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Using the Heavy Metal Indices and Benthic Indices to Assess the Ecological Quality in the Tidal Flats of Garolim Bay, South Korea

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Abstract: During economic growth, anthropogenic activities have exerted detrimental impacts on the tidal flat ecosystems in South Korea. Although scholars have conducted extensive research on the ecological quality of tidal flats in South Korea, most have primarily focused on benthic indices. Hence, we utilised two heavy metal indices and five benthic indices to assess the ecological quality in the tidal flats comprehensively. In our study, although heavy metals and total organic carbon concentrations were low in Garolim Bay, the final ecological quality at most stations was unacceptable (63%). The Benthic Opportunistic Polychaetes Amphipods Index (BOPA) demonstrated commendable outcomes in correlation and kappa analyses. However, the BOPA still had some limits. We believe that using multiple indices to assess the ecological quality in the tidal flats of Garolim Bay is more robust than using a single index.

Keywords: heavy metal indies; benthic indies; ecological quality; tidal flats; Garolim Bay

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1. Introduction

Tidal flats, located at the interface between the ocean and land, are among the world's most productive ecosystems and vital for the health of coastal ecosystems. Serving as habitats for a plethora of marine organisms and birds [1,2], these ecosystems, however, are vulnerable to environmental disturbances. In recent years, increasing human activities have exerted immense pressure on them, leading to their degradation and reduction [3–5]. This is particularly evident in South Korea, where governmental reclamation projects in the late 20th and early 21st centuries have significantly impacted tidal flat ecosystems, especially in areas like Sihwa and Saemangeum [6]. Given this backdrop, there is an urgent need for a precise assessment of the ecological quality of tidal flats in South Korea. Such evaluations will be a foundation for devising adequate protection and restoration policies.

Heavy metals are naturally present in marine environments. However, human activities have significantly amplified the accumulation of these pollutants in marine ecosystems. The persistent presence of heavy metals raises significant concerns due to their toxicity, potential for bioaccumulation, and biomagnification. These factors profoundly affect ecosystems, human health, and various living organisms [7–10]. As a result, heavy metal contamination is one of the most pressing environmental issues confronting global marine ecosystems [11,12]. In marine environments, heavy metals predominantly accumulate in fine sediments. Human interventions further exacerbate the build-up of these polluted sediments within aquatic ecosystems [13]. To gauge the contamination levels and ecological risks posed by heavy metals in sediments, researchers have introduced tools like the pollution load index (PLI) and the Nemerow pollution index ($PI_{Nemerow}$) [14,15]. Both the PLI and $PI_{Nemerow}$ have gained widespread acceptance for evaluating marine sediments [16–19]. Notably, while many studies have employed various heavy metal indices for marine environment assessments, only a handful have integrated both heavy metal and biological indices for a holistic evaluation [20,21].

Macrobenthos, with their unique attributes such as limited mobility, extended life cycles, and varied tolerance to multiple stressors, have become invaluable tools in marine benthic environment assessments [22–24]. Recognising their potential, marine scientists have formulated several benthic indices centred on macrobenthic organisms. Notably, indices like the AZTI Marine Biotic Index (AMBI) [25], BENTIX benthic index [26], the Benthic Opportunistic Polychaetes Amphipods Index (BOPA) [27], and the Multivariate AZTI Marine Biotic Index (M-AMBI) [28] have gained global acceptance [29–32]. These indices categorise macrobenthos communities into distinct ecological groups based on pollution tolerance. For instance, while the AMBI and M-AMBI encompass five ecological groups, the BENTIX and BOPA are more streamlined with three and two groups, respectively. The Korea Ocean Research and Development Institute (KORDI) introduced the Benthic Pollution Index (BPI) in 1995, drawing inspiration from the Infaunal Trophic Index (ITI) [33]. The BPI classifies macrobenthos into four ecological groups, considering their feeding patterns and pollution resilience [34]. In South Korea, indices like the AMBI, BPI, and M-AMBI have been extensively employed for marine evaluations [35–37]. Echoing the trend observed with heavy metal indices, much of the research on benthic indices either delves into their regional applicability or leverages them to gauge ecological quality [38–41].

Garolim Bay is a semi-enclosed bay located on the west coast of South Korea, with a coastline length of 161.8 km and a sea area of 112.6 km^2. The entrance width is 3.2 km, and the north–south width is 22.4 km [42]. This is an essential area for shellfish aquaculture and a habitat for migratory birds in South Korea. In addition, many endangered species inhabit this bay (such as *Phoca largha*, *Sesarmops intermedius*, *Zostera marina*, and *Austruca lacteal*). In July 2016, the Ministry of Oceans and Fisheries designated Garolim Bay as a marine protected area, with a total area of 91.2 km^2, making it the largest marine protected area in South Korea [43].

As far as we know, this is the first time that heavy metal indices and benthic indices have been used to evaluate the ecological quality of the South Korean coast comprehensively. Our objective is to examine the suitability of benthic indices in determining the ecological quality status. By applying both heavy metal and benthic indices, we aim to assess the ecological quality in the tidal flats of Garolim Bay, thereby offering insights for developing conservation and restoration strategies in Garolim Bay.

2. Materials and Methods

2.1. Study Area

Garolim Bay is a semi-enclosed bay located on the west coast of South Korea, with a coastline length of 161.8 km and a sea area of 112.6 km^2 [42]. The tidal flats of Garolim Bay span approximately 70 km^2. The average tidal range at the bay's mouth is 4.7 m, with a spring range of 6.5 m. Flood and ebb current speeds are 1.4 m/s and 1.1 m/s, respectively [44]. Garolim Bay is an important shellfish farming area on the South Korean coast, with an annual production of 4000 tons [45]. The tidal flats of Garolim Bay have reached an area of 1682.7 hectares for shellfish farming, totalling 195 shellfish farms [46]. To our knowledge, the central human pressure was shellfish aquaculture in Garolim Bay.

2.2. Sample Collection and Processing

A Van Veen grab sampler (0.045 m^2) was used to collect the macrobenthos and sediment samples at each station three times. The survey was conducted at 49 stations in June 2015 in the tidal flats (Figure 1).

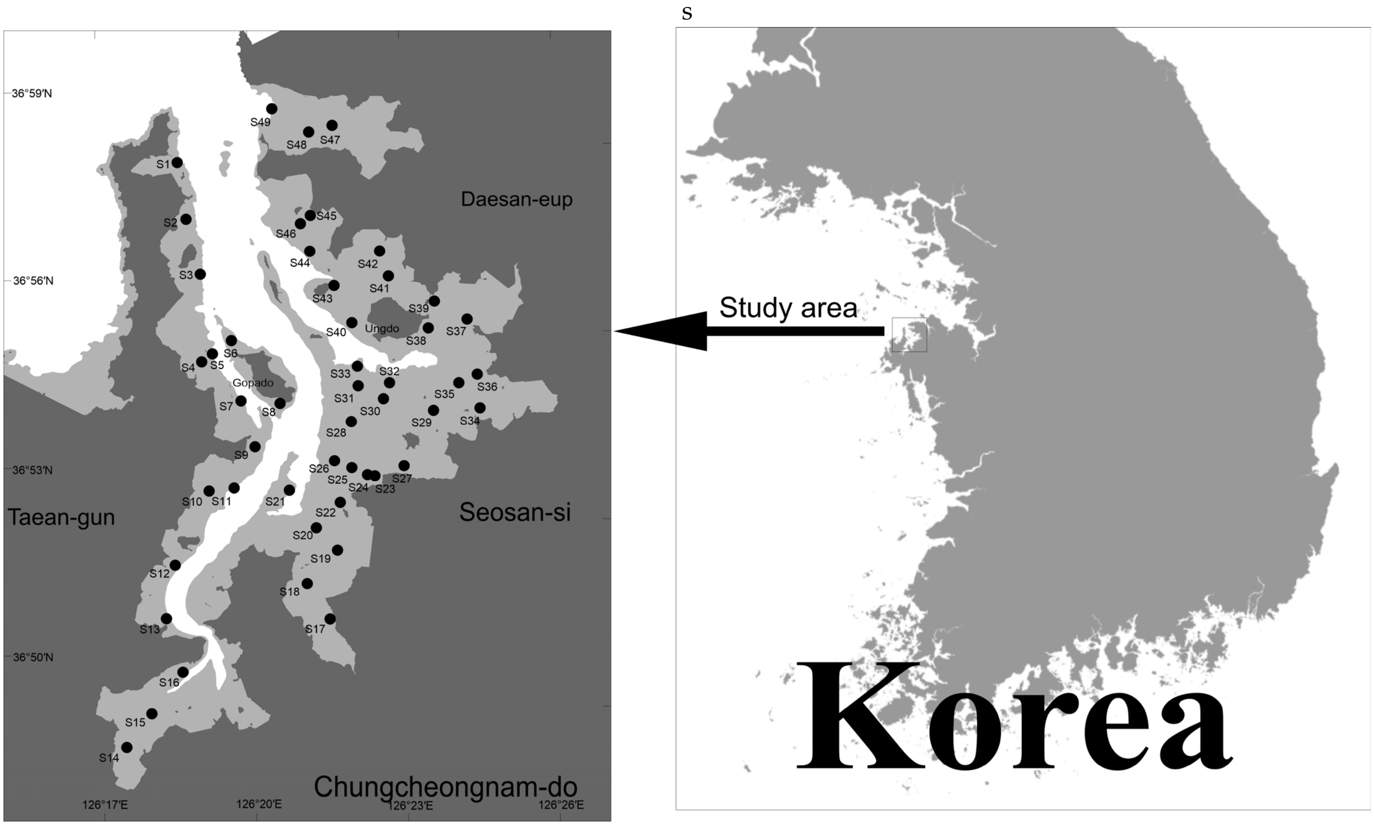

Figure 1. The study area and sampling stations are in the tidal flats of Garolim Bay, South Korea.

Macrobenthos samples were filtered through a 1 mm sieve and fixed in a 4% formalin solution (HanLab Co., Ltd., Cheongju, Republic of Korea). Then, they were preserved in 70% ethanol (HanLab Ltd., Cheongju, Republic of Korea) before being sent to the laboratory for identification up to the level of available species under a stereomicroscope (Olympus SZX-10, Olympus Co., Ltd., Tokyo, Japan).

Sediment samples were preserved at a temperature of −20 °C before being dispatched to the laboratory to undergo analyses for grain size, total organic carbon (TOC), and heavy metal concentrations (chromium, cobalt, nickel, copper, zinc, lead). In the grain size analysis, sample particle size distribution was initially evaluated through wet sieving. For particles exceeding 4∅ in size, further analysis was undertaken using a particle size analyser (Microtrac S3500 series, Microtrac Inc., York, PA, USA). For total organic carbon (TOC) analysis, a powder sediment sample (10 mg) was added to a hydrochloric acid solution (HCl) (Samchun Co., Ltd., Seoul, Republic of Korea), followed by the addition of calcium carbonate ($CaCO_3$) (Samchun Co., Ltd., Seoul, Republic of Korea). Subsequently, the mixture was analysed using an automatic elemental analyser (Flash 2000 series, Thermo Scientific Co., Ltd., Waltham, MA, USA). A 0.2 g sample of powdered sediment was digested in a mixed solution of nitric acid and perchloric acid (HNO_3:$HClO_4$ = 3:1) (Samchun Co., Ltd., Seoul, Republic of Korea) to analyse heavy metal concentrations at 170 °C for 6 h. This was followed by the addition of a mixture of hydrofluoric acid and perchloric acid (HF:$HClO_4$ = 3:1) (Samchun Co., Ltd., Seoul, Republic of Korea). The digested sample was then analysed using an inductively coupled plasma atomic emission spectrometer (OPTIMA 7300DV, PerkinElmer Inc., Waltham, MA, USA) and inductively coupled plasma mass spectrometry (ELAN DRC II, Perkin-Elmer Inc., Waltham, MA, USA). We followed the procedural test standards for sediments for the above analysis [47].

2.3. Heavy Metal Indices and Benthic Indices

The pollution load index (PLI) and Nemerow pollution index ($PI_{Nemerow}$) are widely used for the assessment of sediment quality. Both heavy metal indices are calculated based on geochemical background values. We referred to the study by Song, 2014 to calculate the geochemical background values for six heavy metals in Garolim Bay: Cr (42.7 mg/kg), Co (7.4 mg/kg), Ni (38.9 mg/kg), Cu (6.6 mg/kg), Zn (41.4 mg/kg), and Pb (17.7 mg/kg) [48]. The classes of sediment quality and formulae for the PLI and $PI_{Nemerow}$ are shown in Table 1.

Table 1. Algorithmic approaches to heavy metal and benthic indices: categorisation of levels of risk and ecological quality status for indices.

Indices	Algorithm	Index Values	Level of Risk/Ecological Quality of Status	Note
PLI [a]	$= \sqrt[n]{PI_1 \times PI_2 \times PI_3 \times \ldots PI_n}$	<1 1–2 2–3 >3	Unpolluted Moderately polluted Heavily polluted Extremely polluted	PI is the ratio of heavy metal content in sediments to the geochemical background values.
$PI_{Nemerow}$ [b]	$= \sqrt{\frac{\left(\frac{1}{n}\sum_{i-1}^{n} PI\right)^2 + PI_{max}^2}{n}}$	≤0.7 0.7–1 1–2 2–3 ≥3	Clean Warning limit Slight pollution Moderate pollution Heavy pollution	PI is the ratio of heavy metal content in sediments to the geochemical background values.
AMBI [c]	$= [(0 \times \%\ EGI) + (1.5 \times \%\ EGII) + (3 \times \%\ EGIII) + (4.5 \times \%\ EGIV)(6 \times \%\ EGV)]/100$	0.0–1.2 1.2–3.3 3.3–5.0 5.0–6.0 >6.0	High Good Moderate Poor Bad	EGI: disturbance-sensitive species; EGII: disturbance-indifferent species; EGIII: disturbance-tolerant species; EGIV: second-order opportunistic species; EGV: first-order opportunistic species.
BENTIX [d]	$= [6 \times \%\ GI\ + 2(\%\ GII + \%\ GIII)]/100$	4.5–6 3.5–4.5 2.5–3.5 2.0–2.5 0.0	High Good Moderate Poor Bad	GI = EGI + EGII; GII = EGIII + EGIV; GIII = EGV.
BOPA [e]	$= \log[(fP)/(fA + 1) + 1)]$	0–0.045 0.045–0.139 0.139–0.193 0.193–0.267 0.267–0.301	High Good Moderate Poor Bad	*fp*: opportunistic polychaetes frequency; *fa*: amphipods frequency
BPI [f]	$= [1 - (a \times N1 + b \times N2 + c \times N3 + d \times N4)/(N1 + N2 + N3 + N4)\ /d] \times 100$	60–100 40–60 30–40 20–30 0–20	High Good Moderate Poor Bad	N1: filter feeders or large carnivores; N2: surface deposit feeders or small carnivores; N3: subterranean deposit feeders; N4: opportunistic species
M-AMBI [g]	$= K + (a \times AMBI) + (b \times H') + (c \times S)$	>0.77 0.53–0.77 0.38–0.53 0.20–0.38 ≤0.2	High Good Moderate Poor Bad	H′: Shannon diversity index; S: number of species

Notes: [a], [14]; [b], [15]; [c], [25]; [d], [26]; [e], [27]; [f], [34]; [g], [28].

Five benthic indices were selected to assess ecological quality, namely, the AZTI Marine Biotic Index (AMBI), a benthic index (BENTIX), Benthic Opportunistic Polychaetes Amphipods Index (BOPA), Benthic Pollution Index (BPI), and multivariate AZTI Marine Biotic Index (M-AMBI). Except for the BPI, the other benthic indices have been widely used internationally [49]. The rationale for each of the five indices is different. In addition, five benthic indices have successfully responded to human pressure in some studies. Using these five benthic indices provides a comprehensive and accurate assessment of the ecological quality of Garolim Bay. The AMBI categorises macrobenthos into five ecological groups based on their tolerance to pollution [25]. The BENTIX operates on the same principle as AMBI, but has only three ecological groups [26]. The BOPA is calculated based on the ratio of the abundance of opportunistic polychaetes to the abundance of amphipods [27]. The BPI is inspired by the Infaunal Trophic Index (ITI) and incorporates opportunistic species and pollution indicators into its calculations [34]. The M-AMBI was derived from a factorial analysis of the AMBI, richness, and Shannon–Wiener diversity values [28]. For the reference values of the M-AMBI, we referred to previous studies and increased the highest diversity and species count by 15% [50]. The classes of ecological quality and formulae for all benthic indices are shown in Table 1.

2.4. Data Analysis

Calculation of AMBI and M-AMBI values was performed using AMBI 6.0, accessible at https://ambi.azti.es/ (accessed on 1 June 2022). Utilising the most recent AMBI species list from June 2022, the majority of collected species were categorised into ecological groups. For those species not listed in the AMBI software's database, we assigned them to the same ecological groups as species within their genus [51]. The calculations for the BENTIX and BOPA also reference the AMBI species list (Table S1). Based on previous research, we allocated the BPI function groups [42,52] (Table S2).

For a more straightforward assessment of ecological quality, we classified seven indices—PLI, $PI_{Nemerow}$, AMBI, BENTIX, BOPA, BPI, and M-AMBI—into two categories, 'acceptable' and 'unacceptable', according to their respective values, as detailed in Table 2. Since the evaluation results of the seven indices may vary, we referred to previous research that if more than four indices are acceptable, the final ecological quality is deemed acceptable [53,54].

Table 2. Criteria utilised to translate index values into categories of acceptable or unacceptable for evaluating ecological quality.

Indices	Thresholds	Acceptable, Unacceptable
PLI	<1 ≫1	Acceptable Unacceptable
$PI_{Nemerow}$	<1 ≫1	Acceptable Unacceptable
AMBI	≤3.3 >3.3	Acceptable Unacceptable
BENTIX	≫3.5 <3.5	Acceptable Unacceptable
BOPA	≫0.139 <0.139	Acceptable Unacceptable
BPI	≫40 <40	Acceptable Unacceptable
M-AMBI	≫0.53 <0.53	Acceptable Unacceptable

The Spearman correlation analysis was used to analyse the correlation between the indices and the correlation between the index and the environment. Weighted kappa analysis was performed to evaluate agreement among the indices. The degree of agreement can be classified according to the kappa value [55] (Table S3). For Spearman correlation analysis and weighted kappa analysis of the study data, we used SPSS 29.0 (SPSS Inc., Armonk, NY, USA). Additionally, we utilised Surfer 14 (Golden Software Inc., Golden, CO, USA) for the study map rendering and Origin 2021 (Origin Lab Co., Ltd., Northampton, MA, USA) for producing other figures.

3. Results

3.1. Environmental Factors

The mean value, range of values, and standard deviation for each environmental factor in the tidal flats of Garolim Bay are shown in Table 3. Overall, the highest concentration of Zn was 67.7 mg/kg at station 16, and the lowest concentration of Cu was 1.2 mg/kg at station 6 (Figure 2). The sand (56 ± 22) and silt (42 ± 20) showed a relatively large standard deviation. The total organic carbon content of intertidal sediments in Garolim Bay is relatively low, averaging 0.3 ± 0.4. The environmental factors at each station in the tidal flats of Garolim Bay are shown in Table S4.

Table 3. The metal concentrations, grain size parameters, total organic carbon, ERL values of metal concentrations, and ERM values of metal concentrations of the surface sediments in Garolim Bay.

Environmental Parameter	Max	Min	Mean	SD	ERL	ERM
Cr, mg/kg	44	4.5	30	8	81	370
Co, mg/kg	8.7	1.5	5.5	1.4	/	/
Ni, mg/kg	19	2.5	10.6	3.3	20.9	51.6
Cu, mg/kg	13.4	1.2	6.5	2.6	34	270
Zn, mg/kg	67.7	8.7	38.5	11.7	150	410
Pb, mg/kg	27.9	14.1	20.2	2.7	46.7	218
Mean grain, ∅	5.6	0.5	4	1.1	/	/
Sand, %	95	18	56	22	/	/
Silt, %	77	4	42	20	/	/
Clay, %	8	0	3	2	/	/
Toc, %	2.7	0	0.3	0.4	/	/

Notes: SD: standard deviation; Toc: total organic carbon; ERL: effect range low; ERM: effect range median.

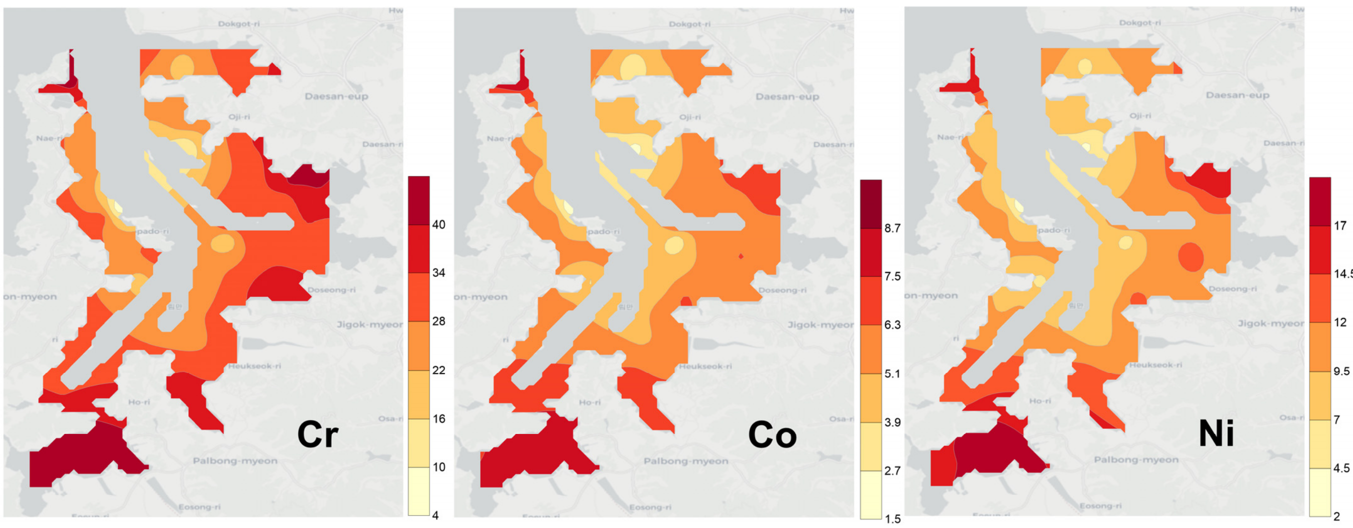

Figure 2. *Cont.*

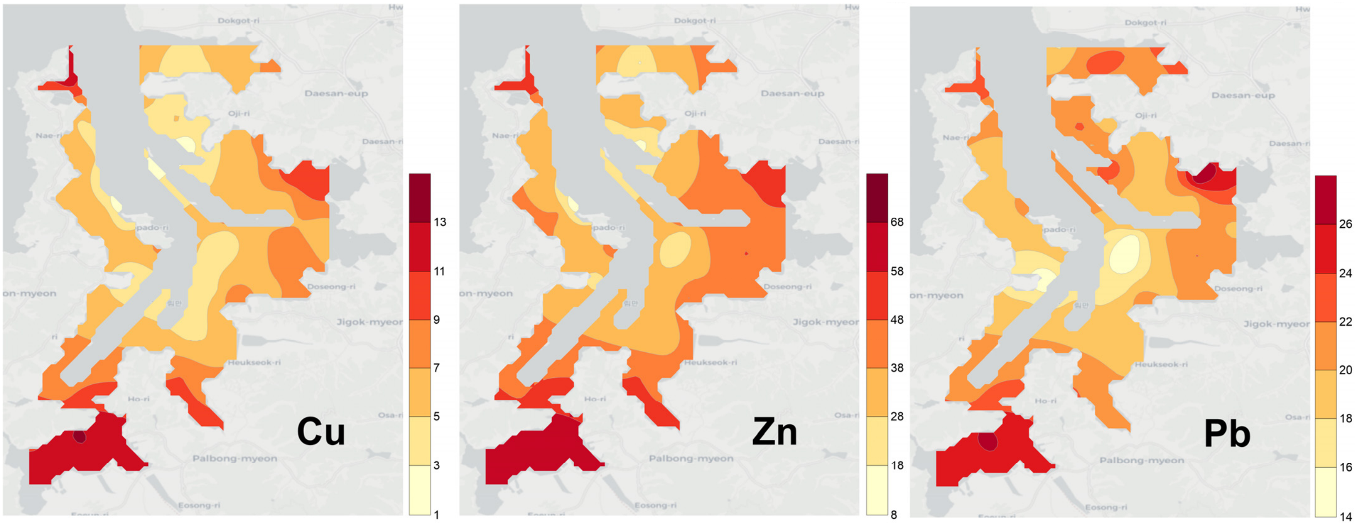

Figure 2. Spatial distribution patterns of heavy metal concentrations in the tidal flats of Garolim Bay.

3.2. Macrobenthos Characteristics

In the tidal flats of Garolim Bay, macrobenthos comprising 118 species across eight phyla were identified. The dominant taxon was Polychaeta, representing 51 species (43%), followed by Arthropoda with 32 species (27%), Mollusca with 30 species (25%), and Echinodermata with 1 species (1%). Other groups accounted for 4 species (3%) (Table S5). The average habitation density was 666 $\pm$ 481.2 ind./m^2. The average biomass was 23.9 $\pm$ 25.2 g/m^2 at each station in the tidal flats of Garolim Bay (Table S6).

3.3. The Level of Pollution and Values of Heavy Metal Indices

The pollution load index (PLI) ranged from 0.8 to 5, averaging 1.5 $\pm$ 0.7. The level of pollution was unpolluted for 6 stations (12%), moderately polluted for 38 stations (78%), heavily polluted for 3 stations (6%), and extremely polluted for 2 stations (4%). Acceptable ecological quality was found for 44 stations (90%), and unacceptable found for 4 stations (10%).

The Nemerow pollution index ($PI_{Nemerow}$) ranged from 0.4 to 1, averaging 0.6 $\pm$ 0.1. The level of pollution was clean for 43 stations (88%), the warning limit was reached for 6 stations (12%), and the ecological quality was acceptable for 49 stations (100%). The level of risk and values for the pollution load index (PLI) and Nemerow pollution index ($PI_{Nemerow}$) at each station are shown in Figure 3. The ecological quality status of acceptable and unacceptable percentages of the heavy metal indices is shown in Figure 4.

3.4. The Ecological Quality Status and Values of Benthic Indices

The AZTI Marine Biotic Index (AMBI) ranged from 0.6 to 4.5, averaging 2.1 $\pm$ 0.8. The ecological quality status was high at 2 stations (4%), good at 29 stations (59%), moderate at 17 stations (35%), and bad at 1 station (2%). The ecological quality of acceptable attained at was 32 stations (65%) and unacceptable at 17 stations (35%).

The benthic index BENTIX ranged from 2 to 5.3, averaging 3.5 $\pm$ 0.8. The ecological quality status was high at 14 stations (29%), good at 4 stations (8%), moderate at 25 stations (51%), and poor at 6 stations (12%). The ecological quality of acceptable was attained at 18 stations (37%) and unacceptable at 31 stations (63%).

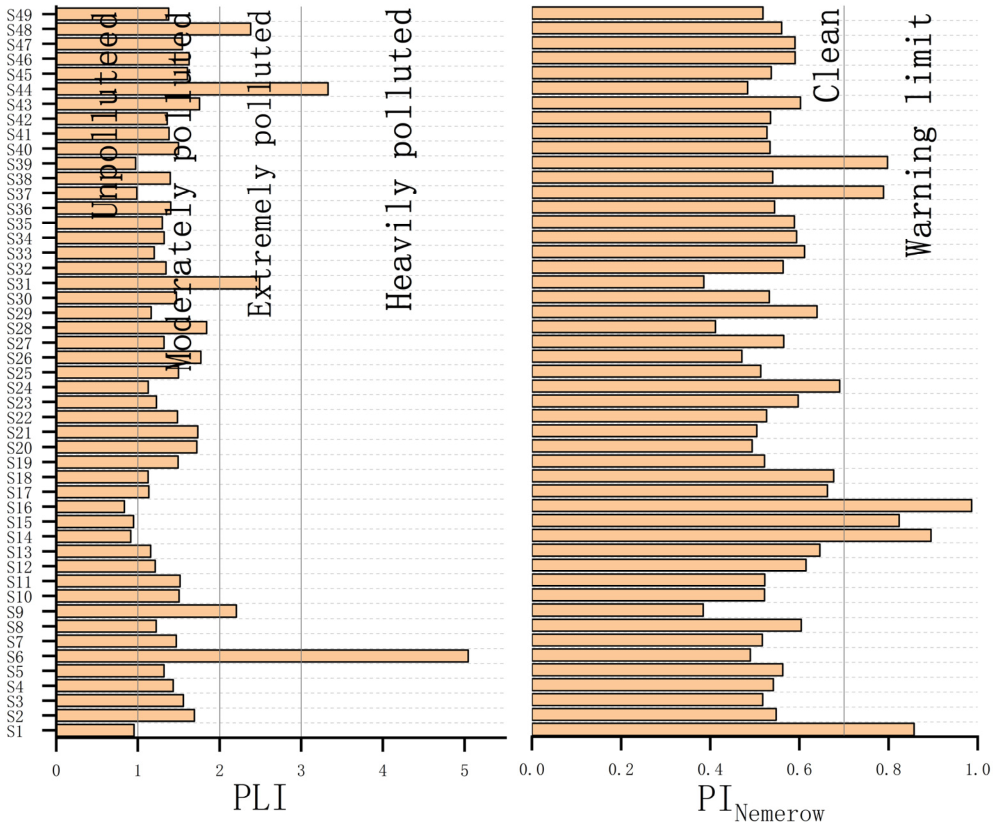

Figure 3. The level of risk and values for heavy metal indices at each station in the tidal flats of Garolim Bay.

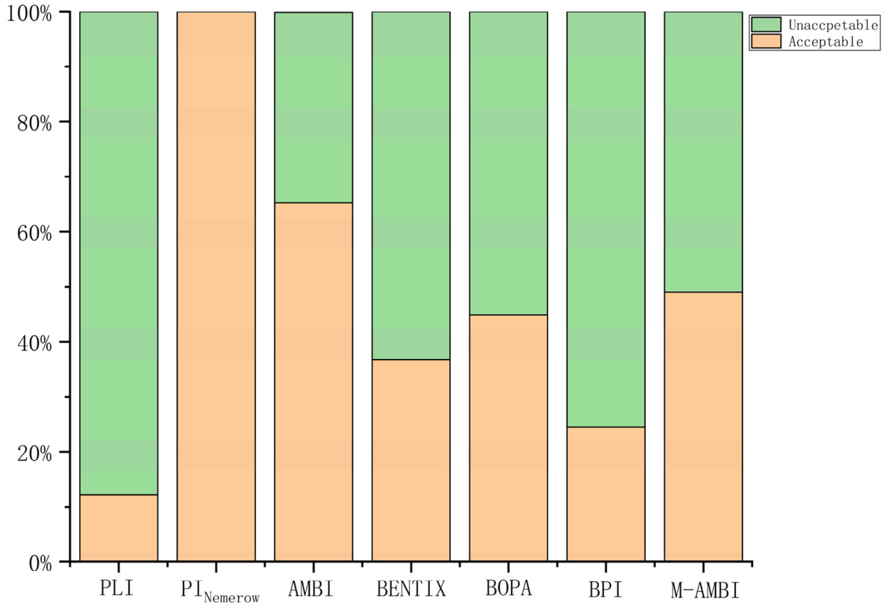

Figure 4. The ecological quality status of the heavy metal and benthic indices for acceptable and unacceptable percentages.

The Benthic Opportunistic Polychaetes Amphipods Index (BOPA) ranged from 0 to 0.3, averaging 0.1 ± 0.1. The ecological quality status was high at 8 stations (16%), good at 14 stations (29%), moderate at 12 stations (24%), poor at 14 stations (29%), and bad at 1 station (2%). The ecological quality of acceptable was attained at 22 stations (45%) and unacceptable at 27 stations (55%).

The Benthic Pollution Index (BPI) ranged from 0 to 69, averaging 27.6 ± 17.2. The ecological quality status was high at 2 stations (4%), good at 10 stations (20%), moderate at 7 stations (14%), poor at 13 stations (27%), and bad at 17 stations (35%). The ecological quality of acceptable was attained at 12 stations (24%) and unacceptable at 27 stations (76%).

The multivariate AZTI Marine Biotic Index (M-AMBI) ranged from 0.1 to 0.8, averaging 0.5 ± 0.1. The ecological quality status was high at 2 stations (4%), good at 22 stations (45%), moderate at 16 stations (33%), poor at 8 stations (16%), and bad at 1 station (2%). The ecological quality of acceptable was attained at 24 stations (49%) and unacceptable at 25 stations (51%). The ecological quality status and values for all benthic indices at each station are shown in Figure 5. The ecological quality status of acceptable and unacceptable percentages of the benthic indices are shown in Figure 4.

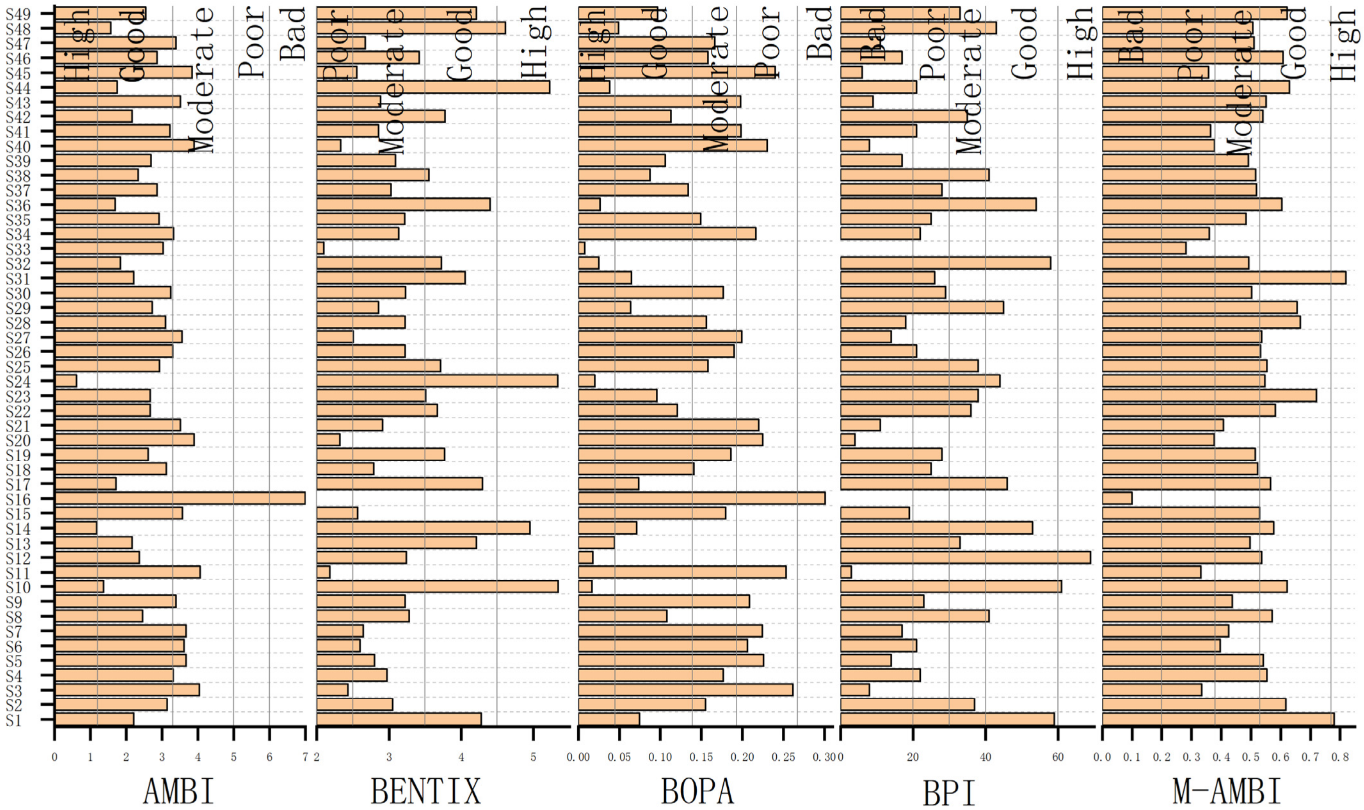

Figure 5. The ecological quality status and values for benthic indices at each station of the tidal flat of Garolim Bay.

3.5. Final Ecological Quality of the Intertidal Zones in Garolim Bay

Based on the ecological quality of the seven indices (PLI, $PI_{Nemerow}$, AMBI, BENTIX, BOPA, BPI, and M-AMBI), we found that the final ecological quality of acceptable was attained at 18 stations (37%) and unacceptable at 31 stations (63%) in the tidal flats of Garolim Bay. The final ecological quality of acceptable was attained at 5 stations in the western tidal flats and at 13 stations in the eastern tidal flats (Figure 6).

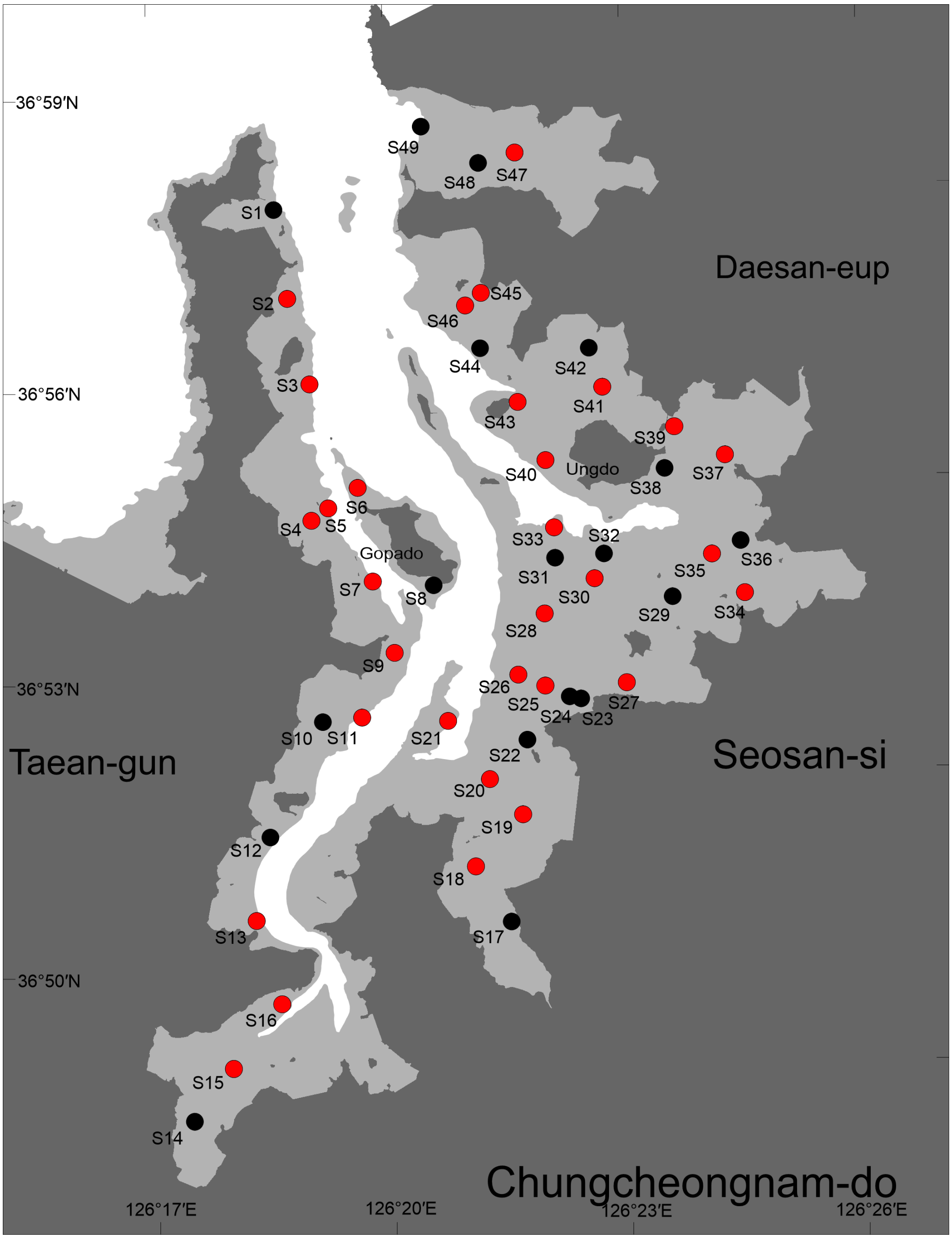

Figure 6. The final ecological quality in the tidal flats of Garolim Bay. Black stations: the final ecological quality is acceptable; red stations: the final ecological quality is unacceptable.

3.6. Results of the Spearman Correlation Analysis

The Spearman correlation analysis showed that the BOPA with environmental factors had the best correlation with other benthic indices. The BENTIX and M-AMBI did not correlate with the environmental factors. All benthic indices correlated with other benthic indices, but only the BOPA correlated with heavy metal indices (PLI and $PI_{Nemerow}$). The PLI and $PI_{Nemerow}$ had a high negative correlation. The results of the Spearman correlation analysis are shown in Figure 7.

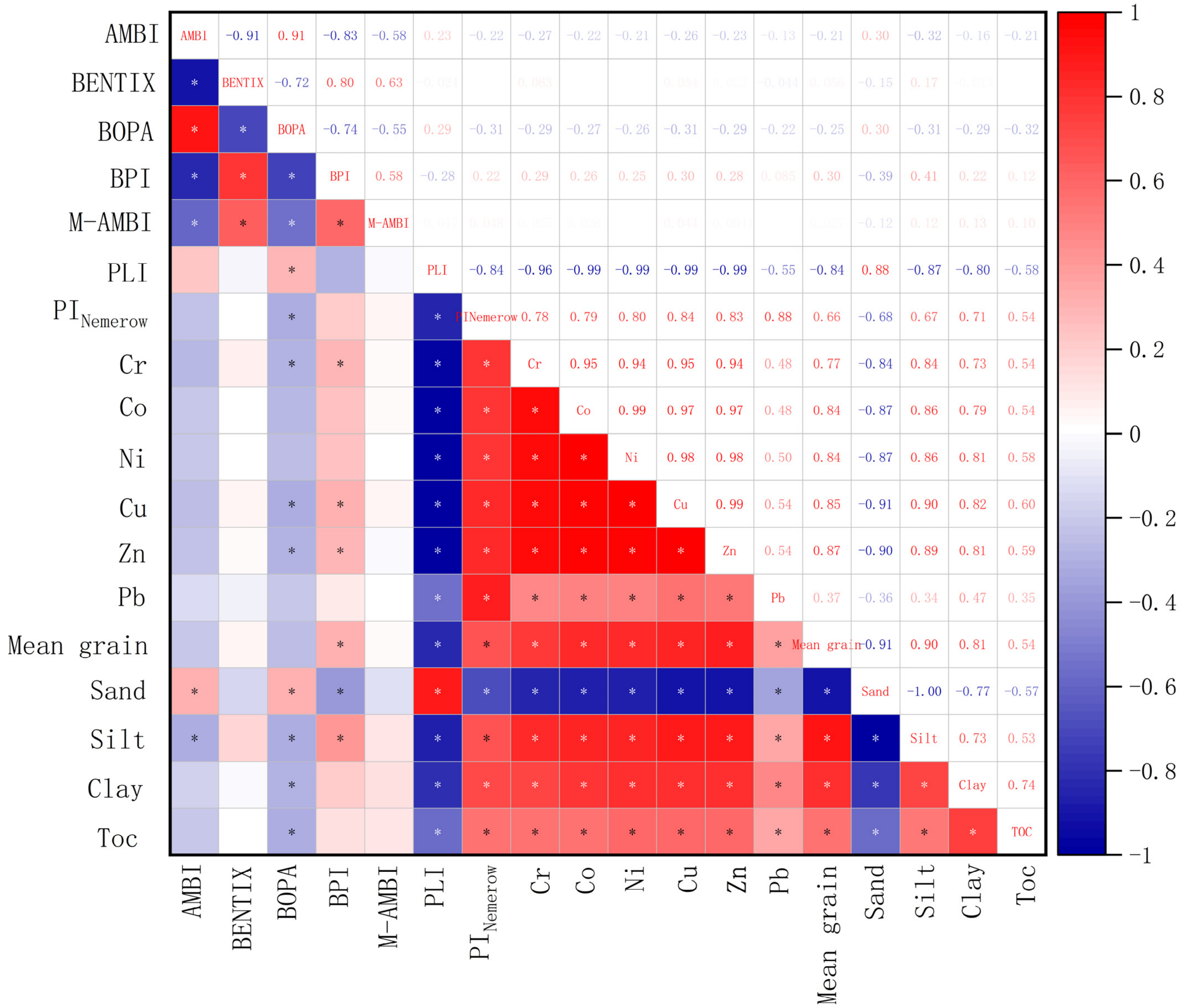

Figure 7. Spearman correlation analysis among the PLI, $PI_{Nemerow}$, AMBI, BENTIX, BOPA, and M-AMBI with environmental factors in the tidal flats of Garolim Bay. *: $p \leq 0.05$.

3.7. Results of the Weighted Kappa Analysis

In the weighted kappa analysis, the level of agreement was null, very low, low or good. Notably, the BENTIX and BOPA had the highest kappa value of 0.7, and the level of agreement was good (84% match). Conversely, the M-AMBI and PIL had the lowest kappa value of −0.1, and the level of agreement was null (47% match). The level of agreement of the BOPA with most indices was good (except for the M-AMBI, PIL, and $PI_{Nemerow}$) (Table S7).

4. Discussion

4.1. The Characteristics of Heavy Metal

In this study, the concentration of all heavy metals inside Garolim Bay was higher than at its entrance (Figure 2). All heavy metals (Cr, Co, Ni, Cu, Zn and Pb) had a high correlation with the other heavy metals (Figure 7). Moreover, the correction between all heavy metals and mean grain, sand, silt, clay, and mud was good. This suggests that heavy metal distribution and content depend on sediment grain size (as the mean grain increases, the heavy metal content also increases). In the southern and western parts of the Yellow

Sea, some heavy metal concentrations have also shown a relationship with the grain size of surface sediments [56,57].

Garolim Bay has the lowest heavy metal content compared to others polluted by various industrial facilities on the coasts of South Korea (i.e., Masan Bay, Youngil Bay, and Shihwa Lake) [58]. We used the effect range low (ERL) and effect range median (ERM) values by Buchman (2008) to assess the metal concentrations (Cr, Ni, Cu, Zn, and Pb) [59] (Table 3). The Cr, Ni, Cu, Zn, and Pb concentrations at each station are less than the ERL and ERM values. This suggests that the tidal flats of Garolim Bay have not been polluted by heavy metals.

4.2. The Level of Risk of Heavy Indices

The heavy indices (PLI and $PI_{Nemerow}$) showed varying results for whether the final ecological quality status was acceptable for the tidal flats in Garolim Bay (12–100%). Although the correlation between the PLI and $PI_{Nemerow}$ was good (Figure 7), the kappa analysis results indicate that the level of agreement between the PLI and $PI_{Nemerow}$ was null. This suggests that the agreement between the two indices is low, possibly due to the different classifications of the evaluation results by the PLI and $PI_{Nemerow}$. In addition, the PLI and $PI_{Nemerow}$ have different emphases. The calculation of the $PI_{Nemerow}$ considers the impact of the highest metal concentration in the sediments [60]. Furthermore, the calculation of the PLI and $PI_{Nemerow}$ requires the geochemical background values of heavy metals, and the geochemical background values have an impact on the results of the indices. Due to the lack of geochemical background values in Garolim Bay, we referred to the latest research [48]. However, that study focused on the geochemical background values of the southern coast of South Korea. Therefore, we believe it is necessary to study the geochemical background values of other coasts of South Korea to assess the pollution level of marine sediments more accurately.

4.3. The Ecological Quality Status of Benthic Indices

The analysis of the five benthic indices (AMBI, BENTIX, BOPA, BPI, and M-AMBI) revealed that the range of acceptable ecological quality status spans from 24% to 65%. In addition, these indices exhibited a broad spectrum of variability in their ecological quality status classifications. In particular, the AMBI classified the ecological quality of most stations as high or good (63%), while the BPI classified the ecological quality of most stations as bad or poor (61%). In comparison with other benthic indices, we believe that the AMBI overestimated the ecological quality status, while the BPI underestimated the ecological quality status in the tidal flats of Garolim Bay. Similar phenomena can also be observed in other research. For example, the AMBI overestimated the ecological quality status of the Baltic Sea and Oujiang estuary [61,62] and the BPI underestimated the ecological quality status of Jinhae Bay and Cheonsu Bay [63,64].

We believe that the high abundance of disturbance-tolerant species (EGIII) in the tidal flats of Garolim Bay leads to AMBI overestimation of ecological quality status. The ecological group of *Mediomastus californiensis* was divided into disturbance-tolerant species (EGIII) in the AMBI. However, this species was divided into opportunistic species (N4) in the BPI because the AMBI was developed based on the European coastal ecosystem [25], and ecological group categorisation of the same species may vary in different geographical regions [65]. In addition, the boundary value separating 'good' and 'moderate' might be impractical, leading to an elevated assessment grade. When using the AMBI, we recommend consulting local experts to adjust the grouping of some macrobenthos, thereby enhancing the accuracy of the assessment results. Additionally, the categorisation of ecological quality status for the AMBI might need revision when assessing tidal flats.

When calculating the BPI, only the dominant species are considered. However, according to Seo's (2016) study [52], evaluating only dominant species can affect the accuracy of the BPI. This might have led to an underestimation of ecological quality in our research using the BPI. Therefore, we suggest considering all macrobenthos when using the BPI.

Although the BPI is a widely used benthic index in South Korea, its lack of a unified functional groups database makes its accurate application challenging.

4.4. Statistical Analysis

The BOPA index exhibited significant correlations with other indices (PLI, $PI_{Nemerow}$, AMBI, BENTIX, BPI, and M-AMBI), as evidenced by Spearman correlation analysis ($p \leq 0.05$) (Figure 7). However, kappa analysis showed that agreement between the BOPA and other benthic indices was low to good (0.3–0.7), with heavy metal indices null (0–0.1). In this study, the high abundance of *Heteromastus filiformis* and the fundamental principles behind the indices are similar, leading to significant correlations and high kappa values between the BOPA and other benthic indices (except the M-AMBI). Polychaetes with limited mobility are regarded as viable biomonitor substitutes in studies of metal contamination [66]. Considering only opportunistic polychaetes and amphipods in BOPA calculations may be a potential reason for the significant correlation between the BOPA and heavy metal indices.

The BENTIX and M-AMBI did not show a significant correlation with environmental factors in Spearman correlation analysis. The BENTIX was formulated for oligotrophic environments in the Mediterranean, where the macrobenthos exhibit a high diversity and uniform distribution [67]. *Heteromastus filiformis* constitutes 48% of the total individuals in the tidal flats of Garolim Bay. Furthermore, the M-AMBI notably relies heavily on diversity and richness, appearing to lack the capacity to discern specific characteristics of benthic communities in transitional waters [68]. This indicates the need for careful consideration when applying the BENTIX and M-AMBI in tidal flat environments, especially in cases with an unusually high abundance of a single species.

In this study, the BOPA seems to be a viable alternative to the AMBI, BENTIX, and BPI. Nevertheless, when calculating the BOPA, considering only opportunistic polychaetes and amphipods, the response to certain disturbances is not evident in some areas [69]. We still recommend employing a combination of various indices to assess benthic ecological quality accurately.

4.5. Final Ecological Quality

The final ecological quality results in the tidal flats of Garolim Bay showed that most stations were unacceptable (63%). Garolim Bay is an important shellfish farming area on the South Korean coast, with an annual production of 4000 tons [45]. The tidal flats of Garolim Bay have reached an area of 1682.7 hectares for shellfish farming, totalling 195 shellfish farms [46]. Shellfish farming in the tidal flats can lead to declining biodiversity and accumulation of organic matter and silt [70]. In addition, disruption to the benthic environment during shellfish harvesting and casual discarding of aquaculture supplies (such as nylon rope) impact the benthic environment of this bay. Shellfish aquaculture may be one of the reasons that the final ecological quality of most stations in Garolim Bay was unacceptable. However, further research is necessary to explore the benthic environmental impacts of shellfish aquaculture.

A telling indicator of the deteriorating benthic environment is the surge in the opportunistic polychaete species *Heteromastus filiformis* in the bay's intertidal zones. While a study in July 2006 recorded a density of 191 ind./m^2 for this species [71], our findings show a significantly elevated density of 317.7 ind./m^2. This stark increase underscores the pressing need for interventions to halt and reverse the degradation of Garolim Bay for the benthic environment.

5. Conclusions

The South Korean government formally proposed the establishment of a national marine ecological park in Garolim Bay on 8 December 2022. Accurate assessment of ecological quality can provide a reference for the conservation policies of national marine ecological parks. In this study, we used heavy metal indices and benthic indices to assess ecological quality in the tidal flats of Garolim Bay. The final ecological quality was unacceptable at most stations, and the appearance of many opportunistic species indicates the degradation of the benthic environment in Garolim Bay. In addition, assessing ecological quality using multiple indices offers greater accuracy than assessments based on a single index.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/w16050736/s1. Table S1: Categorisation of macrobenthos into ecological groups for the AMBI; Table S2: Categorisation of the dominant macrobenthos into functional groups for the BPI; Table S3: The threshold of kappa analysis; Table S4: The environmental factors at each station in the tidal flats of Garolim Bay; Table S5: The abundance of macrobenthos at each station in the tidal flats of Garolim Bay; Table S6: The biomass of macrobenthos at each station in the tidal flats of Garolim Bay; Table S7: Kappa values, match percentages, and levels of agreement for the level of risk and ecological status across index combinations utilised in this research.

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References

1. Cao, W.T.; Zhou, Y.Z.; Li, R.; Li, X.C. Mapping changes in coastlines and tidal flats in developing islands using the full time series of Landsat images. *Remote Sens. Environ.* **2020**, *239*, 111665. [CrossRef]
2. Assessment, M.E. *Ecosystems and Human Well-Being: Current State and Trends*; Island Press: Washington, DC, USA, 2005; pp. 1–155.
3. Boesch, D.; Burreson, E.; Dennison, W.; Houde, E.; Kemp, M.; Kennedy, V.; Newell, R.; Paynter, K.; Orth, R.; Ulanowicz, R. Factors in the Decline of Coastal Ecosystems. *Science* **2001**, *293*, 1589–1591. [CrossRef] [PubMed]
4. Syvitski, J.P.M.; Vörösmarty, C.J.; Kettner, A.J.; Green, P. Impact of Humans on the Flux of Terrestrial Sediment to the Global Coastal Ocean. *Science* **2005**, *308*, 376–380. [CrossRef] [PubMed]
5. Tian, B.; Wu, W.; Yang, Z.; Zhou, Y. Drivers, Trends, and Potential Impacts of Long-Term Coastal Reclamation in China from 1985 to 2010. *Estuar. Coast. Shelf Sci.* **2016**, *170*, 83–90. [CrossRef]
6. Koh, C.-H.; Khim, J.S. The Korean Tidal Flat of the Yellow Sea: Physical Setting, Ecosystem and Management. *Ocean. Coast. Manag.* **2014**, *102*, 398–414. [CrossRef]
7. DeForest, D.K.; Brix, K.V.; Adams, W.J. Assessing Metal Bioaccumulation in Aquatic Environments: The Inverse Relationship between Bioaccumulation Factors, Trophic Transfer Factors and Exposure Concentration. *Aquat. Toxicol.* **2007**, *84*, 236–246. [CrossRef] [PubMed]
8. Järup, L. Hazards of Heavy Metal Contamination. *Br. Med. Bull.* **2003**, *68*, 167–182. [CrossRef] [PubMed]
9. Naser, H.A. Assessment and Management of Heavy Metal Pollution in the Marine Environment of the Arabian Gulf: A Review. *Mar. Pollut. Bull.* **2013**, *72*, 6–13. [CrossRef]
10. Wang, W.-X.; Rainbow, P.S. Comparative Approaches to Understand Metal Bioaccumulation in Aquatic Animals. *Comp. Biochem. Physiol. C Toxicol. Pharmacol.* **2008**, *148*, 315–323. [CrossRef]
11. Batista, D.; Muricy, G.; Rocha, R.C.; Miekeley, N.F. Marine Sponges with Contrasting Life Histories Can Be Complementary Biomonitors of Heavy Metal Pollution in Coastal Ecosystems. *Environ. Sci. Pollut. Res.* **2014**, *21*, 5785–5794. [CrossRef]
12. Lu, Y.; Yuan, J.; Lu, X.; Su, C.; Zhang, Y.; Wang, C.; Cao, X.; Li, Q.; Su, J.; Ittekkot, V.; et al. Major Threats of Pollution and Climate Change to Global Coastal Ecosystems and Enhanced Management for Sustainability. *Environ. Pollut.* **2018**, *239*, 670–680. [CrossRef] [PubMed]
13. Khalil, M.; El-Gharabawy, S. Evaluation of Mobile Metals in Sediments of Burullus Lagoon, Egypt. *Mar. Pollut. Bull.* **2016**, *109*, 655–660. [CrossRef] [PubMed]
14. Gong, Q.J.; Deng, J.; Xiang, Y.C.; Wang, Q.F.; Yang, L.Q. Calculating Pollution Indices by Heavy Metals in Ecological Geochemistry Assessment and a Case Study in Parks of Beijing. *J. China Univ. Geosci.* **2008**, *19*, 230–241. [CrossRef]
15. Varol, M. Assessment of Heavy Metal Contamination in Sediments of the Tigris River (Turkey) Using Pollution Indices and Multivariate Statistical Techniques. *J. Hazard. Mater.* **2011**, *195*, 355–364. [CrossRef]

16. Arisekar, U.; Shakila, R.J.; Shalini, R.; Sivaraman, B.; Jeyasekaran, G.; Asha Hema Malini, N. Heavy Metal Concentration in Reef-Associated Surface Sediments, Hare Island, Gulf of Mannar Marine Biosphere Reserve (Southeast Coast of India): The First Report on Pollution Load and Biological Hazard Assessment Using Geochemical Normalization Factors and Hazard Indices. *Mar. Pollut. Bull.* **2021**, *162*, 111838. [CrossRef]
17. Brady, J.P.; Ayoko, G.A.; Martens, W.N.; Goonetilleke, A. Enrichment, Distribution and Sources of Heavy Metals in the Sediments of Deception Bay, Queensland, Australia. *Mar. Pollut. Bull.* **2014**, *81*, 248–255. [CrossRef]
18. Mandour, A.; El-Sayed, M.K.; El-Gamal, A.A.; Khadr, A.M.; Elshazly, A. Temporal Distribution of Trace Metals Pollution Load Index in the Nile Delta Coastal Surface Sediments. *Mar. Pollut. Bull.* **2021**, *167*, 112290. [CrossRef]
19. Martínez-Guijarro, R.; Paches, M.; Romero, I.; Aguado, D. Enrichment and Contamination Level of Trace Metals in the Mediterranean Marine Sediments of Spain. *Sci. Total Environ.* **2019**, *693*, 133566. [CrossRef]
20. Izegaegbe, J.; Vivier, L.; Mzimela, H. Assessment of Metal Pollution in Sediment and Its Impact on the Macrobenthic Community of Richards Bay Harbour, South Africa. *Afr. J. Aquat. Sci.* **2023**, *48*, 123–137. [CrossRef]
21. Maghsoudlou, A.; Momtazi, F.; Hashtroudi, M.S. Ecological Quality Status (EcoQs) of Chabahar Sub-Tropical Bay Based on Multimetric Macrobenthos-Indexes Approach: Response of Bio-Indexes to Sediment Structural/Pollutant Variables. *Reg. Stud. Mar. Sci.* **2020**, *40*, 101524. [CrossRef]
22. Han, C.; Xu, Z.; Liu, X. Characteristics of Macrofaunal Assemblages and Their Relationships with Environmental Factors in a Semi-Enclosed Bay. *Mar. Pollut. Bull.* **2021**, *167*, 112348. [CrossRef]
23. Liu, L.; Li, A.; Zhu, L.; Xue, S.; Li, J.; Zhang, C.; Yu, W.; Ma, Z.; Zhuang, H.; Jiang, Z.; et al. The Application of the Generalized Additive Model to Represent Macrobenthos near Xiaoqing Estuary, Laizhou Bay. *Biology* **2023**, *12*, 1146. [CrossRef] [PubMed]
24. Pandey, V.; Jha, D.K.; Kumar, P.S.; Santhanakumar, J.; Venkatnarayanan, S.; Prince Prakash Jebakumar, J.; Dharani, G. Effect of Multiple Stressors on the Functional Traits of Sub-Tidal Macrobenthic Fauna: A Case Study of the Southeast Coast of India. *Mar. Pollut. Bull.* **2022**, *175*, 113355. [CrossRef] [PubMed]
25. Borja, A.; Franco, J.; Pérez, V. A Marine Biotic Index to Establish the Ecological Quality of Soft-Bottom Benthos Within European Estuarine and Coastal Environments. *Mar. Pollut. Bull.* **2000**, *40*, 1100–1114. [CrossRef]
26. Simboura, N.; Zenetos, A. Benthic Indicators to Use in Ecological Quality Classification of Mediterranean Soft Bottom Marine Ecosystems, Including a New Biotic Index. *Medit. Mar. Sci.* **2002**, *3*, 77. [CrossRef]
27. Dauvin, J.C.; Ruellet, T. Polychaete/Amphipod Ratio Revisited. *Mar. Pollut. Bull.* **2007**, *55*, 215–224. [CrossRef] [PubMed]
28. Muxika, I.; Borja, Á.; Bald, J. Using Historical Data, Expert Judgement and Multivariate Analysis in Assessing Reference Conditions and Benthic Ecological Status, According to the European Water Framework Directive. *Mar. Pollut. Bull.* **2007**, *55*, 16–29. [CrossRef]
29. Bouchet, V.M.P.; Sauriau, P.-G. Influence of Oyster Culture Practices and Environmental Conditions on the Ecological Status of Intertidal Mudflats in the Pertuis Charentais (SW France): A Multi-Index Approach. *Mar. Pollut. Bull.* **2008**, *56*, 1898–1912. [CrossRef]
30. Jayachandran, P.R.; Jima, M.; Philomina, J.; Bijoy Nandan, S. Assessment of Benthic Macroinvertebrate Response to Anthropogenic and Natural Disturbances in the Kodungallur-Azhikode Estuary, Southwest Coast of India. *Environ. Monit. Assess.* **2020**, *192*, 626. [CrossRef]
31. Keeley, N.B.; Forrest, B.M.; Crawford, C.; Macleod, C.K. Exploiting Salmon Farm Benthic Enrichment Gradients to Evaluate the Regional Performance of Biotic Indices and Environmental Indicators. *Ecol. Indic.* **2012**, *23*, 453–466. [CrossRef]
32. Ruellet, T.; Dauvin, J.-C. Benthic Indicators: Analysis of the Threshold Values of Ecological Quality Classifications for Transitional Waters. *Mar. Pollut. Bull.* **2007**, *54*, 1707–1714. [CrossRef] [PubMed]
33. Word, J.Q. The Infaunal Trophic Index. In *Southern California Coastal Water Research Project, Annual Report*; Bascom, W., Ed.; Southern California Coastal Water Research Project: Los Angeles, CA, USA, 1979.
34. KORDI (Korea Ocean Research and Development Institute). *Marine Environmental Assessment Based on the Benthic Faunal Communities*; Report of Management Technique for Marine Environmental Protection Last Year; KORDI: Ansan, Republic of Korea, 1995.
35. Jung, R.H.; Seo, I.S.; Choi, M.Y.; Park, S.R.; Choi, B.M.; Kim, M.H.; Kim, Y.J.; Yun, S.Y. Community Structure and Health Assessment of Macrobenthic Assemblages during Spring and Summer in the Shellfish Farming Ground of Wonmun Bay, on the Southern Coast of Korea. *Korean J. Fish. Aquat. Sci.* **2014**, *47*, 908–926. [CrossRef]
36. Bae, H. Spatial and Seasonal Variations of Macrozoobenthic Communities of South-West Part of Jinhae Bay, Korea. Master's Thesis, Seoul National University, Seoul, Republic of Korea, 2015.
37. Choi, J.W.; Seo, J.Y. Application of Biotic Indices to Assess the Health Condition of Benthic Community in Masan Bay, Korea. *Ocean Polar Res.* **2007**, *29*, 339–348. [CrossRef]
38. Pelletier, M.C.; Gillett, D.J.; Hamilton, A.; Grayson, T.; Hansen, V.; Leppo, E.W.; Weisberg, S.B.; Borja, A. Adaptation and Application of Multivariate AMBI (M-AMBI) in US Coastal Waters. *Ecol. Indic.* **2018**, *89*, 818–827. [CrossRef]
39. Ryu, J.; Hong, S.; Chang, W.K.; Khim, J.S. Performance Evaluation and Validation of Ecological Indices toward Site-Specific Application for Varying Benthic Conditions in Korean Coasts. *Sci. Total Environ.* **2016**, *541*, 1161–1171. [CrossRef]
40. Simboura, N.; Argyrou, M. An Insight into the Performance of Benthic Classification Indices Tested in Eastern Mediterranean Coastal Waters. *Mar. Pollut. Bull.* **2010**, *60*, 701–709. [CrossRef]

41. Yan, J.; Sui, J.; Xu, Y.; Li, X.; Wang, H.; Zhang, B. Assessment of the Benthic Ecological Status in Adjacent Areas of the Yangtze River Estuary, China, Using AMBI, M-AMBI and BOPA Biotic Indices. *Mar. Pollut. Bull.* **2020**, *153*, 111020. [CrossRef]
42. Oh, S.H.; Choi, J.H.; Son, D.S.; Ma, C.W. Macrobenthos Community on the Intertidal at Garolim Bay in Summer. *J. Environ. Biol.* **2019**, *40*, 896–907. [CrossRef]
43. Cho, Y.B. Seasonal Variation of Subtidal Macrobenthic Communities of GarolimBay, Yellow Sea, Korea. Master's Thesis, Mokpo National University, Mokpo, Republic of Korea, 2017.
44. Sang, H.S.; Bon, J.G.; Jong, G.J. Spatial Distribution of Benthic Macrofauna on the Tidal Flat of Garolim Bay, West Coast of Korea. *J. Wetl. Res.* **2004**, *1*, 52–72.
45. Oh, S.H. The Community Study of Macrobenthos on the Intertidal of Garolim Bay, Chungcheongnam-Do. Master's Thesis, Soonchunhyang University, Asan, Republic of Korea, 2017.
46. Sea Grant. *Development of Garorim Bay Fisheries Development Direction and Basic Plan for Conservation Measures*; Sea Grant: Daejeon, Republic of Korea, 2017.
47. National Institute of Fisheries Science. *National Institute of Fisheries Science Notification of Marine Environmental Process Test Standards 2010*; National Institute of Fisheries Science: Busan, Republic of Korea, 2010. Available online: https://www.nifs.go.kr/board/actionBoard0052List.do?BBS_CL_CD=ALL (accessed on 1 January 2022).
48. Song, Y.; Choi, M.S.; Lee, J.Y.; Jang, D.J. Regional Background Concentrations of Heavy Metals (Cr, Co, Ni, Cu, Zn, Pb) in Coastal Sediments of the South Sea of Korea. *Sci. Total Environ.* **2014**, *482–483*, 80–91. [CrossRef] [PubMed]
49. Borja, Á.; Marín, S.L.; Muxika, I.; Pino, L.; Rodríguez, J.G. Is There a Possibility of Ranking Benthic Quality Assessment Indices to Select the Most Responsive to Different Human Pressures? *Mar. Pollut. Bull.* **2015**, *97*, 85–94. [CrossRef] [PubMed]
50. Borja, Á.; Dauer, D.M.; Grémare, A. The Importance of Setting Targets and Reference Conditions in Assessing Marine Ecosystem Quality. *Ecol. Indic.* **2012**, *12*, 1–7. [CrossRef]
51. Borja, A.; Dauer, D.M.; Díaz, R.; Llansó, R.J.; Muxika, I.; Rodríguez, J.G.; Schaffner, L. Assessing Estuarine Benthic Quality Conditions in Chesapeake Bay: A Comparison of Three Indices. *Ecol. Indic.* **2008**, *8*, 395–403. [CrossRef]
52. Seo, J.Y. A Study on the Determination of Threshold Value of Benthic Community Health and Application of Benthic Pollution Index (BPI) to Special Management Areas the Southern Coasts of Korea. Ph.D. Thesis, Pusan National University, Pusan, Republic of Korea, 2016.
53. Dong, J.-Y.; Wang, X.; Bidegain, G.; Sun, X.; Bian, X.; Zhang, X. Assessment of the Benthic Ecological Quality Status (EcoQs) of Laizhou Bay (China) with an Integrated AMBI, M−AMBI, BENTIX, BO2A and Feeding Evenness Index. *Ecol. Indic.* **2023**, *153*, 110456. [CrossRef]
54. Liang, J.; Ma, C.-W.; Kim, S.-K.; Park, S.-H. Assessing the Benthic Ecological Quality in the Intertidal Zone of Cheonsu Bay, Korea, Using Multiple Biotic Indices. *Water* **2024**, *16*, 272. [CrossRef]
55. Monserud, R.A.; Leemans, R. Comparing Global Vegetation Maps with the Kappa Statistic. *Ecol. Modell.* **1992**, *62*, 275–293. [CrossRef]
56. Liu, S.; Zhang, Y.; Bi, S.; Zhang, X.; Li, X.; Lin, M.; Hu, G. Heavy Metals Distribution and Environmental Quality Assessment for Sediments off the Southern Coast of the Shandong Peninsula, China. *Mar. Pollut. Bull.* **2015**, *100*, 483–488. [CrossRef]
57. He, Z.; Song, J.; Zhang, N.; Zhang, P.; Xu, Y. Variation Characteristics and Ecological Risk of Heavy Metals in the South Yellow Sea Surface Sediments. *Environ. Monit. Assess.* **2009**, *157*, 515–528. [CrossRef]
58. Park, K.-K. Trace Metals in Surface Sediments of Garolim Bay, Korea. Master's Thesis, Chungnam National University, Daejeon, Republic of Korea, 2020.
59. Buchman, M.F. *NOAA Screening Quick Reference Tables*; Buchman, M.F., Ed.; NOAA: Washington, DC, USA, 2008. Available online: https://repository.library.noaa.gov/view/noaa/9327 (accessed on 1 January 2022).
60. Kowalska, J.B.; Mazurek, R.; Gąsiorek, M.; Zaleski, T. Pollution Indices as Useful Tools for the Comprehensive Evaluation of the Degree of Soil Contamination–A Review. *Environ. Geochem. Health* **2018**, *40*, 2395–2420. [CrossRef]
61. Hu, C.; Shui, B.; Li, W.; Yang, X.; Zhang, X. Assessing the Ecological Quality Status of Transplanted Mangrove Wetland in the Oujiang Estuary, China. *Mar. Pollut. Bull.* **2018**, *133*, 1–8. [CrossRef]
62. Zettler, M.L.; Schiedek, D.; Bobertz, B. Benthic Biodiversity Indices versus Salinity Gradient in the Southern Baltic Sea. *Mar. Pollut. Bull.* **2007**, *55*, 258–270. [CrossRef]
63. Bae, H.; Lee, J.-H.; Song, S.J.; Park, J.; Kwon, B.-O.; Hong, S.; Ryu, J.; Choi, K.; Khim, J.S. Impacts of Environmental and Anthropogenic Stresses on Macrozoobenthic Communities in Jinhae Bay, Korea. *Chemosphere* **2017**, *171*, 681–691. [CrossRef] [PubMed]
64. Kim, S.K. Assessment of Long-Term Variation in Macrobenthic Community and Ecological Quality Status in the Subtidal Zone of Cheonsu Bay, Korea. Master's Thesis, Soonchunhyang University, Asan, Republic of Korea, 2023.
65. Wu, H.-Y.; Fu, S.-F.; Hu, W.-J.; Chen, F.-G.; Cai, X.-Q.; Chen, Q.-H.; Wu, Y.-B. Response of Different Benthic Biotic Indices to Eutrophication and Sediment Heavy Metal Pollution, in Fujian Coastal Water, East China Sea. *Chemosphere* **2022**, *307*, 135653. [CrossRef] [PubMed]
66. Eça, G.F.; Pedreira, R.M.A.; Hatje, V. Trace and Major Elements Distribution and Transfer within a Benthic System: Polychaete Chaetopterus Variopedatus, Commensal Crab Polyonyx Gibbesi, Worm Tube, and Sediments. *Mar. Pollut. Bull.* **2013**, *74*, 32–41. [CrossRef] [PubMed]

67. Simboura, N.; Reizopoulou, S. An Intercalibration of Classification Metrics of Benthic Macroinvertebrates in Coastal and Transitional Ecosystems of the Eastern Mediterranean Ecoregion (Greece). *Mar. Pollut. Bull.* **2008**, *56*, 116–126. [CrossRef] [PubMed]
68. Munari, C.; Mistri, M. Towards the Application of the Water Framework Directive in Italy: Assessing the Potential of Benthic Tools in Adriatic Coastal Transitional Ecosystems. *Mar. Pollut. Bull.* **2010**, *60*, 1040–1050. [CrossRef] [PubMed]
69. Riera, R.; de-la-Ossa-Carretero, J.A. Response of Benthic Opportunistic Polychaetes and Amphipods Index to Different Perturbations in Coastal Oligotrophic Areas (Canary archipelago, North East Atlantic Ocean). *Mar. Ecol.* **2014**, *35*, 354–366. [CrossRef]
70. Bendell-Young, L.I. Contrasting the Community Structure and Select Geochemical Characteristics of Three Intertidal Regions in Relation to Shellfish Farming. *Environ. Conserv.* **2006**, *33*, 21–27. [CrossRef]
71. Wi, C.W.; Lee, J.H.; Shin, H.C. Spatio-Temporal Distribution of Benthic Polychaetous Communities and Their Health Conditions in Garolim Bay, West Coast of Korea. *Sea J. Korean Soc. Oceanogr.* **2014**, *19*, 256–264. [CrossRef]