China—continue to optimize measures for marine environmental protection [15–20]. In 2021, among the 44 major bays in China that were monitored, 25% exhibited substandard water quality (category IV or worse) during the spring, summer, and fall monitoring periods. This finding suggests that these bays are particularly affected by concentrated areas of polluted waters. The improvement of water quality in some bays is unstable, with pollution rebounding, and pollution from beach litter is particularly prominent [21]. The "CPC Central Committee's Proposals for Formulating the 14th Five-Year Plan for National Economic and Social Development and the Long-Range Objectives Through the Year 2035" (referred to as 'Proposals') clarified the task deployment of 'promoting the protection and construction of beautiful bays' [21–23]. As delineated in the 14th Five-Year Plan for Marine Ecology and Environmental Protection, the MEE will persist in the implementation of its plans, adhere to problem-, goal-, and result-oriented approaches, emphasize targeted, scientific, and law-based pollution control, and implement a systematic plan for the protection and construction of beautiful bays [24].

Coastal bays are subject to factors that reflect how the land and ocean interact [25,26]. There are a total of 1,467 bays in China [24]. Due to the different characteristics of the bays, their ecological functions are more complicated and fragile than those of the open sea because of the impact of many human activities and the resulting pollution from land-based sources [26–32]. Sediment, an essential component of marine ecosystems, serves as a historical record of alterations to the sea areas and the repercussions of anthropogenic activities [33–38]. Its physicochemical characteristics and pollutant contents constitute pivotal sources of information for the examination of alterations in the quality of the sea environment, the evaluation of ecological risks, and the development of ecological protection strategies [39–43]. The structure of the community, biodiversity, and distribution patterns of benthic organisms serve as fundamental indicators of the health of marine ecosystems and the degree of coercion [44–46]. These characteristics serve as crucial indicators for assessing the service function of marine ecosystems, monitoring environmental pollution, and evaluating ecological restoration effects. The present study was undertaken to evaluate the current status of the marine environment in bays. A systematic study of the sediment quality and benthic community composition characteristics is necessary to accomplish this objective [47–52].

This study investigates various indicators of surface sediments and the structural composition of benthic communities in Quanzhou Bay. The study methodically analyzes the spatial distribution features of sediment, potential pollution sources, ecological risk evaluation, and biodiversity characteristics. It also encompasses the ecological status of the sedimentary environment and benthic organisms in Quanzhou Bay and more comprehensively aims to provide a scientific basis for the construction of a beautiful bay and the sustainable development of the marine economy.

2. Materials and Methods

2.1. Description of the Study Area, Sample Collection and Sediment Pretreatment

Quanzhou Bay, located in eastern China on the southeastern coast of Fujian Province, borders the Taiwan Strait [53–55]. Quanzhou Bay is the most important of the three bays (Quanzhou Bay, Weitou Bay, and Shenzhen-Shanghai Bay) in Quanzhou, serving as a key link between the inland and the sea [56,57]. The mouth of the bay opens to the east in a distinctive trumpet shape, and the northern part is the confluence of the Jinjiang and Luoyang rivers [53,57–60]. This bay is not only endowed with abundant natural ecological resources but also plays a crucial role in the economic activities of neighboring regions, particularly in the domains of fishery, shipping, and tourism [53,61]. In recent years, with the acceleration of urbanization and the increase of human activities, the sea areas of Quanzhou Bay have suffered from varying degrees of pollution and ecological damage, all of which have had far-reaching impacts on the ecological environment of Quanzhou Bay [62–65].

In October 2020, a total of 12 stations were deployed in the sea area of Quanzhou Bay (Figure 1), and samples of marine surface sediments were collected. The collection and pretreatment of the samples were carried out in accordance with the relevant requirements stipulated in the Specification for Marine Monitoring (SMM) [66] and the Specifications for Oceanographic Survey-Part 6: Marine Biological Survey (SOS) [67,68]. The benthic organisms survey utilized a mud sampler with a mud collection area of 0.05 m^2, and four parallel valid mud samples were collected continuously at each station and amalgamated into a single sample. The mud samples were eluted, and the specimens were sorted using a set of sieves with a mesh aperture of 0.5 mm. The residues in the set of sieves were fixed and preserved for subsequent transport to the laboratory. The specimens were then sorted under the dissecting microscope, and the sample treatment was carried out in accordance with the SMM.

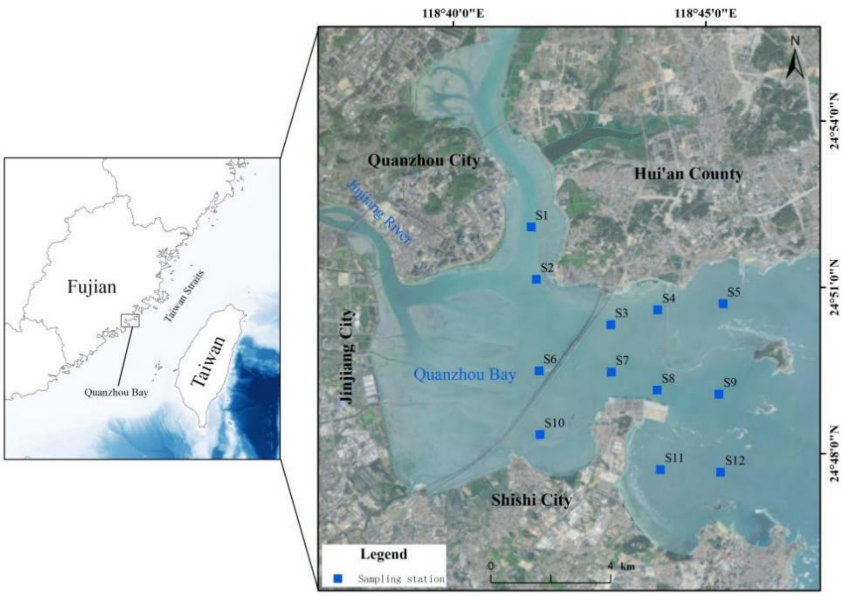


Figure 1. The Quanzhou Bay and the distribution of sampling locations

2.2. Methods for Evaluating the Quality of Marine Sediments

In this study, a total of 10 sediment parameters were analyzed and tested, including petroleum hydrocarbons, sulfides, organic carbon, and heavy metals (copper [Cu], lead [Pb], zinc [Zn], chromium [Cr], cadmium [Cd], arsenic [As], and total mercury [THg]), which are some of the most common heavy metal pollutants [69]. The determination of each parameter in the sediment was performed according to the analytical methods specified in the SMM. For instance, ultraviolet spectrophotometry was employed for the analysis of petroleum hydrocarbons, while the potassium dichromate oxidation-reduction capacity method was utilized for the determination of organic carbon. The sulfide analysis was executed through methylene blue spectrophotometry, and inductively coupled plasma mass spectrometry (ICP-MS) was employed for the analysis of Cu, Pb, Zn, Cr, and Cd. The atomic fluorescence method was employed for the analysis of As and Hg. The testing process for all aforementioned samples incorporated standard substances for quality control to ensure the reliability of the test results, and the monitoring results are shown in Table 1. The station sites were divided into three groups through cluster analysis of the sediment results. The first group consists of S2, S8, S9, and S10; the second group consists of S3, S4, S5, and S12; and the third group consists of S1, S6, S7, and S11.

The quality of marine sediments in the sea area of the aforementioned 12 stations is implemented in the Type I standard of Marine Sediment Quality (MSQ) (GB18668-2002) [70]. In this study, petroleum hydrocarbons, sulfides, and organic carbon were evaluated by the single factor index method [71], and heavy metals (including Cu, Pb, Zn, Cr, Cd, As, and THg) were evaluated by the comprehensive evaluation method, which was referred to the Specification for Offshore Environmental Monitoring (SOEM) [72].

2.3. Methods for Evaluating the Status of Benthic Communities

The analysis and identification of benthic organisms, as well as the subsequent data processing, are conducted in accordance with the stipulated requirements of the SMM. The species diversity index (H′), species richness index (d), evenness index (J′), and dominance index (Y) were utilized to assess benthic biodiversity. These indices were calculated according to the following equations: (1), (2), (3), and (4), respectively [73].

$$H' = -\sum_{i=1}^{s} P_i \log_2 P_i \quad (1)$$

$$d = (S-1)/\log_2 N \quad (2)$$

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

$$Y_i = (n_i/N) \times f_i \quad (4)$$

In this study, S denotes the number of species, N signifies the total number of individuals across all species, and P_i is defined as the proportion of the number of individuals of species i to the total number of individuals in

Table 1. Different types of observed surface sediment parameters in Quanzhou Bay

Station	OC	S^{2-}(mg/kg)	Oil(mg/kg)	Cr(mg/kg)	Cu(mg/kg)	Zn(mg/kg)	Cd(mg/kg)	Pb(mg/kg)	As(mg/kg)	Hg(mg/kg)
S1	0.78%	80.90	243.00	29.90	14.20	81.20	0.12	50.20	10.20	0.03
S2	0.22%	0.99	25.50	35.30	19.80	108.00	0.14	47.90	9.51	0.03
S3	1.16%	134.00	764.00	28.00	30.30	185.00	0.78	80.00	8.19	0.03
S4	1.28%	128.00	44.40	41.20	22.50	116.00	0.15	47.60	10.70	0.03
S5	1.22%	24.70	105.00	37.00	17.60	97.20	0.11	42.40	10.30	0.06
S6	0.84%	262.00	359.00	24.90	28.10	195.00	0.72	80.30	6.51	0.03
S7	0.56%	14.50	34.10	37.70	19.30	102.00	0.15	43.50	9.79	0.02
S8	0.14%	23.10	11.60	37.30	18.70	107.00	0.17	41.10	9.20	0.03
S9	0.20%	2.00	14.50	32.20	16.50	90.00	0.15	41.90	7.54	0.02
S10	0.20%	0.80	120.00	18.40	16.30	116.00	0.34	43.20	6.13	0.02
S11	0.89%	0.30	19.00	32.60	14.10	76.20	0.09	47.60	13.10	0.04
S12	1.12%	22.60	62.30	49.70	18.40	92.10	0.07	33.10	9.32	0.03

the sample. fi is the frequency of occurrence of species i in each sample, and ni is the number of individuals of organisms of species i in the sample.

The Index of Relative Importance (IRI) of Pinkas was employed to ascertain the dominant species, employing the following formula [74]:

$$\mathrm{IRI} = (\mathrm{N} + \mathrm{W})\mathrm{F} \times 10^4 \quad (5)$$

where N denotes the percentage of total tails for a species; W denotes the percentage of a certain type of mass to the total mass; and F denotes the percentage of stations where a species occurs out of the total number of stations surveyed.

In the context of the given data, species exhibiting an IRI greater than 500 are identified as dominant. Individuals exhibiting an IRI value between 100 and 500 are designated as "common"; those with an IRI value between 10 and 100 are classified as "common"; those with an IRI value between 1 and 10 are designated as "uncommon"; and those with an IRI value less than 1 are categorized as "rare."

3. Results

3.1. The Spatial Distribution Features of Sediment Quality

In this study, the spatial distribution features of petroleum hydrocarbons, sulfides, organic carbon, and heavy metals (Cu, Pb, Zn, Cr, Cd, As, and THg) in sediments in Quanzhou Bay were analyzed (Figure 2). The present study indicated that the organic carbon content of the sediments in Quanzhou Bay ranged from 0.14% to 1.28%, with an average of 0.72%. The content of sulfides ranged from 0.30 to 262.00 milligrams per kilogram (mg/kg), with an average of 57.80 mg/kg. The content of petroleum hydrocarbons ranged from 11.60 to 764.00 mg/kg, with an average of 150.00 mg/kg. Concurrently, an analysis of the heavy metal content of the sediments in Quanzhou Bay revealed that Cr content ranged from 18.40 to 49.70 mg/kg, with an average of 33.70 mg/kg. Cr content exhibited a range from 18.40 to 49.70 mg/kg, with an average of 33.70 mg/kg. Similarly, Cu content varied between 14.10 and 30.30 mg/kg, with an average of 19.60 mg/kg. Zn content varied between 76.20 and 195.00 mg/kg, with an average of 114.00 mg/kg, and Cd content varied between 0.07 and 0.78 mg/kg, with an average of 0.25 mg/kg. The range of Pb content was from 33.10 to 80.30 mg/kg, with an average of 44.90 mg/kg. The range of As content was from 6.13 to 13.10 mg/kg, with an average of 9.22 mg/kg. The range of THg content was from 0.02 to 0.06 mg/kg, with an average of 0.03 mg/kg.

In order to further understand the spatial distribution pattern of each index, an intergroup difference analysis was conducted for 10 sediment parameters. The results indicated that the content of organic carbon exhibited significant spatial differences, demonstrating a spatial distribution pattern of Group Ⅱ > Group Ⅲ > Group Ⅰ ($P < 0.01$). Furthermore, the presence of petroleum hydrocarbons, sulfides, and seven types of heavy metals was observed to be comparable across the three subgroups ($P > 0.05$). This finding

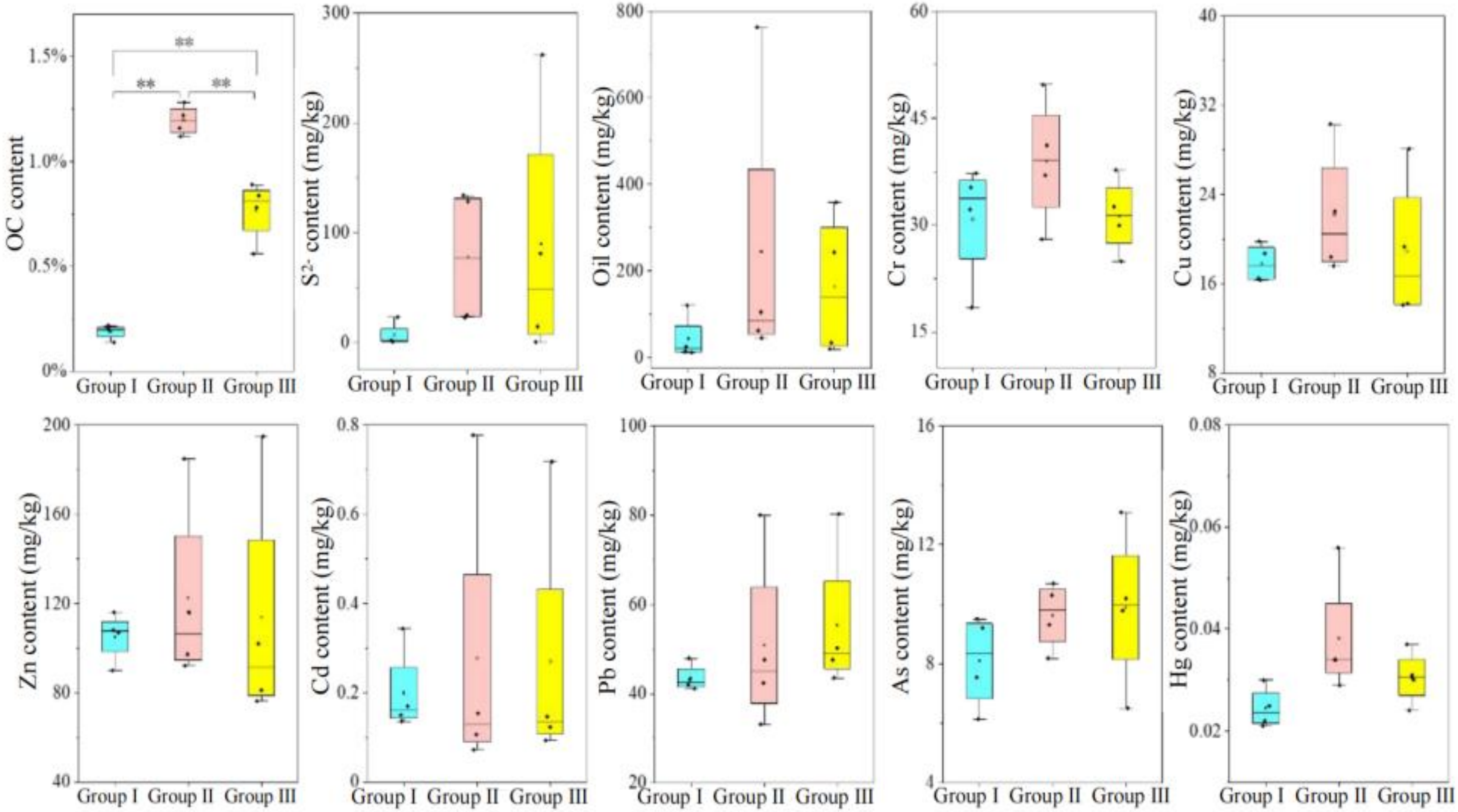


Figure 2. Spatial distribution features of surface sediments in Quanzhou Bay

suggests that the sediment quality (with the exception of OC) in the nearshore waters of Quanzhou Bay exhibited spatial homogeneity.

3.2. Evaluation of Sediment Contamination Quality

The spatial distribution pattern of sediment content was studied, and the pollution status of each station was analyzed through a combination of single-factor and comprehensive evaluation methods. These evaluations were then compared with the quality standards for marine sediment set by the MSQ first category. The findings indicated that, with the exception of petroleum hydrocarbons, the concentrations of Zn, Cd, and Pb in the sediment at the S3 station, as well as the concentrations of Zn, Cd, and Pb in the sediment at the S6 station, were all in accordance with the established environmental quality objectives in Table 2. This phenomenon may be attributed to the utilization of feed additives, including those containing Cr, Zn, and Pb, within the aquaculture practices at station S10. These additives have been observed to result in elevated levels of heavy metals at stations S3 and S6. Concurrently, the generation of oily wastewater and aquaculture activities has been demonstrated to be a significant factor in the production of organic carbon. This organic carbon functions as an adsorbent or complexant for the heavy metals, resulting in their deposition into the sediments. A comprehensive evaluation and analysis of heavy metals in the sediments at each site was conducted, and the heavy metal pollution indices (WQIs) calculation results were utilized to determine the cleanliness levels. It was found that the WQIs of 12 station sites were less than 1, indicating that these sites were classified as clean. This finding indicates that the quality of Quanzhou Bay sediments is satisfactory. However, it is imperative to maintain vigilance with respect to pollution prevention and control, particularly in the context of aquaculture processes, where pollution prevention, control, and remediation measures must be prioritized.

3.3. Composition Characterization of Benthic Community

A total of 88 species of benthic organisms were identified and classified into four categories (Tables 3 and 4). Of these, 56 species of polychaetes were the most numerous, accounting for 63.64% of the total number of species. This was followed by 19 species of crustaceans, accounting for 21.59%. The remaining species were distributed among seven species of mollusks (7.95%), two species of echinoderms (2.27%), and four species of other groups of animals (4.55%).

Concurrently, the biomass and average habitat density of benthic organisms in the sea area were analyzed in this study (Table 3). The mean biomass in the nearshore waters of Quanzhou Bay was 2.72 g/m^2. Of these, crustaceans were the most dominant, accounting for 57.84% of the total biomass with 1.58 g/m^2. This was followed by polychaetes, which accounted for 37.24% of the total biomass, with an average density of 1.01 g/m^2. Mollusks and other species accounted for 0.07 g/m^2 and 0.06 g/m^2, respectively,

Table 2. Results of single-factor or comprehensive evaluation of sediments in Quanzhou Bay

Station	OC	S^{2-}	Oil	Cr	Cu	Zn	Cd	Pb	As	THg	WQI
S1	0.39	0.27	0.49	0.37	0.41	0.54	0.25	0.84	0.51	0.15	0.44
S2	0.11	0.00	0.05	0.44	0.56	0.72	0.27	0.80	0.48	0.15	0.49
S3	0.58	0.45	1.53	0.35	0.86	1.23	1.55	1.33	0.41	0.17	0.85
S4	0.64	0.43	0.09	0.51	0.64	0.77	0.31	0.79	0.54	0.15	0.53
S5	0.61	0.08	0.21	0.46	0.50	0.65	0.21	0.71	0.52	0.28	0.48
S6	0.42	0.87	0.72	0.31	0.80	1.30	1.44	1.34	0.33	0.15	0.81
S7	0.28	0.05	0.07	0.47	0.55	0.68	0.29	0.73	0.49	0.12	0.48
S8	0.07	0.08	0.02	0.47	0.53	0.71	0.34	0.69	0.46	0.13	0.47
S9	0.10	0.01	0.03	0.40	0.47	0.60	0.30	0.70	0.38	0.11	0.42
S10	0.10	0.00	0.24	0.23	0.47	0.78	0.69	0.72	0.31	0.11	0.47
S11	0.44	0.00	0.04	0.41	0.40	0.51	0.19	0.79	0.66	0.19	0.45
S12	0.56	0.08	0.12	0.62	0.52	0.61	0.14	0.55	0.47	0.17	0.44

representing 2.57% and 2.24% of the total biomass. The smallest recorded biomass of echinoderms was 0.003 g/m2, accounting for 0.11% of the total biomass. The distribution of biomass at each station ranged from 0.05 g/m^2 to 14.94 g/m^2, with substantial variations.

The mean habitat density of benthic organisms in Quanzhou Bay was found to be 240 per square meter. Polychaetes dominated the composition of the habitat density, with an average density of 210 per square meter, accounting for 87.50% of the total habitat density. Crustaceans were observed in the following order, with an average density of 14 per square meter, accounting for 5.83% of the total habitat density. The mollusks and other species constituted 7 per square meter (2.92% of the total density), while echinoderms were the least abundant, with only 2 per square meter (0.83% of the total density). Mollusks and other species accounted for 7 per square meter and 2.92% of the total density, while echinoderms were the least abundant, with only 2 per square meter and 0.83% of the total density in Table 3.

Table 3. The observed benthic groups and indicators information in Quanzhou Bay

Group	Number of species	Percentage of number of species (%)	Biomass composition (%)	Habitat density composition (%)
Polychaetes	56	63.64	37.24	87.50
Crustaceans	19	21.59	57.84	5.83
Mollusks	7	7.95	2.57	2.92
Echinoderms	2	2.27	0.11	0.83
Other	4	4.55	2.24	2.92

The IRI has the capacity to consider the three ecological parameters of density, biomass, and frequency of occurrence. This allows for a more comprehensive reflection of the actual distribution of benthic organisms in the surveyed area. The IRI was calculated and analyzed for all the benthic organisms collected, and the results showed that two dominant species of polychaete were present in this survey: *Chaetozone setosa* and *Cossurella dimorpha*. *Chaetozone setosa* was the most prevalent species, with an IRI of 3193.85, significantly higher than that of *Cossurella dimorpha* (693.00) in Table 4.

Table 4. List of benthic organisms found in Quanzhou Bay

Group	Species		
Polychaetes	*Notomastus latericeus*	*Magelona cincta*	*Cossurella dimorpha*
	Sternaspis sculata	*Ophelina acuminata*	*Cirratulidae*
	Aglaophamus orientalis	*Prionospio queenslandica*	*Gyptis pacificus*
	Micronephtys sphaerocirratlis orientalis	*Scolelepis squamata*	*Scalibregma inflatum*

	Aricidea fragilis	*Spio martinensis*	*Amaeana occidentalis*
	Bhawania brevis	*Pseudopolydora kempi*	*Cirratulus filiformis*
	Pseudopolydora paucibranchiata	*Lumbrineris nagae*	*Ophiodromus angutifrons*
	Nectoneanthes multignatha	*Paralacydonia paradoxa*	*Neanthes glandicincta*
	Perinereis nuntia	*Paraprionospio pinnata*	*Cirriformia tentaculata*
	Nephtys polybranchia	*sp. Nectoneanthes sp.*	*Harmothoe asiatica*
	Nonparahalosydna pleiolepis	*Amphictena japonica*	*Phyllodoce（sensu stricto）laminosa*
	Chaetozone setosa	*Magelona japonica*	*Eteone (mysta) tchangsii*
	Glycinde gurjanovae	*Barda villosa*	*Haploscoloplos elongatus*
	Nephtys oligobranchia	*sp. Nereis sp.*	*Diopatra chiliensis*
	Scoloplos rubra	*Ampharete gunneri*	*Aglaophamus sinensis*
	Sigambra hanaokai	*Poecilochaetus serpens*	*Heterospio sinica*
	Amphinome cf. pulchra	*Terebellides stroemii*	*Glycera rouxi*
	Eunice indica	*Lumbrineris cruzensis*	*Aonides oxycephala*
	Mediomastus californiensis	*Aglaophamus dibranchis*	*Cossurella dimorpha*
Crustaceans	*Palaemon sewelli*	*Typhlocarcinus villosus*	*Lucifer typus*
	Ogyrides orientalis	*Neoxenophthalmus obscurus*	*Bodotria chinensis*
	Xenophthalmus pinnotheroides	*Grandidierella japonica*	*Acetes chinensis*
	Dogielinotidae sp.	*Parapanope euagora*	*Corophium sinensis*
	Aoroides columbiae	*Sinoediceros homopalmulus*	*Calanus sinicus*
	Eucrate crenata	*Ogyrides striaticauda*	
	Ampelisca cyclops	*Iphione tenera*	
Mollusks	*Solen dunkeriana*	*Leptomya minuta*	*Tellinides chinensis*
	Macoma candida	*Trigonothracia pusilla*	
	Bivalvia larva	*Nitidotellina minuta*	
Echinoderms	*Ophiarachnella gorgonian*	*Ophiomaza cacaetica*	
Other	*Cerebratulina communis*	*Gobiidae sp.*	
	Edwardsia japonica	*Stachyptilum doflemi*	

3.4. Spatial Change Pattern of Benthic Biodiversity

The diversity index of the benthic samples from Quanzhou Bay was calculated and analyzed (Figure 3). This revealed that the diversity index (H′) of the nearshore benthic species of Quanzhou Bay ranged from 1.06 to 3.10, with a mean value of 2.08, and the richness index (d) ranged from 1.92 to 6.97, with a mean value of 3.95. Notably, the richness index of the S6 station was the highest. The distribution of the evenness index (J′) ranged from 0.51 to 1.00, with a mean value of 0.79. The evenness index of stations S7 and S8 exhibited lower values due to the influence of the dominant species *Chaetozone setosa* and *Cossurella dimorpha*. In contrast, the evenness index at station S9, which was not occupied by any dominant species, was the highest. There was a strong positive correlation between the dominant index (D) and the evenness index. Stations S7 and S8 exhibited the largest dominant index because individual species were more dominant there. In contrast, station S9 exhibited the smallest dominant index, due to an even distribution of species.

A subsequent analysis of the richness index, evenness index, diversity index, and dominant index for intergroup differences revealed that the richness index exhibited significant spatial difference characteristics, manifesting as a spatial distribution pattern of Group Ⅲ > Group Ⅱ ($P < 0.01$) and Group Ⅲ > Group Ⅰ ($P < 0.001$ or $P < 0.01$). However, the remaining three indices exhibited equivalent levels of spatial heterogeneity. The average diversity index for the Quanzhou Bay survey was found to be 2.08 (less than 3), indicating that the bay has experienced external intrusion, resulting in damage to the benthic organisms' ecological environment to some extent. This highlights the need to restore the marine environment and protect ecological balance.

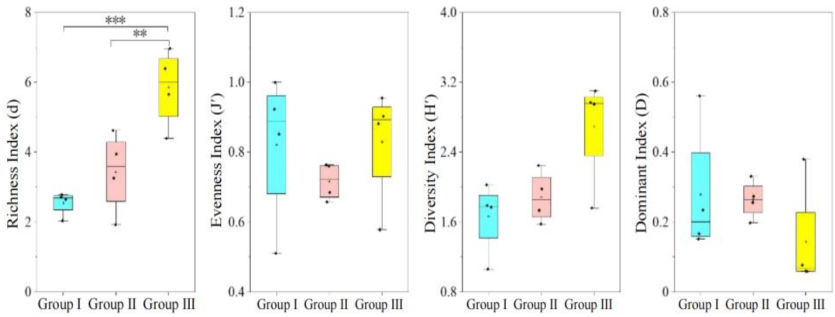


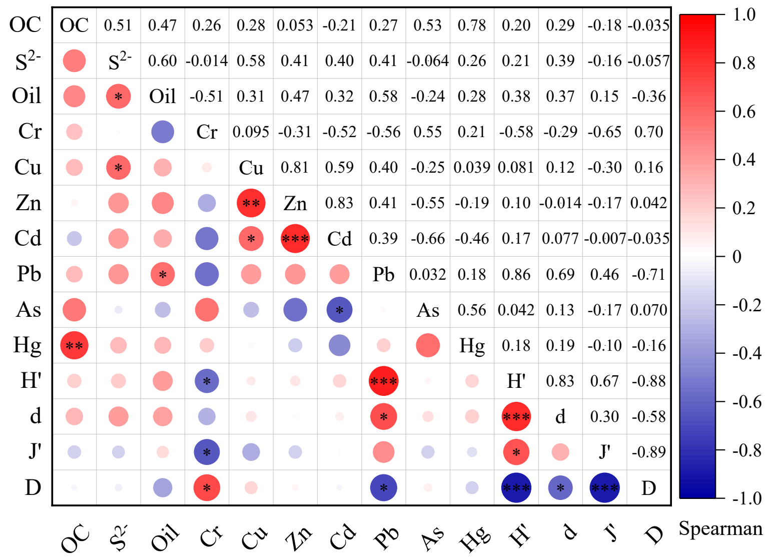
Figure 3. Spatial change pattern of benthic biodiversity index in Quanzhou Bay

4. Discussion

An analysis of the correlation between different sediment quality indicators in Quanzhou Bay (Figure 4) revealed varying degrees of correlation between the following heavy metal elements: Cr, Cu, Zn, Pb, As, and Hg. The findings indicate a highly significant positive correlation between Cd and Zn

($P < 0.001$), a positive correlation between Zn and Cu ($P < 0.01$), and a negative correlation between Cd and As ($P < 0.05$). A robust positive correlation was identified among Cr, As, Zn, Cu, sulfides, and Cd. Additionally, positive correlations were observed between Cu and sulfides, as well as between Cu and petroleum hydrocarbons. It is hypothesized that these elements share a common origin, primarily attributable to industrial discharges and anthropogenic inputs from urban activities. The significant spatial heterogeneity affecting the quality of marine sediments in Quanzhou Bay further indicates that industrial emissions and the intensity of human activities greatly influence the quality of marine sediments.

A correlation analysis of organic carbon, petroleum hydrocarbons, sulfides, seven heavy metal elements, and the species diversity index was conducted to identify the potential sources of pollution (Figure 5) [75]. This analysis was then further facilitated by means of the principal component analysis (PCA) method [76]. The results of this analysis indicated that the ten indicators could be classified into three principal components, with respective variance contribution rates of 57.11% and 23.248% and a cumulative contribution rate of 80.358%. These findings suggest that the two principal components are capable of reflecting the majority of the information concerning the sediment quality in Quanzhou Bay. The first principal component encompasses sulfides, petroleum hydrocarbons, Cu, Pb, Zn, and Cr, among which Zn exhibited a higher positive loading. This suggests that the point-source discharges into the sea, predominantly from industrial activities, urban rivers, and coastal streams, contribute more to the content of the first principal component factor in the sediments [77]. The second principal component includes organic carbon, Cr, As, and Hg. Among these elements, the load of organic carbon exhibited larger, indicating that organic matter plays an important role in the complexation and desorption process of heavy metals in sediments. As demonstrated in Figure 5, Cd, As, and Hg exhibited a substantial positive correlation with organic carbon. This suggests that these three elements form metal-organic complexes through surface adsorption with organic matter present in surface sediments. This process leads to their migration out of the water body [78]. Figure 6 shows the discrete degree of each element and more intuitively reflects the two predominant sources of heavy metals in the surface sediments of Quanzhou Bay: industrial discharges and organic matter degradation processes.



* $P \leq 0.05$ ** $P \leq 0.01$ *** $P \leq 0.001$

Figure 4. Correlations between sediment ecosystem indicators in Quanzhou Bay

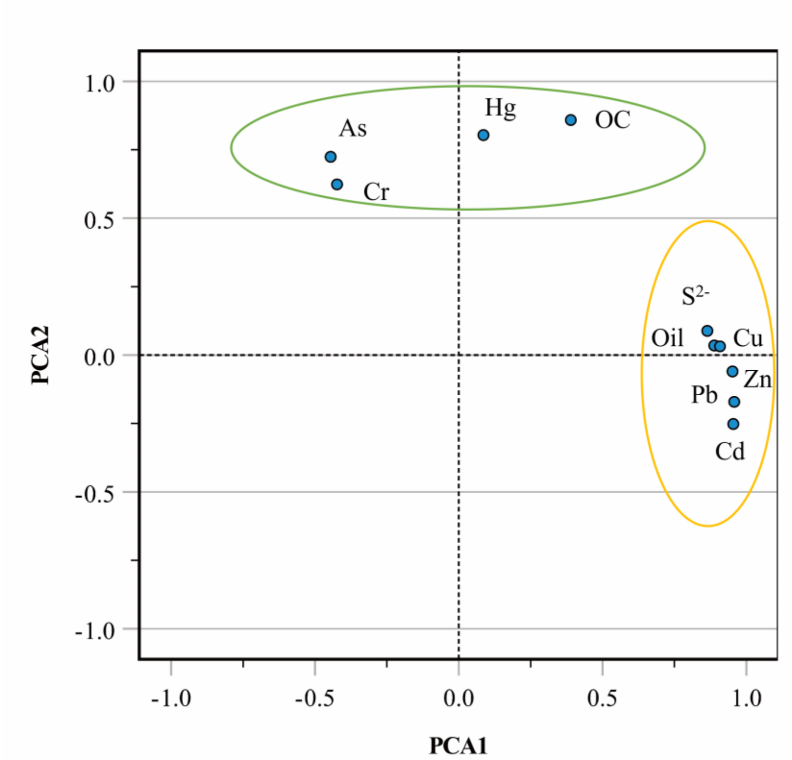


Figure 5. Principal component analysis of sediment indicators in Quanzhou Bay

The principal component analysis scores and the final evaluation results show that there is a negative correlation between the content of the monitored sediment factors and the sediment environmental quality. That is to say, as the content of the monitored sediment factors decreases, the environmental quality of the sediments improves. The values for stations S1 to S12 are -0.32, -0.72, 2.61, 0.45, 0.80, 2.09, -0.77, -0.98, -1.40, -1.09, -0.49, and -0.17, respectively. Overall, stations S3 and S6 demonstrated the poorest performance, while S7-S12 exhibited relatively good performance.

A significant correlation between Cr and Pb with biodiversity was identified. According to Figure 4, Cr exhibited a positive correlation with the benthic dominance index ($P < 0.05$) and a negative correlation with the dominance index and evenness index ($P < 0.05$). Pb demonstrated a highly significant correlation with the diversity index ($P < 0.001$) and positive and negative correlations with the richness and dominance indices ($P < 0.05$, respectively). A redundancy analysis was conducted for sediment factors and benthic biodiversity (Figure 6). The results showed how different environmental factors were distributed in Quanzhou Bay. The findings indicated a robust positive correlation between organic carbon, Pb, Hg, and petroleum hydrocarbons. Additionally, a relatively positive correlation was observed between the richness index and diversity index and organic carbon, Pb, Hg, petroleum hydrocarbons, and Cd. These observations imply a close relationship between the organic carbon, petroleum hydrocarbons, and certain heavy metals present in the sediment environment and the biological characteristics within the water body. This phenomenon may be due to the fact that the growth and reproduction of benthic animals occasionally results in the uptake of these substances, thereby influencing the biological characteristics of benthic organisms.

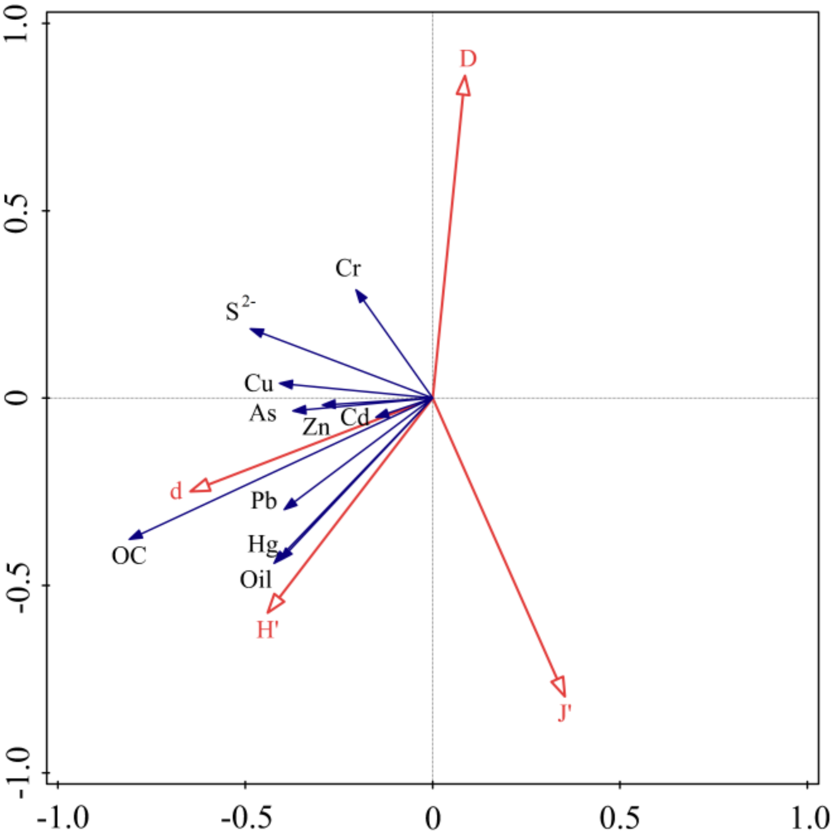


Figure 6. Redundancy analysis of sediment quality in Quanzhou Bay

5. Conclusion

The results of the sediment survey in Quanzhou Bay revealed that all other monitoring indexes complied with the established requirements, except for exceedances of petroleum hydrocarbons and Zn, Cd, and Pb contents in the sediments at stations S3 and S6. Furthermore, all of the WQIs in Quanzhou Bay were less than 1, indicating that the levels of heavy metal pollution in the bay are low and that there are no obvious problems with heavy metal pollution. The findings indicated that the sediment quality at stations S3 and S6 was the most deficient, and that two primary sources of heavy metals were identified in the surface sediment of Quanzhou Bay.

In order to protect and restore the ecological environment of Quanzhou Bay, targeted management is urgently required. Two key recommendations are proposed: Firstly, the supervision of pollution sources in industrial zones and river estuaries surrounding Stations S3 and S6 should be prioritised. Real-time monitoring networks using technologies such as multi-parameter water quality sensors, buoy systems and remote sensing image analysis should be deployed in these critical areas. Secondly, implement a land-based pollution zoning control strategy to enhance the real-time monitoring and early warning capabilities of the nearshore ecological environment. Secondly, a long-term, systematic ecological monitoring programme should be promptly established. This should continuously track the accumulation of pollutants (e.g., industrial heavy metals and organic pollutants) and assess the potential for ecological recovery (e.g., dynamic changes in benthic biodiversity). This programme will provide the scientific data needed to inform adjustments to the dynamic management strategy and the formulation of adaptive restoration measures, thereby advancing the construction of a Beautiful Bay in a scientific, effective and high-standard manner.

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References

1. Wang, Y.; Hu, Y.; Liu, J. Overview of China's National Park System Reform Process. *Chin. J. Popul. Resour. Environ.* **2024**, *22*, 481–492, doi:10.1016/j.cjpre.2024.11.011. [Crossref]
2. Deng, Y.; Shi, Y. Recent Developments of China's Institutional Reform for Ocean Management: An Appraisal. *Coast. Manag.* **2023**, *51*, 91–114, doi:10.1080/08920753.2023.2176277. [Crossref]
3. Su, S.; Tang, Y.; Chang, B.; Zhu, W.; Chen, Y. Evolution of Marine Fisheries Management in China from 1949 to 2019: How Did China Get

Here and Where Does China Go Next? *Fish Fish.* **2020**, *21*, 435–452, doi:10.1111/faf.12439. [Crossref]

4. Zhang, K.; Chang, Y.-C. Daily Penalty System under Revision of the Marine Environment Protection Law in China: Review and Prospect. *Sustainability* **2022**, *14*, doi:10.3390/su142214994. [Crossref]
5. Liu, J.; Diamond, J. China's Environment in a Globalizing World. *Nature* **2005**, *435*, 1179–1186, doi:10.1038/4351179a. [Crossref]
6. Chen, Q.; Yu, H.; Wang, Y. Research on Modern Marine Environmental Governance in China: Subject Identification, Structural Characteristics, and Operational Mechanisms. *Int. J. Environ. Res. Public. Health* **2021**, *18*, doi:10.3390/ijerph18094485. [Crossref]
7. Ye, F.; He, Y.; Yi, Y.; Quan, Y.; Deng, Y. Promotion of Environmental Regulation on the Decoupling of Marine Economic Growth from Marine Environmental Pollution—Based on Interprovincial Data in China. *J. Environ. Plan. Manag.* **2022**, *65*, 1456–1482, doi:10.1080/09640568.2021.1932771. [Crossref]
8. Dzidzornu, D.M. Four Principles in Marine Environment Protection: A Comparative Analysis. *Ocean Dev. Int. Law* **1998**, *29*, 91–123, doi:10.1080/00908329809546119. [Crossref]
9. Yang, W.; Chen, X.; Liu, Y. Recent Developments in Building Sustainable Marine Fisheries in China: Reflections on the 2023 Revision of the Marine Environmental Protection Law. *Mar. Policy* **2025**, *171*, doi:10.1016/j.marpol.2024.106439. [Crossref]
10. Chang, Y.-C.; Wang, C.; Khan, M.I.; Wang, N. The Legal System for Environmental Protection during Exploration and Exploitation of Marine Mineral Resources in China. *Resour. Policy* **2020**, *67*, doi:10.1016/j.resourpol.2020.101670. [Crossref]
11. Jiang, X.; Huang, Z. Extraterritorial Application of China's Marine Environmental Protection Law: Towards Effective Marine Environmental Protection Enforcement. *Mar. Policy* **2024**, *167*, doi:10.1016/j.marpol.2024.106241. [Crossref]
12. Jahiel, A.R. The Organization of Environmental Protection in China. *China Q.* **1998**, *156*, 757–787, doi:10.1017/S030574100005133X. [Crossref]
13. Ning, J.; Pang, S.; Arifin, Z.; Zhang, Y.; Epa, U.P.K.; Qu, M.; Zhao, J.; Zhen, F.; Chowdhury, A.; Guo, R.; et al. The Diversity of Artificial Intelligence

Applications in Marine Pollution: A Systematic Literature Review. *J. Mar. Sci. Eng.* **2024**, *12*, doi:10.3390/jmse12071181. [Crossref]

14. Deng, Y.-C.; Jiang, X. Wetland Protection Law of the People's Republic of China: New Efforts in Wetland Conservation. *Int. J. Mar. Coast. Law* **2023**, *38*, 141–160, doi:10.1163/15718085-bja10115. [Crossref]
15. Qian, X. Research on the Coordinated Development Model of Marine Ecological Environment Protection and Economic Sustainable Development. *J. Sea Res.* **2023**, *193*, doi:10.1016/j.seares.2023.102377. [Crossref]
16. Zhang, C.; Quan, Y.; Zhong, H. The Building of Marine Ecological Civilization and Sustainable Development: Conference Report. *Mar. Policy* **2019**, *110*, doi:10.1016/j.marpol.2019.103627. [Crossref]
17. Wang, W.J. The Protection and Development of Marine Resources under the Perspective of the Sustainable Development Concept. *Mar. Econ. Manag.* **2024**, *7*, 181–191, doi:10.1108/MAEM-09-2024-0016. [Crossref]
18. Noel, J.F.; Weigel, J.Y. Marine Protected Areas: From Conservation to Sustainable Development. *Int. J. Sustain. Dev.* **2007**, *10*, 233, doi:10.1504/IJSD.2007.017645. [Crossref]
19. Islam, M.M.; Shamsuddoha, M. Coastal and Marine Conservation Strategy for Bangladesh in the Context of Achieving Blue Growth and Sustainable Development Goals (SDGs). *Environ. Sci. Policy* **2018**, *87*, 45–54, doi:10.1016/j.envsci.2018.05.014. [Crossref]
20. Pellizzoni, L. Responsibility and Environmental Governance. *Environ. Polit.* **2004**, *13*, 541–565, doi:10.1080/0964401042000229034. [Crossref]
21. Ministry of Ecology and Environment, P.R. of C. One Picture to Understand the Beautiful Bay Available online: https://www.mee.gov.cn/zcwj/zcjd/202206/t20220623_986575.shtml (accessed on 28 December 2024).
22. Wei, H.; Nian, M.; Li, L. China's Strategies and Policies for Regional Development During the Period of the 14th Five-Year Plan. *Chin. J. Urban Environ. Stud.* **2020**, *08*, doi:10.1142/S2345748120500086. [Crossref]
23. Hu, A.; Zhou, S.; Xie, Y. 2035 China: Achieving the Vision of Common Prosperity. In *Study on the National Conditions of Modernization with Chinese Characteristics*; Understanding Xi Jinping's Governance; Springer Nature Singapore: Singapore, 2025; pp. 319–359 ISBN 978-981-9774-46-3. [Google Scholar]

24. *2020 Press Conference Records of Ministry of Ecology and Environment, the People's Republic of China*; Ministry of Ecology and Environment, P.R. of C., Ed.; Springer Singapore Pte. Limited: Singapore, 2022; ISBN 9789811690617. [Google Scholar]
25. Xiao, Y.; Zhang, H.; Ma, K.; Perera, H.A.C.C.; Ramli, M.Z.; Deng, Y. Exploring the Relationships between Tradeoffs and Synergies among Island Ecosystem Service Bundles: A Study on Zhoushan Archipelago Located on the Southeast Coast of China. *Sustainability* **2024**, *16*, doi:10.3390/su16010394. [Crossref]
26. Huang, L.; Tan, Y.; Song, X.; Huang, X.; Wang, H.; Zhang, S.; Dong, J.; Chen, R. The Status of the Ecological Environment and a Proposed Protection Strategy in Sanya Bay, Hainan Island, China. *Mar. Pollut. Bull.* **2003**, *47*, 180–186, doi:10.1016/S0025-326X(03)00070-5. [Crossref]
27. Molisani, M.M.; Marins, R.V.; Machado, W.; Paraquetti, H.H.M.; Bidone, E.D.; Lacerda, L.D. Environmental Changes in Sepetiba Bay, SE Brazil. *Reg. Environ. Change* **2004**, *4*, 17–27, doi:10.1007/s10113-003-0060-9. [Crossref]
28. Ueda, N.; Tsutsumi, H.; Yamada, M.; Takeuchi, R.; Kido, K. Recovery of the Marine Bottom Environment of a Japanese Bay. *Mar. Pollut. Bull.* **1994**, *28*, 676–682, doi:10.1016/0025-326X(94)90303-4. [Crossref]
29. Fulton, E.A.; Smith, A.D.M.; Johnson, C.R. Biogeochemical Marine Ecosystem Models I: IGBEM—a Model of Marine Bay Ecosystems. *Ecol. Model.* **2004**, *174*, 267–307, doi:10.1016/j.ecolmodel.2003.09.027. [Crossref]
30. Jacinto, G.S.; Azanza, R.V.; Velasquez, I.B.; Siringan, F.P. Manila Bay: Environmental Challenges and Opportunities. In *The Environment in Asia Pacific Harbours*; Wolanski, E., Ed.; Springer Netherlands: Dordrecht, 2006; pp. 309–328 ISBN 978-1-4020-3654-5. [Google Scholar]
31. Su, M.M.; Wall, G.; Wu, B.; Xu, H.; Fu, X.; Deng, Y. Tourism Place Making through the Bioluminescent "Blue Tears" of Pingtan Islands, China. *Mar. Policy* **2021**, *133*, doi:10.1016/j.marpol.2021.104744. [Crossref]
32. Deng, Y.; Čuka, A.; Fu, Y.; Wu, J. Multiple Paths towards Eco Islands and Blue Development: Conference Report. *Mar. Policy* **2023**, *149*, doi:10.1016/j.marpol.2023.105526. [Crossref]
33. Levin, L.A.; Boesch, D.F.; Covich, A.; Dahm, C.; Erséus, C.; Ewel, K.C.; Kneib, R.T.; Moldenke, A.; Palmer, M.A.; Snelgrove, P.; et al. The Function of Marine Critical Transition Zones and the Importance of

Sediment Biodiversity. *Ecosystems* **2001**, *4*, 430–451, doi:10.1007/s10021-001-0021-4. [Crossref]

34. Dubois, N.; Saulnier-Talbot, É.; Mills, K.; Gell, P.; Battarbee, R.; Bennion, H.; Chawchai, S.; Dong, X.; Francus, P.; Flower, R.; et al. First Human Impacts and Responses of Aquatic Systems: A Review of Palaeolimnological Records from around the World. *Anthr. Rev.* **2018**, *5*, 28–68, doi:10.1177/2053019617740365. [Crossref]
35. James, L.A. Legacy Sediment: Definitions and Processes of Episodically Produced Anthropogenic Sediment. *Anthropocene* **2013**, *2*, 16–26, doi:10.1016/j.ancene.2013.04.001. [Crossref]
36. Walling, D.E. Human Impact on Land–Ocean Sediment Transfer by the World's Rivers. *Geomorphology* **2006**, *79*, 192–216, doi:10.1016/j.geomorph.2006.06.019. [Crossref]
37. Crain, C.M.; Halpern, B.S.; Beck, M.W.; Kappel, C.V. Understanding and Managing Human Threats to the Coastal Marine Environment. *Ann. N. Y. Acad. Sci.* **2009**, *1162*, 39–62, doi:10.1111/j.1749-6632.2009.04496.x. [Crossref]
38. Thrush, S.; Hewitt, J.; Cummings, V.; Ellis, J.; Hatton, C.; Lohrer, A.; Norkko, A. Muddy Waters: Elevating Sediment Input to Coastal and Estuarine Habitats. *Front. Ecol. Environ.* **2004**, *2*, 299–306, doi:10.1890/1540-9295(2004)002[0299:MWESIT]2.0.CO;2. [Crossref]
39. Yu, R.; Hu, G.; Wang, L. Speciation and Ecological Risk of Heavy Metals in Intertidal Sediments of Quanzhou Bay, China. *Environ. Monit. Assess.* **2010**, *163*, 241–252, doi:10.1007/s10661-009-0830-z. [Crossref]
40. Yu, R.; Zhang, W.; Hu, G.; Lin, C.; Yang, Q. Heavy Metal Pollution and Pb Isotopic Tracing in the Intertidal Surface Sediments of Quanzhou Bay, Southeast Coast of China. *Mar. Pollut. Bull.* **2016**, *105*, 416–421, doi:10.1016/j.marpolbul.2016.01.047. [Crossref]
41. Sun, G.-X.; Wang, X.-J.; Hu, Q.-H. Using Stable Lead Isotopes to Trace Heavy Metal Contamination Sources in Sediments of Xiangjiang and Lishui Rivers in China. *Environ. Pollut.* **2011**, *159*, 3406–3410, doi:10.1016/j.envpol.2011.08.037. [Crossref]
42. Qiao, Y.; Yang, Y.; Gu, J.; Zhao, J. Distribution and Geochemical Speciation of Heavy Metals in Sediments from Coastal Area Suffered Rapid Urbanization, a Case Study of Shantou Bay, China. *Mar. Pollut. Bull.* **2013**, *68*, 140–146, doi:10.1016/j.marpolbul.2012.12.003. [Crossref]

43. Tian, F.; Ni, Z.; Huang, B.; Lou, Q.; Zhong, Y.; Deng, W. Distribution Characters of Heavy Metals in Seawater and Surface Sediments in Daya Bay. *J. Appl. Oceanogr.* **2022**, *41*, 462–474. [Crossref]
44. Camargo, C.; Maldonado, J.H.; Alvarado, E.; Moreno-Sánchez, R.; Mendoza, S.; Manrique, N.; Mogollón, A.; Osorio, J.D.; Grajales, A.; Sánchez, J.A. Community Involvement in Management for Maintaining Coral Reef Resilience and Biodiversity in Southern Caribbean Marine Protected Areas. *Biodivers. Conserv.* **2009**, *18*, 935–956, doi:10.1007/s10531-008-9555-5. [Crossref]
45. Gao, L.; Ning, J.; Bao, W.; Yan, A.; Yin, Q. A Study on the Marine Ecological Security Assessment of Guangdong-Hong Kong-Macao Great Bay Area. *Mar. Pollut. Bull.* **2022**, *176*, doi:10.1016/j.marpolbul.2022.113416. [Crossref]
46. Angel, E.; Edwards, D.N.; Hawkshaw, S.; Wor, C.; Parlee, C.E. An Indicator Framework to Support Comprehensive Approaches to Sustainable Fisheries Management. *Ecol. Soc.* **2019**, *24*, doi:10.5751/ES-11242-240412. [Crossref]
47. Mou, J.; Huang, Y.; He, X.; Lin, J.; Zhang, S.; Lin, H.; Liu, K.; Jiang, J.; Li, R.; Zheng, C.; et al. Studies on Benthic Macrofaunal Community in Tidal Zone of the North of Quanzhou Bay. *J. Appl. Oceanogr.* **2017**, *36*, 158–166. [Crossref]
48. Wang, J.; Wang, Y.; Huang, J.; Wang, B.; Wang, J.; Lin, S.; Sun, B. Community Structures of Macrobenthos and Their Relationship with Environmental Factors in Rizhao Subtidal Zone in Spring and Autumn. *J. Appl. Oceanogr.* **2021,** *40*, 564–574. [Crossref]
49. Mosbahi, N.; Serbaji, M.M.; Pezy, J.-P.; Neifar, L.; Dauvin, J.-C. Response of Benthic Macrofauna to Multiple Anthropogenic Pressures in the Shallow Coastal Zone South of Sfax (Tunisia, Central Mediterranean Sea). *Environ. Pollut.* **2019**, *253*, 474–487, doi:10.1016/j.envpol.2019.06.080. [Crossref]
50. Warwick, R.M. Environmental Impact Studies on Marine Communities: Pragmatical Considerations. *Aust. J. Ecol.* **1993**, *18*, 63–80, doi:10.1111/j.1442-9993.1993.tb00435.x. [Crossref]
51. Borja, A.; Bricker, S.B.; Dauer, D.M.; Demetriades, N.T.; Ferreira, J.G.; Forbes, A.T.; Hutchings, P.; Jia, X.; Kenchington, R.; Marques, J.C.; et al. Overview of Integrative Tools and Methods in Assessing Ecological

Integrity in Estuarine and Coastal Systems Worldwide. *Mar. Pollut. Bull.* **2008**, *56*, 1519–1537, doi:10.1016/j.marpolbul.2008.07.005. [Crossref]

52. Danovaro, R.; Carugati, L.; Berzano, M.; Cahill, A.E.; Carvalho, S.; Chenuil, A.; Corinaldesi, C.; Cristina, S.; David, R.; Dell'Anno, A.; et al. Implementing and Innovating Marine Monitoring Approaches for Assessing Marine Environmental Status. *Front. Mar. Sci.* **2016**, *3*, doi:10.3389/fmars.2016.00213. [Crossref]
53. Wang, W.; Huo, Y.; Lin, C.; Lian, Z.; Wang, L.; Liu, Y.; Sun, X.; Chen, J.; Lin, H. Occurrence, Accumulation, Ecological Risk, and Source Identification of Potentially Toxic Elements in Multimedia in a Subtropical Bay, Southeast China. *J. Hazard. Mater.* **2024**, *476*, doi:10.1016/j.jhazmat.2024.135110. [Crossref]
54. Lu, C.; Liu, J.; Jia, M.; Liu, M.; Man, W.; Fu, W.; Zhong, L.; Lin, X.; Su, Y.; Gao, Y. Dynamic Analysis of Mangrove Forests Based on an Optimal Segmentation Scale Model and Multi-Seasonal Images in Quanzhou Bay, China. *Remote Sens.* **2018**, *10*, doi:10.3390/rs10122020. [Crossref]
55. Hu, G.; Yu, R.; Zhao, J.; Chen, L. Distribution and Enrichment of Acid-Leachable Heavy Metals in the Intertidal Sediments from Quanzhou Bay, Southeast Coast of China. *Environ. Monit. Assess.* **2011**, *173*, 107–116, doi:10.1007/s10661-010-1374-y. [Crossref]
56. Cao, S.; Liu, C.; Li, Y.; Li, J.; Hao, Q.; Gao, J.; Dong, Y.; Lu, C. Sources and Ecological Risk of Heavy Metals in the Sediments of Offshore Area in Quanzhou Bay, Fujian Province. *Geol. China* **2022**, *49*, 1481–1496, doi:10.12029/gc20220508. [Google Scholar]
57. Ding, S.; Chang, J.; Zhang, W.; Ji, S.; Chi, Y. Environmental Microbial Diversity and Water Pollution Characteristics Resulted from 150 Km Coastline in Quanzhou Bay Offshore Area. *Front. Microbiol.* **2024**, *15*, doi:10.3389/fmicb.2024.1438133. [Crossref]
58. Yu, R.; Yuan, X.; Zhao, Y.; Hu, G.; Tu, X. Heavy Metal Pollution in Intertidal Sediments from Quanzhou Bay, China. *J. Environ. Sci.* **2008**, *20*, 664–669, doi:10.1016/S1001-0742(08)62110-5. [Crossref]
59. Gong, X.; Qi, S.; Wang, Y.; Julia, E.B.; Lv, C. Historical Contamination and Sources of Organochlorine Pesticides in Sediment Cores from Quanzhou Bay, Southeast China. *Mar. Pollut. Bull.* **2007**, *54*, 1434–1440, doi:10.1016/j.marpolbul.2007.05.006. [Crossref]

60. Zhao, W.L.; Yang, S.Y.; Wang, J.; Xiao, J.M.; Lu, X.X.; Lin, J.; Huang, P.; Cai, M.G. Load Estimation and Assessment of Land-Based Pollution for Quanzhou Bay and Their Relevance to the Total Quantity Control of Pollutants Discharged into the Sea (TQCPS) Program in China. *Estuar. Coast. Shelf Sci.* **2015**, *166*, 230–239, doi:10.1016/j.ecss.2015.06.026. [Crossref]
61. Xiao, X.; Li, Y.; Shu, F.; Wang, L.; He, J.; Zou, X.; Chi, W.; Lin, Y.; Zheng, B. Coupling Relationship of Human Activity and Geographical Environment in Stage-Specific Development of Urban Coastal Zone: A Case Study of Quanzhou Bay, China (1954–2020). *Front. Mar. Sci.* **2022**, *8*, doi:10.3389/fmars.2021.781910. [Crossref]
62. Guan, B.; Lei, H.; Lin, B.; Liu, H.; Shi, Y.; Lin, J. Elemental Characteristics and Geochemical Significance of Surface Sediments in Quanzhou Bay. *J. Oceanogr. Taiwan Strait* **2010,** *29*, 58–65. [Crossref]
63. Yan, Y.; Han, L.; Yu, R.; Hu, G.; Zhang, W.; Cui, J.; Yan, Y.; Huang, H. Background Determination, Pollution Assessment and Source Analysis of Heavy Metals in Estuarine Sediments from Quanzhou Bay, Southeast China. *CATENA* **2020**, *187*, doi:10.1016/j.catena.2019.104322. [Crossref]
64. Yang, D.; Qi, S.; Zhang, Y.; Xing, X.; Liu, H.; Qu, C.; Liu, J.; Li, F. Levels, Sources and Potential Risks of Polycyclic Aromatic Hydrocarbons (PAHs) in Multimedia Environment along the Jinjiang River Mainstream to Quanzhou Bay, China. *Mar. Pollut. Bull.* **2013**, *76*, 298–306, doi:10.1016/j.marpolbul.2013.08.016. [Crossref]
65. Chen, K.; Ni, M.; Cai, M.; Wang, J.; Huang, D.; Chen, H.; Wang, X.; Liu, M. Optimization of a Coastal Environmental Monitoring Network Based on the Kriging Method: A Case Study of Quanzhou Bay, China. *BioMed Res. Int.* **2016**, *2016*, 1–12, doi:10.1155/2016/7137310. [Crossref]
66. SAC. Specification for Marine Monitoring Available online: https://std.samr.gov.cn/gb/search/gbDetailed?id=71F772D76E64D3A7E05397BE0A0AB82A (accessed on 20 December 2024).
67. SAC. Specifications for Oceanographic Survey-Part 6: Marine Biological Survey Available online: https://std.samr.gov.cn/gb/search/gbDetailed?id=71F772D788FDD3A7E05397BE0A0AB82A (accessed on 20 December 2024).
68. Wu, B.; Li, X.; Song, J.; Hu, L.; Shi, X. Impact of Extreme Metal Contamination at the Supra-Individual Level in a Contaminated Bay

Ecosystem. *Sci. Total Environ.* **2016**, *557–558*, 102–109, doi:10.1016/j.scitotenv.2016.03.047. [Crossref]

69. Zhang, W.; Liu, X.; Cheng, H.; Zeng, E.Y.; Hu, Y. Heavy Metal Pollution in Sediments of a Typical Mariculture Zone in South China. *Mar. Pollut. Bull.* **2012**, *64*, 712–720, doi:10.1016/j.marpolbul.2012.01.042. [Crossref]
70. SAC. Marine Sediment Quality Available online: https://std.samr.gov.cn/gb/search/gbDetailed?id=71F772D7BECED3A7E05397BE0A0AB82A (accessed on 25 December 2024).
71. Xu, H.; Yang, H.; Ge, Q.; Jiang, Z.; Wu, Y.; Yu, Y.; Han, D.; Cheng, J. Long-Term Study of Heavy Metal Pollution in the Northern Hangzhou Bay of China: Temporal and Spatial Distribution, Contamination Evaluation, and Potential Ecological Risk. *Environ. Sci. Pollut. Res.* **2021**, *28*, 10718–10733, doi:10.1007/s11356-020-11110-6. [Crossref]
72. SAC. Specification for Offshore Environmental Monitoring Available online: https://std.samr.gov.cn/hb/search/stdHBDetailed?id=BBE8A5D349175D96E05397BE0A0AAE2E%20 (accessed on 25 December 2024).
73. Jiang, W.; Zhang, M.; Liu, X. Effects of Different Pollution Stresses on Macrofaunal Communities in the Adjacent Waters of Dongjiakou, Qingdao, China. *Acta Ecol. Sin.* **2024**, *44*, 7830–7843, doi:10.20103/j.stxb.202312292871. [Google Scholar]
74. Dong, D.; Li, X.; Wang, H.; Zhang, B.; Kou, Q.; Gan, Z.; Xu, P. Macrobenthic Community Characters of Coral Reef at Sanya, Hainan. *Mar. Sci.* **2015**, *39*, 83–91, doi:10.11.759/hykx20131209001. [Google Scholar]
75. Peng, S. The Nutrient, Total Petroleum Hydrocarbon and Heavy Metal Contents in the Seawater of Bohai Bay, China: Temporal–Spatial Variations, Sources, Pollution Statuses, and Ecological Risks. *Mar. Pollut. Bull.* **2015**, *95*, 445–451, doi:10.1016/j.marpolbul.2015.03.032. [Crossref]
76. Lan, J.; Sun, Y.; Xiao, S.; Yuan, D. Polycyclic Aromatic Hydrocarbon Contamination in a Highly Vulnerable Underground River System in Chongqing, Southwest China. *J. Geochem. Explor.* **2016**, *168*, 65–71, doi:10.1016/j.gexplo.2016.05.013. [Crossref]
77. Xu, X.; Cai, Y.; Shi, H.; Chen, J. Spatial Distribution and Ecological Risk Assessment on Heavy Metals in Surface Sediments in Haikou Bay. *Mar.*

Environ. Sci. **2023**, *42*, 493–501, doi:10.13634/j.cnki.mes.2023.04.016. [Crossref]

78. Nie, R.; Wang, F.; Zhou, T.; Liang, J. Pollution Situation of Land-Based Outlets and Distribution Characteristics of Main Pollutants in Haikou. *Environ. Pollut. Control* **2016**, *38*, 12–18. [Google Scholar]