Journal of
Marine Science and Engineering

MDPI

Article

Community Structures of Benthic Macrofauna in Reclaimed and Natural Intertidal Areas in Bahrain, Arabian Gulf

Humood Abdulla Naser

Department of Biology, College of Science, University of Bahrain, Sakhir P.O. Box 32038, Bahrain; hnaser@uob.edu.bh; Tel.: +973-17437424; Fax: +973-17449158

Abstract: Costal reclamation has been carried out extensively along the coastlines of the Arabian Gulf during the last decades. As a small archipelago country, coastal reclamation continues to be a major option for securing land to meet the needs of the expanding population and economic development in Bahrain. Macrobenthic communities often reflect the integrity of ecosystems as they respond to natural and anthropogenic stressors. This study characterized the community structures of macrobenthic invertebrates in three reclaimed intertidal areas and a protected natural mudflat in Bahrain (August 2019 and December 2020). Macrobenthic community structures and sediment characteristics differed significantly between natural and reclaimed areas. A total of 43 species were recorded in the four study areas, of which 38 were collected from the natural mudflat. Polychaetes dominated macrobenthic communities, followed by molluscs and crustaceans. Polychaetes accounted for more than 90% of the communities in the reclaimed coastal areas. Macrobenthic monitoring is considered essential for detecting changes in coastal and marine ecosystems due to dredging and reclamation activities along the coastlines of the Arabian Gulf. The findings of this study can provide insights into the ecological dynamics of macrobenthic communities in reclaimed coastal areas for environmental monitoring and coastal planning and management in the Arabian Gulf.

Keywords: benthic macrofauna; community structure; intertidal areas; coastal reclamation; Bahrain; Arabian Gulf

check for updates

Citation: Naser, H.A. Community Structures of Benthic Macrofauna in Reclaimed and Natural Intertidal Areas in Bahrain, Arabian Gulf. *J. Mar. Sci. Eng.* **2022**, *10*, 945. https://doi.org/10.3390/jmse10070945

Academic Editor: Jean-Claude Dauvin

Received: 15 June 2022
Accepted: 5 July 2022
Published: 9 July 2022

1. Introduction

Coastal land reclamation for ports, industry, residences, aquaculture and agriculture has been a common practice in many parts of the world [1–3]. Due to the land scarcity in small countries and coastal cities, reclamation continues to be a major option for providing land to meet the needs of rapidly growing populations, urbanization and economic development [4–6]. However, these economic and social benefits of land reclamation are associated with environmental impacts that may affect the integrity of coastal ecosystems and cause a decline in biodiversity and ecosystem services [7–10]. Based on the second World Ocean Assessment, land reclamation has been identified among the main stressors on coral reefs and muddy, sandy and rocky shores [11].

In the last decades, the Arabian Gulf countries have witnessed rapid economic, industrial and social developments associated with rapid population growth [12]. Therefore, urbanization has increased rapidly, mainly in coastal areas, to supply infrastructure for the increasing populations and industries [13]. Presently, more than 40% of the coasts of the Arabian Gulf have been developed [14]. It is estimated that around 186 km^2 of the inland and coastal waters has been converted into land in Saudi Arabia during the past 30 years [15]. Reclamation and dredging activities are regularly conducted to expand coastal areas or to construct offshore artificial islands throughout the subtidal marine environment of the Arabian Gulf. Examples of mega-scale coastal developments in the Arabian Gulf include the Palm Islands and the World Islands in Dubai (United Arab Emirates), Durrat Al-Bahrain (Bahrain), the Pearl (Qatar), Half Moon Bay (Saudi Arabia) and Sabah Al Ahmed City (Kuwait) [12].

Reclamation and dredging activities can cause direct and indirect physical, chemical and biological impacts on the fragile coastal and marine ecosystems of the Arabian Gulf. These can range from the direct burial of sensitive habitats such as mangrove swamps, mudflats, coral reefs and seagrass beds to the loss of nursery and feeding areas for turtles, fishes, crustaceans and avifauna [16–18]. Reclamation and dredging can also induce changes in circulation patterns and waterflow, alterations in the biogeophysical and hydrological characteristics of coastal ecosystems and elevations in the levels of suspended sediment, organic material and heavy metals [19–21].

The identity of Bahrain, as an archipelago country, has been shaped by the sea. The marine environment in Bahrain provides immense economic, social and environmental benefits and services [22]. The waters surrounding Bahrain's islands support a variety of habitats such as seagrass beds, coral reefs, mangrove swamps and mudflats that provide important ecological goods and services. These habitats support many species of national, regional and international importance such as turtles, dugongs, dolphins and sea birds [23]. Today, the marine environment in Bahrain contributes to food security and supports many sectors including industry, trade, shipping, tourism, power production and water desalination [24].

Due to the limited land area, coastal reclamation allows land expansion to support rapid urbanization and economic growth in Bahrain. Additionally, dredging provides the sand resource required for reclamation and construction activities [25]. Land reclamation has been carried out in a rapid rise since the early 1960s in Bahrain [26]. According to the Information and e-Government Authority, the total land area of Bahrain in 2020 was about 785 km^2 in comparison with 667 km^2 in 1963 [27]. Currently, it is estimated that more than 80% of the Bahraini coastlines have been modified [28]. Land reclamation will continue to be a major option to secure land for large-scale projects as the population in Bahrain continues to grow in the coming decades. According to the Land Use Planning Strategy in Bahrain 2030, several major projects are planned to be developed on reclaimed land. This strategy specifies the total land area of Bahrain in 2030 to be around 934.57 km^2, which indicates a 28% increase in comparison with 1963.

Given the continued extensive coastal development in Bahrain, coastal and marine habitats can be significantly degraded. Signs of such degradation may include a decline in mangrove trees and seagrass beds, a loss of habitats for migratory and breeding birds, reduced primary production and a loss in corals [24]. For instance, the natural mangrove cover has decreased from 328 ha to 48 ha, representing a loss of 95%, during the period of 1967–2020. This is primarily attributed to coastal development [29]. Reclamation can also affect the amenity, aesthetic, cultural and economic values associated with coastal habitats. For instance, it has been estimated that the various marine ecosystems of Bahrain are worth approximately US$ 2 billion per year [30], which could be affected by large-scale coastal modifications.

Benthic communities are directly affected by reclamation and dredging activities. Consequently, macrobenthic communities are widely used as an important bioindicator to monitor and assess changes in estuarine and marine environments due to coastal modification in many parts of the world [31–36]. However, the use of macrobenthic invertebrates to assess the extent of environmental impacts associated with dredging and reclamation activities on coastal and marine ecosystems has been limited in the Arabian Gulf [37,38].

Therefore, the aim of this study is to characterize the spatial and temporal community structures of macrobenthic communities in two reclaimed coastal areas, a constructed nearshore island and a natural mudflat in Bahrain. The specific objectives of the study are to compare (a) the environmental and sediment characteristics in the reclaimed and natural coastal areas and (b) the community characteristics of benthic macrofauna in the reclaimed and natural coastal areas. The findings of this study can provide insights into the ecological conditions of macrobenthic communities in reclaimed coastal areas for environmental monitoring and coastal planning and management in the Arabian Gulf.

2. Materials and Methods

2.1. Study Sites

The study was conducted along the northern coastline of Bahrain. As most of the coastlines of Bahrain have been modified, initial inspection was conducted to identify the suitable coastal areas for the study. Site selection was based on specified criteria, including: (1) the coast is reclaimed, (2) no coastal defenses, (3) exposed to intertidal regime, (4) soft sediment (muddy and or sandy) and (5) gentle shore profile that exposes a large part of the intertidal zone. Google historical maps were used to estimate the approximate dates by which these sites were reclaimed.

Selecting control sites typically involves areas that are minimally affected by the measured disturbance. However, suitable reference sites in Bahrain are constrained due the physical alteration by dredging and reclamation along most of the coastal areas. Arad Bay is one of remaining natural mudflats in Bahrain. Therefore, the Arad Bay protected area was selected as a natural site to be compared with the reclaimed study areas. Sampling was conducted in August 2019 (Summer) and December 2020 (winter).

2.2. Description of Selected Sites

The first site is Nurana Island (N). The reclamation of this artificial island was completed in 2010. The estimated area of the island is around 1 km^2. The island is separated from the northern coastline by around 600 m of subtidal water. The eastern and northern coasts of the island are protected by coastal defenses composed mostly of large rocks. Sampling was conducted from the southern coast of the island. Around 10 m of the tidal area is exposed during low tide. The second site is the Karbabad coastal area (K). This coast was reclaimed in 2007. The intertidal area length of Karbabad is around 15 m. This area is used by fishermen for anchoring their boats. The third site is the Sayah coastal area (S). This coast was reclaimed in 2009. The intertidal area of this site is around 25 m. A new causeway at the proximity of the Sayah area was being constructed during the sampling period. The fourth site, which represents a natural intertidal mudflat, is Arad Bay (A). This is a sheltered bay located in the northeast of Bahrain. The estimated area of this bay is around 0.5 km^2. This mudflat bay was designated as a natural marine protected area in 2003. It is characterized by a gentle shore profile that exposes a large intertidal area (approximately 1 km in length). This bay is considered as a feeding ground for important shorebird populations [39]. Figure 1 shows the approximate locations of the sampling sites. Images of the sites are presented in Figure 2.

2.3. Measurements of Environmental Variables

Salinity (psu), pH and seawater temperature (°C) were measured in situ using the refractometer Atago F, a model pH 82 radiometer and a glass thermometer, respectively. Three seawater samples from each site were collected to analyze the content of the selected nutrients (mg l^{-1}), namely, ammonia, nitrate, nitrite, sulphate, phosphate and silicate, in the laboratory. A Palintest photometer 800 and proprietary assay kits (Palintest Ltd., Tyne and Wear, UK) were used to conduct nutrient analyses. The methods of analysis are based on measuring the intensity of the colors produced by reagents using the Palintest photometer. This instrument calculates the test result by comparing the amount of absorbed light with the pre-programmed calibrations. Analyses were performed according to the Palintest manual of instructions.

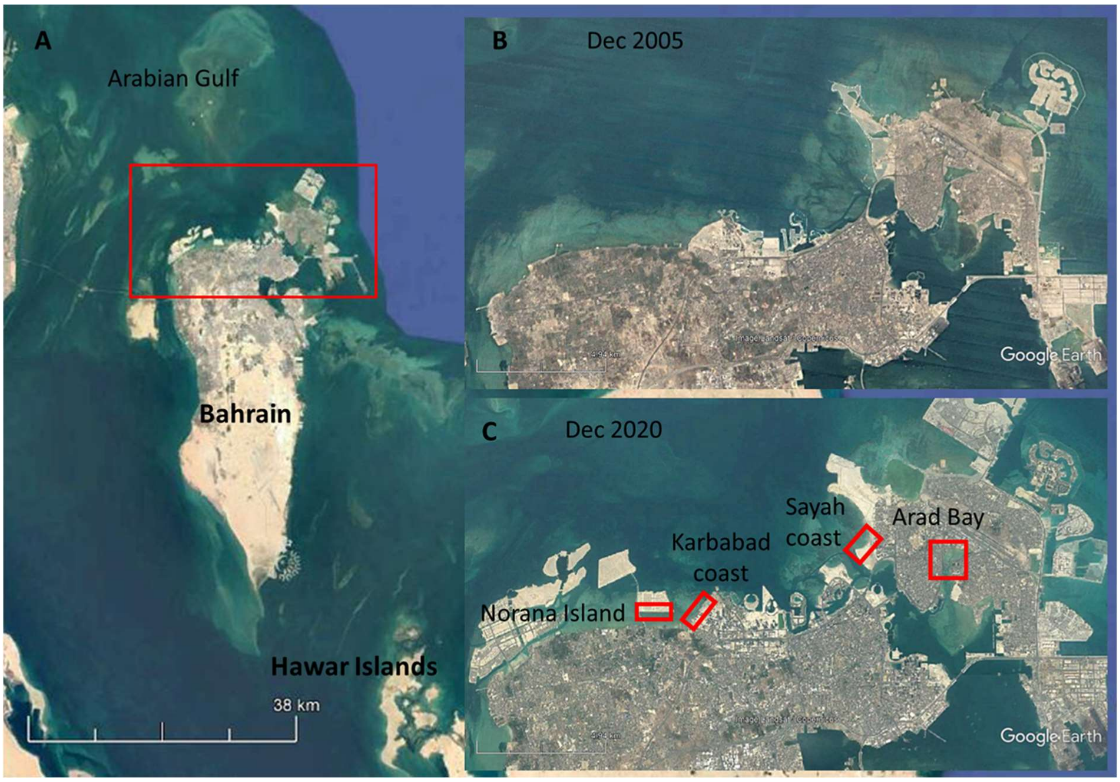

Figure 1. A map of Bahrain (**A**), the northern coastline of Bahrain in December 2005 (**B**) and the northern coastline of Bahrain in December 2020, showing the approximate locations of the sampling sites (**C**) (Google Earth Pro).

Figure 2. Images of the sampling areas: Nurana (**A**), Karbabad (**B**), Sayah (**C**) and Arad (**D**).

2.4. Benthic Macrofaunal Sampling

Three transects (T1, T2 and T3) along the intertidal areas of each sampling site were established. One sample was collected from the upper, mid and lower internal area of each transect. In total, nine samples of macrofauna were collected from each site. Another nine sediment samples were collected for subsequent grain size analyses. The geographical coordinates of the transects in the sampling sites are presented in Table 1.

Table 1. Geographical coordinates of transects in the sampling sites.

Sampling Site	Transect 1	Transect 2	Transect 3
Nurana Island	26°14′27.89″ N 50°30′22.08″ E	26°14′27.89″ N 50°30′35.23″ E	26°14′27.89″ N 50°30 48.30″ E
Karbabad area	26°14′34.56″ N 50°31′44.66″ E	26°14′34.15″ N 50°31′43.52″ E	26°14′33.56″ N 50°31′41.82″ E
Sayah area	26°15′51.31″ N 50°35′28.70″ E	26°15′50.00″ N 50°35′26.65″ E	26°15′48.96″ N 50°35′24.25″ E
Arad Bay	26°15′45.13″ N 50°37′43.99″ E	26°15′42.30″ N 50°37′44.52″ E	26°15′39.59″ N 50°37′45.47″ E

Macrobenthic invertebrates were collected from a 20 cm × 20 cm quadrat using a shovel for a depth of 25 cm. The collected sediments were sieved in situ using a 1 mm mesh size sieve. Macrobenthic invertebrates were fixed using 5% buffered formalin mixed with Rose Bengal stain and subsequently preserved using 70% ethanol. Macrobenthic organisms were first sorted into major groups and then identified to the lowest possible taxonomic level using a stereomicroscope with a total magnification of 10–80x (Nikon SMZ800N). The nomenclatures of benthic organisms were verified using the World Register of Marine Species (available online: http://www.marinespecies.org/ (accessed on 15 February 2021)).

2.5. Sediment Organic Content and Grain Size Analysis

The percentage of organic content of the sediment was calculated by incinerating a known weight at a temperature of 450 °C for 24 h. Sediment grain size analysis was conducted by dray sieving through a set of sieves ranging from 2 to 0.038 mm using a mechanical shaker (KARL KOLB). Individual dimensional classes were weighed and recorded. The grain sizes were measured in millimeters (mm) or micrometers (µm); however, the most common grade scale of size is the Wentworth Phi (Φ) scale. All of the grain sizes were converted to the Φ scale based on conversion tables and used in plots and subsequent calculations following Holme and McIntyre [40].

2.6. Data Analyses

The statistical programs PRIMER v7 [41,42] and IBM SPSS Statistics 21 were employed to conduct univariate and multivariate analyses.

Environmental variables, including seawater chemistry (temperature, salinity, pH and nutrient concentrations) and sediment characteristics (grain size particles), were tested for normality using the Shapiro–Wilk test utilizing the SPPS. All of the variables were found to be statistically significant ($p < 0.05$). Therefore, the non-parametric test of Kruskal Wallis was used to test the significant differences of the environmental variables in the sampling areas and seasons, followed by multiple comparisons of the areas.

The species density and relative abundance were calculated for the sampling areas and seasons. The total density of each species (individual m^{-2}) was estimated from the total area sampled in each study area. The relative abundance (RA) of each species was estimated as the percentage of individuals belonging to the total number of individuals of all of the combined species in each study area. The relative abundances of the major taxonomic groups were calculated for each study area and for the total individuals sampled during the study period.

Ecological indices are widely used in ecological studies to summarize the abundance of species in a single number reflecting the whole community status. Univariate ecological indices, namely, the Shannon–Wiener diversity index (H'), Margalef's species richness index (d) and Pielou's evenness index (J), were calculated using the DIVERSE routine in

PRIMER. The Shapiro–Wilk test of normality was applied on the calculated ecological indices, which were found to be statistically significant ($p < 0.05$). The non-parametric analysis of Kruskal Wallis was conducted to compare the ecological indices in the sampling areas and seasons.

Multivariate analysis of the community structure was conducted using PRIMER. The species abundance data were square-root-transformed to reduce the influence of numerically dominant taxa. A similarity matrix using the transformed data was constructed based on the Bray–Curtis coefficient, which was used to generate a non-metric multi-dimensional scaling ordination (MDS). The MDS showed the relative similarity of macrobenthic invertebrates among the four sampling areas. Cluster analysis based on the similarity matrix of species abundance was conducted to generate a similarity of 40% on the MDS. A stress value between 0.09 and 0.1 on the MDS is considered a satisfactory ordination with no real prospect of a misleading interpretation. Additionally, the similarity of the percentages routine (SIMPER) in PRIMER was used to identify the species responsible for the dissimilarity between the natural mudflat and the reclaimed areas.

The BIO-ENV routine of the PRIMER was used to examine the potential influence of environmental variables, nutrients and sediment characteristics on macrobenthic invertebrates. BIO-ENV computes weighted Spearman rank correlations between the macrofaunal species Bray–Curtis similarity matrix and the Euclidean distance matrix generated from normalized environmental data to identify the combination of variables that could best explain the patterns of the macrobenthic community.

3. Results

3.1. Environmental Measurements

The mean measurements of the physical and chemical characteristics of the seawater in the study areas are presented in Table 2. Significant differences between the study areas were observed in ammonia ($p = 0.010$), nitrate ($p = 0.042$) and silicate ($p = 0.001$). Multiple comparisons revealed significant differences between Arad Bay and the remaining coastal areas in the concentrations of ammonia and silicate. Higher concentrations of silicate were reported in the three reclaimed areas (average 3.73 mg l^{-1}) in comparison with the natural mudflat of Arad Bay (average 0.79 mg l^{-1}). Seasonally, a significant variation in seawater temperature was detected ($p < 0.001$) (Maximum summer: 32.3, Minimum winter: 18.5 °C). Silicate also exhibited significant differences between seasons ($p = 0.019$).

Table 2. Environmental measurements and nutrient concentrations (mg L^{-1}) in the four study areas in the summer and winter seasons (N: Nurana; S: Sayah; K: Karbabad; A: Arad).

	Summer				Winter			
	N	**S**	**K**	**A**	**N**	**S**	**K**	**A**
Salinity psu	44	43	43	43	43	43	43	45
Temp. °C	32.3	31.0	32.0	32.0	19.5	18.5	19	20
pH	7.5	7.3	7.4	7.4	7.9	7.7	7.8	7.8
Ammonia	0.39	0.49	0.42	0.52	0.41	0.47	0.42	0.50
Nitrate	0.82	0.78	0.85	0.83	0.79	0.78	0.82	0.82
Nitrite	0.04	0.02	0.02	0.03	0.04	0.04	0.04	0.04
Phosphate	0.11	0.05	0.05	0.08	0.10	0.09	0.08	0.09
Silicate	4.10	3.30	2.65	0.36	5.10	3.70	3.60	0.86
Sulphate	0.35	0.30	0.26	0.32	0.32	0.32	0.35	0.35

Sediment characteristics in the study areas are presented in Figure 3. The overall graphic means (Φ) indicate that all the sediments of the study areas were described as fine sand, apart from two transects in Nurana, which were predominantly medium sand. The Nurana area differed significantly from the remaining areas in the sediment graphic means ($p \leq 0.001$).

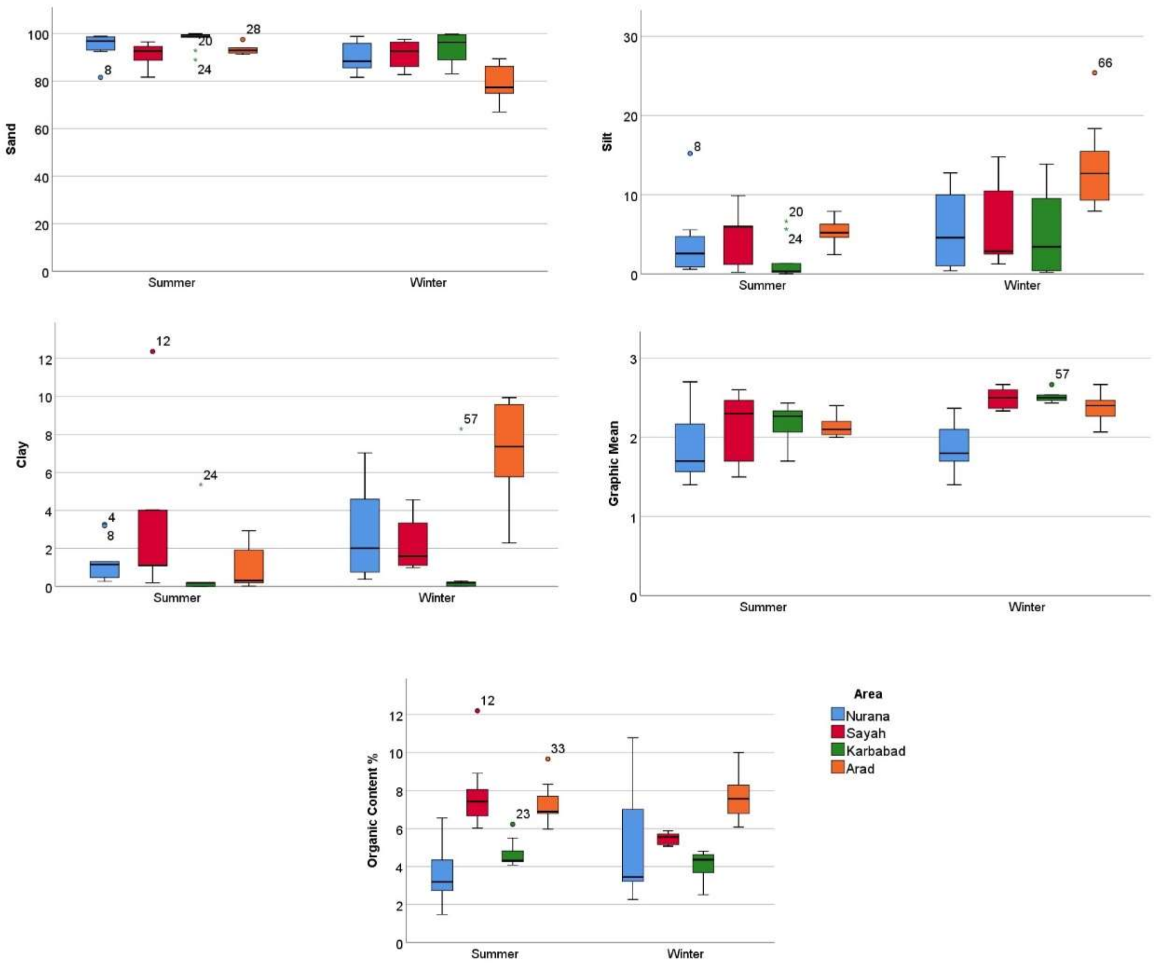

Figure 3. Percentages of sediment particles (sand, silt and clay) and organic content in the sampling areas in the summer and winter seasons, presented as the median and interquartile range.

Additionally, it was observed that study areas exhibited a relative increase in fine sedimentation in the second period of sampling (winter season). The highest fine sedimentation, represented by the overall mean Φ, was observed in Sayah (summer: 2.15, winter: 2.50), followed by Karbabad (summer: 2.20, winter: 2.51), Arad Bay (Summer: 2.12, winter: 2.40) and Nurana (summer: 1.85, winter: 1.87). The averaged organic content was relatively higher in sediments collected from Arad Bay (7.45%), followed by Sayah (6.65%), Nurana (4.45%) and Karbabad (4.37%). Multiple comparisons analysis revealed that the organic content differed significantly in Arad compared with Nurana and Karbabad ($p < 0.001$).

3.2. Macrobenthic Community Structure

A total of 5137 individuals belonging to 43 species were recorded in the four study areas in the summer and winter seasons. The species represented four major taxonomic groups, namely, polychaetes (22), crustaceans (6), bivalves (8) and gastropods (7). However, variability in the species numbers was observed between the study areas. Higher numbers of species were recorded in Arad Bay (total: 38, summer: 29, winter: 32), followed by Sayah (total: 25, summer: 18, winter: 15), Karbabad (total: 20, summer: 18, winter: 10) and Nurana (total: 17, summer: 9, winter: 13). Significant differences in the number of species were detected between areas and seasons ($p < 0.001$ and 0.020, respectively). Multiple comparisons analysis revealed that Arad differed from the other sampling areas ($p < 0.001$).

The polychaete *Perinereis nigropunctata* showed the highest density (individual m^{-2}) in all the study areas, with the maximum recorded in the Karbabad area during the winter (369.4) and the minimum in the Nurana area during the summer (103.3). Arad Bay exhibited higher levels of density for the gastropod *Cerithium scabridum* (summer: 153.9, winter: 53.3) and the bivalve *Dosinia contracta* (summer: 76.1, winter: 114.4).

The relative abundance of species indicated the contribution of the species to the macrobenthic populations in the study areas. The polychaete *P. nigropunctata* showed the highest relative abundance in all the study areas. The other top dominant species in Arad during the sampling period were the gastropod *Cerithium scabridum*, the bivalve *Dosinia contracta* and the polychaete *Scoloplos* sp. In Nurana the polychaetes *Ceratonereis mirabilis*, *Petaloproctus terricolus* and *Armandia* sp. and the bivalve *Dosinia contracta* showed the highest relative abundance. The polychaetes *Ceratonereis mirabilis*, *Petaloprocyus terricolus* and *Eulalia* sp. and the bivalve *Tellina* sp. were dominant in Sayah. The polychaete *Armandia* sp. and the bivalve *Tellina* sp. were dominant in Karbabad. The recorded species present in the four study areas in the summer and winter are presented in Table 3. Details of the recorded species and their abundance are provided as Supplementary Material (Table S1).

Polychaetes were the most abundant among the major taxonomic groups, representing 73.0% of the total individuals sampled during the study period, followed by bivalves (15.5%), gastropods (10.0%) and crustaceans (1.5%). However, there were differences in the occurrence of major taxonomic groups between the study areas (Figure 4). Polychaetes dominated the populations of both Nurana and Sayah (summer: 97%, winter: 92%), Karbabad (summer: 81%, winter: 96%) and Arad (summer: 54%, winter: 42%). Crustaceans were not recorded in Nurana (winter and summer) and Karbabad (winter). They were only reported in smaller percentages of the populations in Arad (5%) and the other areas (<1%). Gastropods were not found in Nurana (winter and summer), Karbabad (winter) and Sayah (winter).

The ecological indices for the four study areas are presented in Figure 5. The highest Shannon–Wiener diversity index was recorded in Arad Bay (summer: 1.8, winter 2.2), followed by Karbabad (summer and winter: 1.1), Nurana (summer: 0.87, winter: 1.0) and Sayah (summer: 0.51, winter 0.98). Significant differences in the diversity and richness indices were detected between the sampling areas (p = 0.010 and 0.002, respectively). There was no significant difference in the evenness index between the sampling areas. However, multiple comparisons analysis revealed that Arad differed from the other sampling areas in the ecological indices ($p < 0.001$).

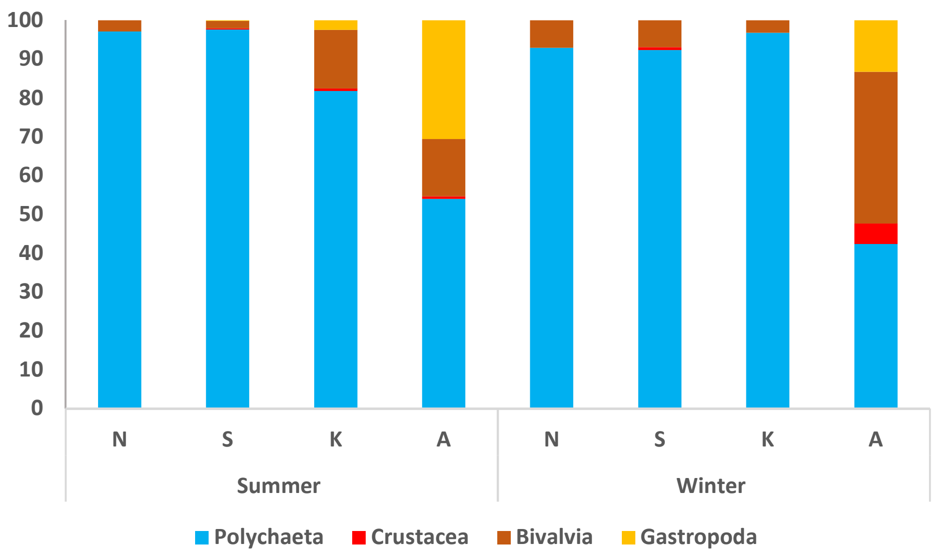

Figure 4. Relative abundance of the major taxonomic groups in the four study areas in the summer and winter seasons.

Table 3. List of macrofaunal species recorded in the four study areas during the summer and winter seasons (+ indicates the presence of species).

		Summer				**Winter**			
Group	**Species**	**N**	**S**	**K**	**A**	**N**	**S**	**K**	**A**
Polychaeta	*Eunice indica*				+	+			+
	Marphysa sp.			+	+		+		+
	Lumbrineris sp.	+	+		+	+			+
	Nephtys sp.				+				+
	Arabella iricolor		+	+	+	+	+	+	+
	Goniada sp.		+		+				+
	Owenia fusiformis		+		+				
	Eulalia sp.		+	+	+	+	+	+	+
	Phyllodoce sp.						+		+
	Ceratonereis mirabilis	+	+	+	+	+	+	+	+
	Glycinde sp.						+		
	Glycera alba						+		+
	Perinereis nigropunctata	+	+	+	+	+	+	+	+
	Sabella sp.						+		
	Petaloproctus terricolus	+	+	+	+				
	Scoloplos sp.		+	+	+	+	+	+	+
	Paradoneis sp.					+	+	+	+
	Armandia sp.		+	+	+	+	+	+	+
	Magelona sp.			+		+		+	
	Polydora sp.								+
	Scolelepis sp.								+
	Cirriformia sp.								+
Crustacea	*Diogenes avarus*		+	+	+				+
	Penaeus semisulcatus		+		+				
	Grandidierella exilis								+
	Apanthura sandalensis						+		
	Parapenaeopsis stylifera								+
	Alpheus sp.								+
Bivalvia	*Callista florida*	+	+	+	+	+			+
	Marcia cordata	+	+	+	+	+			+
	Irus macrophylla	+			+				+
	Dosinia contracta	+	+		+	+	+	+	+
	Circenita callipyga			+	+				
	Marcia sp.				+				
	Cardiolucina semperiana		+	+	+				+
	Tellina sp.		+	+	+	+	+	+	+
Gastropoda	*Clypeomorus bifasciatus persica*		+	+	+				+
	Mitrella blanda			+	+				+
	Cerithium scabridum			+	+				+
	Priotrochus obscurus				+				+
	Trochus erithreus				+				
	Cerithium caeruleum				+				+
	Natica sp.				+				+

Non-metric multidimensional scaling (MDS) and associated ANOSIM revealed a significant difference in the macrobenthic composition between Arad Bay and the other areas (Global R = 0.51, p = 0.001, Stress value = 0.14). Arad Bay distinctly differed from Nurana (R = 0.95, p = 0.002), Sayah (R = 0.89, p = 0.002) and Karbabad (R = 0.84, p = 0.002). However, there were no significant differences observed between the Nurana, Sayah and Karbabad areas (p > 0.05). The Resemblance Matrix of 40% similarity exhibited two groups, one for Arad Bay and the other areas aggregating together in one group (Figure 6). The top three species contributing to the dissimilarity between the natural mudflat of Arad Bay and the reclaimed areas are *Cerithium scabridum* (gastropod), *Dosinia contracta* (bivalve) and *Perinereis nigropunctata* (polychaete).

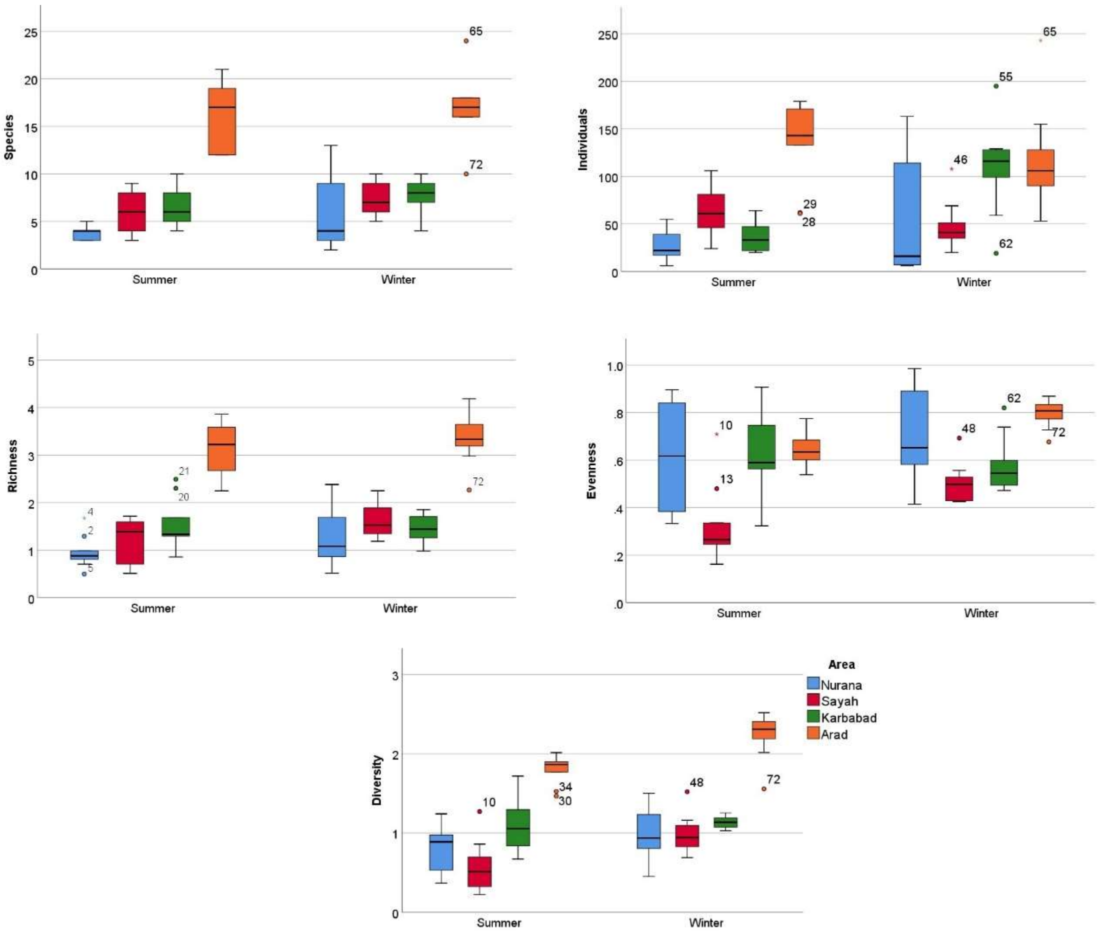

Figure 5. Ecological indices in the four sampling areas in the summer and winter seasons, presented as the median and interquartile range.

Rank correlations (BIO-ENV) between the environmental, nutrient and sediment variables in the study areas and the abundance of macrobenthos indicated that around 72% of the macrobenthic communities' patterns were explained by the combination of four environmental variables, namely, silt %, seawater temperature, ammonia and silicate. The top five combinations that best explained the macrobenthic invertebrates' patterns in the four study areas in the two seasons are presented in Table 4. Generally, these variables represent silt %, sand %, seawater temperature, salinity, ammonia and silicate.

Table 4. Top five combinations of environmental, nutrient and sediment variables that best explained the macrobenthic invertebrates' patterns in the four study areas in the two seasons.

Combination	Number of Variables	Correlation	Selection of Variables
1	4	0.718	Silt %, Temp., Ammonia, Silicate
2	3	0.706	Silt %, Temp. Silicate
3	4	0.697	Silt %, Salinity, Temp., Silicate
4	5	0.696	Sand %, Silt %, Salinity, Temp., Silicate
5	5	0.692	Sand %, Silt %, Temp. Ammonia, Silicate

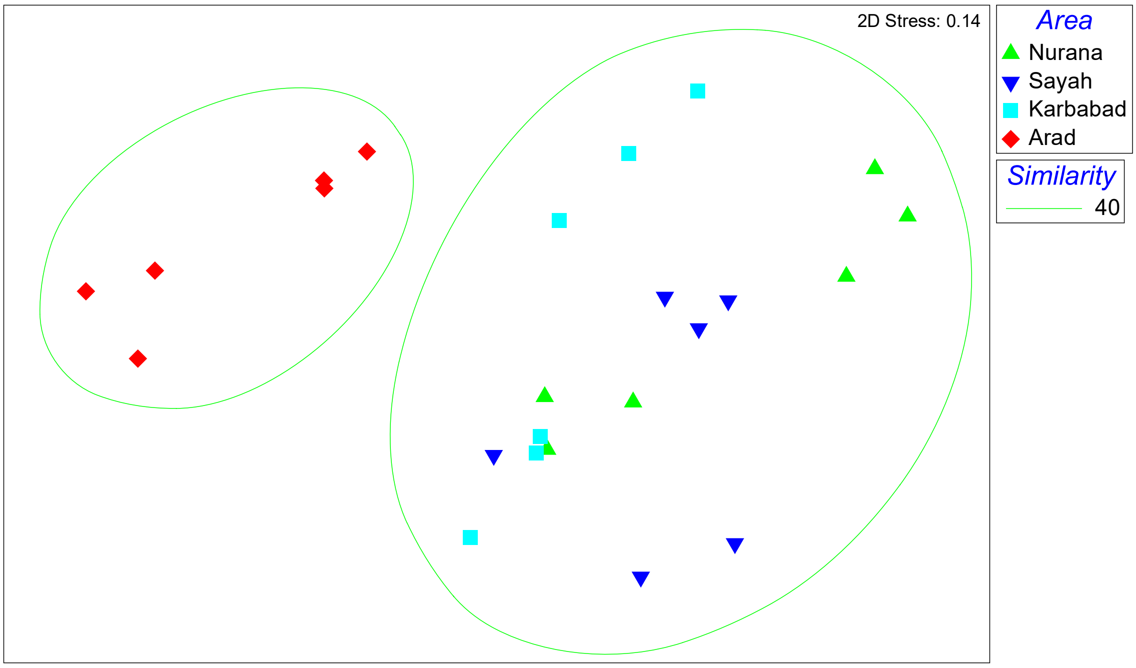

Figure 6. MDS of macrobenthic invertebrates in the study areas in the summer and winter revealed two distinct clusters for Arad Bay and the remaining study areas. Cluster analysis was imposed on the MDS, showing a 40% similarity.

4. Discussion

4.1. Environmental Variables

The hydrographical conditions of the coastal environment such as salinity and temperature can result in direct and indirect effects on macrobenthic organisms [43]. The Arabian Gulf is considered among the water bodies with the highest levels of salinity and temperature in the world [44–46]. The average salinity is 42 psu, increasing to 50 psu in bays and reaching 70 psu in coastal lagoons. The sea surface temperature generally ranges between 36 °C in the summer and 12 °C in the winter [21]. The levels of recorded salinity and temperature in the present study (43–45 psu and 13.8 °C seasonal difference, respectively) reflected the harsh environmental characteristics of the Arabian Gulf. Studies conducted in Bahrain reported similar levels of salinity and temperature [47,48].

Nutrients in the coastal environment play an important role in primary productivity and therefore food availability for macrobenthic communities [49]. In the present study, silicate exhibited higher levels in three reclaimed study areas. Some studies indicated that sediment mobilization can alter the biogeochemistry of coastal regions, including silicate levels [50,51]. Therefore, the ongoing reclamation activities along the northern coastline of Bahrain may have contributed to the increasing levels of silicate in the seawater.

The physical characteristics of the sediment have direct physical, biological and ecological impacts on coastal and marine ecosystems [52]. The present study reported increasing levels of fine sediments during the second round of sampling (winter season). Particularly, the Sayah and Karbabad areas showed the highest levels of fine sediments in the winter. These two areas are witnessing increasing rates of ongoing reclamation and dredging activities. The fourth new causeway linking the Capital Manama with the Muharraq island that was being constructed during the sampling period (2019–2020) is at a close proximity to the Sayah study area. Similarly, reclamation activities around the Karbabad area may alter the sediment and tidal characteristics. Therefore, dredging and disposal operations in these areas may have contributed to increasing levels of suspended solids and subsequently fine sedimentation. Despite being confined to the immediate footprint of projects, the dredging and disposal of sediment can increase suspended solids in the surrounded areas. For instance, Zainal et al. [53] investigated the spatial and temporal variation patterns of the total suspended solids around the coastal areas of Bahrain due to dredging activities in the period 2010–2016. The study found that around 27% of the dredging companies carried out dewatering without allowing sufficient time for settling during the sand disposal process [53].

4.2. Community Structure

Coastal reclamation directly occupies habitats and leads to the direct mortality of macrobenthic invertebrates. Reclamation activities can cause severe changes in the abundance, community structures and biodiversity of benthic organisms [54]. In the present study, ecological indices revealed lower levels of the richness, diversity and evenness of macrobenthic invertebrates in the reclaimed areas in comparison with those of the natural mudflat. Several studies indicted severe impacts of reclamation on macrobenthic organisms. For instance, Wu et al. [55] found that reclamation was the most enduring and significant activity among the extreme human disturbances along the Xiamen Sea area in China. The study reported reduced benthic abundance and decreased biodiversity of benthic organisms due to coastal reclamation [55].

Multivariate analysis revealed significant differences between the natural mudflat and the reclaimed areas. The community structure of macrobenthic invertebrates in Arad Bay is distinctively separated from the reclaimed areas (Sayah and Karbabad) and the artificial island (Nurana). Similarly, significant variations in the benthic community structures between the natural and reclaimed coastal areas have been reported by several studies [35,55].

Polychaetes constitute an abundant and diverse taxonomic group of macrobenthic communities [56]. Polychaetes are globally used as indicators for marine pollution [57]. Polychaetes exhibited a higher total abundance adjacent to wastewater and sewage outfalls in Australian marine waters and along the west south Atlantic coastal areas [58,59]. Yang et al. [60] investigated the long-term impacts of coastal reclamation on macrobenthic communities in the coastal wetlands of the Yellow River Delta in China and found a shift in the dominant species from Mollusca to Polychaeta between the period from 1980 to 2000.

In the Arabian Gulf, the majority of macrobenthic communities are composed of polychaetes. For instance, polychaetes accounted for more than 59% of the macrobenthic communities along the Saudi Arabian Gulf coast [61]. Similarly, polychaetes comprise 69% of the soft sediment benthos associated with the offshore oilfield in the Arabian Gulf [62]. In the present study, polychaetes accounted for 73% of the total benthic population in the study areas. Polychaetes solely dominated more than 90% of the population in the Nurana island and the Sayah reclaimed coast in both seasons. Conversely, polychaetes accounted for a seasonal average of 48% of the population in the natural mudflat of Arad Bay.

Polychaetes inhabit a variety of habitats due to their ability to survive in a wide range of environmental conditions. They are also considered pioneering species that rapidly colonize soft bottoms [56]. For instance, Botter-Carvalho et al. [63] reported that polychaetes were the first to recover in a defaunated sediment of a tropical estuary within three days of the experiment. Jones and Nithyanandan [38] investigated the recovery and colonization in artificially created soft sediment in the Arabian Gulf. The study found that polychaetes accounted for 90% of the population during the initial settlement on newly created soft sediments along the Kuwaiti coastline [38]. Likewise, polychaetes dominated the macrobenthic communities around oilfields and their associated platforms in the marine environment of the Arabian Gulf [64,65].

In the present study, the polychaete *Perinereis* was the dominant species in all of the study areas. Nereididae generally inhabit all types of substrata, with the majority occurring in shallow water. Additionally, they can survive a wide range of environmental disturbances [56]. *Perinereis* showed the highest percentage of survival (57.1%) in a microcosm experiment conducted in order to examine the effects of mud burial on selected macrobenthic species collected from a proposed reclaimed coastal area in Bahrain [37]. Additionally, several studies indicated that *Perinereis* was among the dominant polychaetes in the coastal and marine habitats of the Arabian Gulf [61,66].

Molluscs are among the dominant groups within the shallow marine benthos. Molluscs are sensitive to marine stressors and are frequently used to assess the ecological quality of marine habitats [67]. In the present study, the bivalves *Dosinia* and *Tellina* were recorded in relatively high averaged seasonal densities in Arad Bay (190.5 and 27.2 individual m^{-2}, respectively). The gastropods *Cerithium* and *Mitrella* were also abundant in Arad Bay. These species are frequently reported along the coastline of the Arabian Gulf [66,68].

Crustaceans widely contribute to trophic chains in marine ecosystems. They are considered a sensitive indicator for environmental disturbances, including dredging activities [69]. In the present study, crustaceans were recorded in the mudflat of Arad Bay (5% of the population). *Grandidierella exilis* is considered a sensitive crustacean species that associates with healthy environmental conditions [70]. This species was reported only in Arad Bay, with a relatively high density (70 individual m^{-2}), suggesting healthier environmental conditions in this bay in comparison with those of the reclaimed areas. However, the abundance and diversity of crustaceans are generally reduced along coastlines influenced by sedimentation due to dredging, reclamation and pollution from land-based effluents. For instance, Naser [71] reported only 18 crustacean species in Tubli Bay, which has been subjected to disturbance due to reclamation activities and sewage discharges. Conversely, 47 [47] and 74 [72] crustacean species were recorded in the protected area of the Hawar islands during two environmental surveys. The remote location of the Hawar islands makes them less vulnerable to human disturbance. These islands were also internationally designated as a Ramsar site in 1997.

The correlation analysis between the environmental variables and the macrobenthic invertebrates revealed that around 72% of the biota patterns are governed by a combination of four environmental variables related to physical and sedimentological characteristics and nutrients.

Studies showed that sediment grain size can influence the recolonization of infaunal organisms. Although most species were able to recolonize both fine and coarse sands, higher numbers of species and individuals were reported in coarse sand during short-term recolonization in a defaunated sediment [73]. Conversely, Guerra-Garcia and Garcia-Gomez [74] found no significant differences in the macrofauna recolonization of fine and coarse sands in a harbor.

Organic input is an important factor affecting the community structure of macrobenthic organisms. The colonization of species affected by organic enrichment from a fish-farm was characterized by increased levels of total abundance and diversity and by peaks for the abundance of a few opportunistic polychaete species [75]. Silicates play an important role in the growth and diversity of phytoplankton communities, which serve as a major source of macrobenthic organisms [76].

Due to higher seawater temperatures, macrobenthic recolonization could be faster in tropical areas in comparison with other regions [73]. Additionally, seasonal variations in temperature can influence the benthic community structure. For instance, Shou et al. [77] reported significant differences between seasons in terms of species number, density and diversity in China, which were related to the temperature in the summer.

Dredging and reclamation activities can alter seabed characteristics, release contaminants and increase nutrients mobility [78]. A close correspondence between the sediment characteristics and distribution of macrobenthic invertebrates in the coastal and marine environment has been reported [79]. Similarly, reclamation has severe impacts on the ability of wetlands to maintain nutrients [78]. In the Arabian Gulf, temperature extremes, fine sediments and the variability of nutrients have been found to influence the diversity and abundance of macrobenthic communities [80,81].

4.3. Dredging and Reclamation Management

Investigating the changes of the macrobenthic communities in reclaimed and natural coastal areas is important to understanding marine ecosystem dynamics and predicting associated changes due to natural and anthropogenic stressors. Therefore, integrated monitoring is considered essential for providing insights into the changes in coastal and marine ecosystems due to dredging and reclamation activities along the coastlines of the Arabian Gulf. This provides important implications for several environmental management tools related to the protection and management of the coastal and marine environment. These tools may include adaptive management and stewardship in coastal zones [43], environmental impact assessment [82], climate change mitigation [83], the restoration and rehabilitation of ecosystems [84], coastal spatial planning [85] and habitat sensitivity mapping for the coastal and marine environment [86].

Coastal and marine environments in Bahrain support some of the most productive ecosystems, including mangroves, seagrass beds, coral reefs and mudflats. Due to rapid modernization and economic growth, these ecosystems are under threat from multiple stressors, including dredging and reclamation activities. The effective and holistic management of marine dredging and coastal reclamation can ensure legitimate development while protecting the vulnerable habitats and marine resources in Bahrain.

5. Conclusions

The present study provided a spatial and temporal characterization of the benthic communities in the reclaimed and natural coastal areas in Bahrain. Higher levels of ecological indices, including the richness, evenness and diversity of macrobenthic invertebrates, were recorded in the natural mudflat of Arad Bay in comparison with the reclaimed areas. Additionally, the community structure of the benthic organisms in Arad Bay differed distinctly from that of the other study areas. This work also provides an initial characterization of benthic structures for future monitoring studies to assess biological and ecological alterations associated with dredging and reclamation in the Arabian Gulf. Further studies related to the recovery and succession of macrobenthic communities in newly reclaimed coastal areas in the Arabian Gulf are needed. These studies can include the recovery times required for the re-establishment of acceptable levels of diversity and ecosystem stability after the disturbances of reclamation and dredging activities. This could help in establishing ecological restoration and compensation plans for degrading habitats and coastal management.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jmse10070945/s1, Table S1: list of species and their abundance in the sampling areas.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: A list of species and their abundance is provided in the Supplementary Materials.

Acknowledgments: The logistical support provided by the Department of Biology, College of Science, University of Bahrain is greatly appreciated. Special thanks are extended to the Supreme Council for Environment, Kingdom of Bahrain for providing the permission for collecting samples from the protected area of Arad Bay. The statistical advice provided by Simone Perna, associate professor, is highly appreciated.

Conflicts of Interest: The author declares no competing interests.

References

1. Martín-Antón, M.; Negro, V.; del Campo, J.M.; López-Gutiérrez, J.S.; Esteban, M.D. Review of coastal land reclamation situation in the world. *J. Coast. Res.* **2016**, *75*, 667–671. [CrossRef]
2. Salomon, M.; Markus, T. *Handbook on Marine Environmental Protection: Science, Impacts and Sustainable Management*; Springer: Berlin/Heidelberg, Germany, 2018.
3. Wu, W.; Yang, Z.; Tian, B.; Huang, Y.; Zhou, Y.; Zhang, T. Impacts of coastal reclamation on wetlands: Loss, resilience, and sustainable management. Estuarine. *Coast. Shelf Sci.* **2018**, *210*, 153–161. [CrossRef]
4. Chee, S.Y.; Othman, A.G.; Sim, Y.K.; Adam, A.N.; Firth, L.B. Land reclamation and artificial islands: Walking the tightrope between development and conservation. *Glob. Ecol. Conserv.* **2017**, *12*, 80–95. [CrossRef]
5. Sengupta, D.; Chen, R.; Meadows, M. Building beyond land: An overview of coastal land reclamation in 16 global megacities. *Appl. Geogr.* **2018**, *90*, 229–238. [CrossRef]
6. Zhang, Y.; Chen, R.; Wang, Y. Tendency of land reclamation in coastal areas of Shanghai from 1998 to 2015. *Land Use Policy* **2020**, *91*, 104370. [CrossRef]
7. Grydehoj, A. Making ground, losing space: Land reclamation and urban public space in island cities. *Urban Isl. Stud.* **2015**, *1*, 96–117. [CrossRef]
8. Duan, H.; Zhang, H.; Huang, Q.; Zhang, Y.; Hu, M.; Niu, Y.; Zhu, J. Characterization and environmental impact analysis of sea land reclamation activities in China. *Ocean. Coast. Manag.* **2016**, *130*, 128–137. [CrossRef]
9. Lewis, C.; Baldock, J.; Hawke, B.; Gadd, P.; Zawadzki, A.; Heijnis, H.; Jacobsen, G.; Rogers, K.; Macreadie, P. Impacts of land reclamation on tidal marsh 'blue carbon' stocks. *Sci. Total Environ.* **2019**, *672*, 427–437. [CrossRef]
10. Ma, T.; Li, X.; Bai, J.; Cui, B. Habitat modification in relation to coastal reclamation and its impacts on waterbirds along China's coast. *Glob. Ecol. Conserv.* **2019**, *17*, e00585. [CrossRef]
11. UN. *The Second World Ocean Assessment*; United Nations: New York, NY, USA, 2021.
12. Burt, J. The environmental costs of coastal urbanization in the Arabian Gulf. *City* **2014**, *18*, 760–770. [CrossRef]
13. Burt, J.; Bartholomew, A. Towards a more sustainable coastal development in the Arabian Gulf: Opportunities for ecological engineering in an urbanized seascape. *Mar. Pollut. Bull.* **2019**, *142*, 93–102. [CrossRef] [PubMed]
14. Hamza, W.; Munawar, M. Protecting and managing the Arabian Gulf: Past, present and future. *Aquat. Ecosyst. Health Manag.* **2009**, *12*, 429–439. [CrossRef]
15. Donchyts, G.; Baart, F.; Winsermius, H.; Gorelick, N.; Kwadijk, J.; Van de Giesen, N. Earth's surface water change over the past 30 years. *Nat. Clim. Chang.* **2016**, *6*, 810–813. [CrossRef]
16. Erftemeijer, P.; Lewis, R. Environmental impacts of dredging on seagrasses: A review. *Mar. Pollut. Bull.* **2006**, *52*, 1553–1572. [CrossRef] [PubMed]
17. Erftemeijer, P.; Riegl, B.; Hoeksema, B.; Todd, P. Environmental impacts of dredging and other sediment disturbances on corals: A review. *Mar. Pollut. Bull.* **2012**, *64*, 1737–1765. [CrossRef]
18. Jones, R.; Ricardo, G.; Negri, A. Effects of sediments on the reproductive cycle of corals. *Mar. Pollut. Bull.* **2015**, *100*, 13–33. [CrossRef]
19. Lokier, S. Coastal Sabkha Preservation in the Arabian Gulf. *Geoheritage* **2013**, *5*, 11–22. [CrossRef]
20. Xu, L.; Yang, W.; Jiang, F.; Qiao, Y.; Yan, Y.; An, S. Effects of reclamation on heavy metal pollution in a coastal wetland reserve. *J. Coast. Conserv.* **2018**, *22*, 209–215. [CrossRef]
21. Vaughan, G.; Al-Mansoori, N.; Burt, J. The Arabian Gulf. In *World Seas: An Environmental Evaluation*, 2nd ed.; Sheppard, C., Ed.; Elsevier Science: Amsterdam, The Netherlands, 2019.
22. Abdulla, K.; Naser, H. Protection of marine environmental quality in the Kingdom of Bahrain. *Ocean. Coast. Manag.* **2021**, *203*, 105520. [CrossRef]
23. Naser, H. Management of Marine Protected Zones-Case Study of Bahrain, Arabian Gulf. In *Applied Studies of Coastal and Marine Environments*; Marghany, M., Ed.; INTECH Publishing: London, UK, 2016; pp. 322–350.
24. Zainal, K.; Al-Sayyed, H.; Al-Madany, I. Coastal pollution in Bahrain and its management. In *Protecting the Gulf's Marine Ecosystems from Pollution*; Abuzinada, A., Barth, H., Krupp, F., Boer, B., Abdessalaam, T.A., Eds.; Springer: Berlin/Heidelberg, Germany, 2008; pp. 147–162.
25. Zainal, K.; Al-Madany, I.M.; Al-Sayyed, H.; Khamis, A.; Al Shuhaby, S.; Al Hisaby, A.; Elhoussiny, W.; Khalaf, E. The cumulative impacts of reclamation and dredging on the marine ecology and land-use in the Kingdom of Bahrain. *Mar. Pollut. Bull.* **2012**, *64*, 1452–1458. [CrossRef]
26. Noor Al-Nabi, M. *History of Land Use and Development of Bahrain*; Government Printing Press, Information Affairs Authority: Manama, Bahrain, 2012.
27. IEGA. Bahrain Open Data Portal, Information and E-Government Authority, Bahrain. 2021. Available online: https://www.data.gov.bh/en/ResourceCenter (accessed on 3 June 2021).
28. Fuller, S. *Towards a Bahrain National Report on the Convention on Biological Diversity*; Report prepared for the General Directorate of Environment and Wildlife Protection; Kingdom of Bahrain and United Nations Development Program (UNDP): Manama, Bahrain, 2005.

29. Aljenaid, S.; Abido, M.; Redha, G.; Alkuzaei, M.; Marsan, Y.; Khamis, A.; Nase, H.; AlRumaidh, M.; Alsabbagh, M. Assessing the spatiotemporal changes, associated carbon stock, and potential emissions of mangroves in Bahrain using GIS and remote sensing data. *Reg. Stud. Mar. Sci.* **2022**, *52*, 102282. [CrossRef]
30. Sheppard, C. Coral reefs in the Gulf are mostly dead now, but can we do anything about it? *Mar. Pollut. Bull.* **2016**, *105*, 593–598. [CrossRef] [PubMed]
31. Lv, W.; Ma, C.; Huang, Y.; Yang, Y.; Yu, J.; Zhang, M.; Zhao, Y. Macrobenthic diversity in protected, disturbed, and newly formed intertidal wetlands of a subtropical estuary in China. *Mar. Pollut. Bull.* **2014**, *89*, 259–266. [CrossRef] [PubMed]
32. Arizaga, J.; Amat, J.; Monge-Ganuzas, M. The negative effect of dredging and dumping on shorebirds at coastal wetland in northern Spain. *J. Nat. Conserv.* **2017**, *37*, 1–7. [CrossRef]
33. Liu, Z.; Chen, M.; Li, Y.; Huang, Y.; Fan, B.; Lv, W.; Yu, P.; Wu, D.; Zhao, Y. Different effects of reclamation methods on macrobenthos community structure in the Yangtze Estuary, China. *Mar. Pollut. Bull.* **2018**, *127*, 429–436. [CrossRef]
34. Pilo, D.; Carvalho, A.; Pereira, F.; Coelho, H.; Gaspar, M. Evaluation of microbenthic community responses to dredging through a multimeric approach: Effective or apparent recovery? *Ecol. Indic.* **2019**, *96*, 656–668. [CrossRef]
35. Xue, J.; Yang, J.; Wang, Q.; Aronson, R.; Wu, H. Community structure of benthic macroinvertebrates in reclaimed and natural tidal flats of the Yangtze River estuary. *Aquac. Fish.* **2019**, *4*, 205–213. [CrossRef]
36. Mulik, J.; Sukumaran, S.; Srinivas, T. Factors structuring spatio-temporal dynamics of macrobenthic communities of three differently modified tropical estuaries. *Mar. Pollut. Bull.* **2020**, *150*, 110767. [CrossRef]
37. Naser, H. Effects of reclamation on macrobenthic assemblages in the coastline of the Arabian Gulf: A microcosm experimental approach. *Mar. Pollut. Bull.* **2011**, *62*, 520–524. [CrossRef]
38. Jones, D.; Nithyanandan, M. Recruitment of marine biota onto hard and soft artificially created subtidal habitats in Sabah Al-Ahmad Sea City, Kuwait. *Mar. Pollut. Bull.* **2013**, *72*, 351–356. [CrossRef]
39. Al-Sayed, H.; Naser, H.; Al-Wedaei, K. Observations on macrobenthic invertebrates and wader bird assemblages in a protected marine mudflat in Bahrain. *Aquat. Ecosyst. Health Manag.* **2008**, *11*, 450–456.
40. Holme, N.; Mcintyre, A. *Methods for the Study of Marine Benthos*; Blackwell Scientific Publications: Oxford, UK, 1984.
41. Clarke, K.; Gorley, R.; Somerfield, P.; Warwick, R. *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation*, 3rd ed.; PRIMER-E.: Plymouth, UK, 2014.
42. Clarke, K.; Gorley, R. *PRIMER v7: User Manual/Tutorial*; PRIMER-E.: Plymouth, UK, 2015.
43. Thrush, S.; Hewitt, J.; Pilditch, C.; Norkko, A. *Ecology of Coastal Marine Sediments: Form, Function, and Change in the Anthropocene*; Oxford University Press: Oxford, UK, 2021.
44. Riegl, B.; Purkis, S. *Coral Reefs of the Gulf: Adaptation to Climatic Extremes*; Springer: Amsterdam, The Netherlands, 2012; p. 379.
45. Alosairi, Y.; Alsulaiman, N.; Rashed, A.; Al-Houti, D. World record extreme sea surface temperatures in the northwestern Arabian/Persian Gulf verified by in situ measurements. *Mar. Pollut. Bull.* **2020**, *161*, 111766. [CrossRef] [PubMed]
46. Bouwmeester, J.; Riera, R.; Range, P.; Ben-Hamadou, R.; Samimi-Namin, K.; Burt, J. Coral and reef fish communities in the thermally extreme Persian/Arabian Gulf: Insights into potential climate change effects. In *Perspectives on the Marine Animal Forests of the World*; Rossi, S., Bramanti, L., Eds.; Springer Nature: Cham, Switzerland, 2020; pp. 63–86.
47. Zainal, K.; Al-Sayed, H.; Ghanem, E.; Butti, E.; Nasser, H. Baseline ecological survey of Huwar Islands, The Kingdom of Bahrain. *Aquat. Ecosyst. Health Manag.* **2007**, *10*, 290–300. [CrossRef]
48. Naser, H. Variability of marine macrofouling assemblages in a marina and a mariculture centre in Bahrain, Arabian Gulf. *Reg. Stud. Mar. Sci.* **2017**, *16*, 162–170. [CrossRef]
49. Ellis, J.; Clark, D.; Atalah, J.; Jiang, W.; Taiapa, C.; Patterson, M.; Sinner, J.; Hewitt, J. Multiple stressor effects on marine infauna: Responses of estuarine taxa and functional traits to sedimentation, nutrient and metal loading. *Sci. Rep.* **2017**, *7*, 12013. [CrossRef]
50. Zhang, P.; Xu, J.; Zhang, J.; Li, J.; Zhang, Y.; Li, Y.; Luo, X. Spatiotemporal dissolved silicate variation, sources, and behavior in the Eutrophic Zhanjing Bay, China. *Water* **2020**, *12*, 3586. [CrossRef]
51. Kumar, B. Spatial and temporal variation in dissolved silicate along the Indian coastal groundwaters and their export to adjacent coastal waters. *Groundw. Sustain. Dev.* **2021**, *14*, 100637. [CrossRef]
52. Gray, J.; Elliot, M. *Ecology of Marine Sediment from Science to Management*, 2nd ed.; Oxford University Press: Oxford, UK, 2009.
53. Zainal, K.; Isa, A.; Mandeel, Q. Spatial and temporal variation patterns of total suspended solids around the coastal areas of Bahrain, a water quality guideline. *Aquat. Ecosyst. Health Manag.* **2020**, *23*, 136–144. [CrossRef]
54. Meng, W.; Hu, B.; He, M.; Liu, B.; Mo, X.; Li, H.; Wang, Z.; Zhang, Y. Temporal-spatial variations and driving factors analysis of coastal reclamation in China. Estuarine. *Coast. Shelf Sci.* **2017**, *191*, 39–49. [CrossRef]
55. Wu, H.; Fu, S.; Wu, J.; Cai, X.; Chen, Q. Spatiotemporal variation of benthic biodiversity under persistent and extreme human disturbances in the Xiamen Sea area, China. *Ocean. Coast. Manag.* **2021**, *207*, 105556. [CrossRef]
56. Diaz-Castaneda, V.; Reish, D. Polychaetas in Environmental Studies. In *Annelids in Modern Biology*; Shain, D.H., Ed.; Whiley-Blackwell: Hoboken, NJ, USA, 2009.
57. Dean, H. The use of polychaetes (Annelida) as indicator species of marine pollution: A review. *Int. J. Trop. Biol.* **2008**, *56*, 11–38.
58. Bottero, M.; Jaubet, M.; Llanos, E.; Becherucci, M.; Elias, R.; Garaffo, G. Spatial-temporal variations of a SW Atlantic macrobenthic community affected by a chronic anthropogenic disturbance. *Mar. Pollut. Bull.* **2020**, *156*, 111189. [CrossRef] [PubMed]

59. Andrew-Priestley, M.; Newton, K.; Platell, M.; Le Strange, L.; Houridis, H.; Stat, M.; Yu, R.; Evans, C.; Rogers, Z.; Pallot, J.; et al. Benthic infaunal assemblages adjacent to an ocean outfall in Australian marine waters: Impact assessment and identification of indicator taxa. *Mar. Pollut. Bull.* **2022**, *174*, 113229. [CrossRef] [PubMed]
60. Yang, W.; Sun, T.; Yang, Z. Effect of activities associated with coastal reclamation on the macrobenthos community in coastal wetlands of the Yellow River Delta, China: A literature review and systematic assessment. *Ocean. Coast. Manag.* **2016**, *129*, 1–9. [CrossRef]
61. Nazeer, Z.; Khan, A.; Manikandan, K.; Manokaran, S.; Hsu, H.; Joydas, T.; Lyla, P. Macrofaunal assemblage in the intertidal area Saudi Arabian Gulf coast. *Reg. Stud. Mar. Sci.* **2021**, *47*, 101954. [CrossRef]
62. Lozano-Cortes, D.; Joydas, T.; Abdulkader, K.; Krishnakumar, P.; Qurban, M. Marine invertebrates colonizing a causeway in the Manifa offshore. *Mar. Biodivers.* **2019**, *49*, 2473–2483. [CrossRef]
63. Botter-Carvalho, M.; Carvalho, P.; Santos, P. Recovery of macrobenthos in defaunated tropical estuarine sediments. *Mar. Pollut. Bull.* **2011**, *62*, 1867–1876. [CrossRef]
64. Stachowitsch, M.; Kikinger, R.; Herler, J.; Zolda, P.; Geutebruck, E. Offshore oil platforms and fouling communities in the southern Arabian Gulf (Abu Dhabi). *Mar. Pollut. Bull.* **2002**, *44*, 853–860. [CrossRef]
65. Albano, P.; Filippova, N.; Steger, J.; Schmielbaur, H.; Tomasovych, A.; Stachowitsch, M.; Zuschin, M. Contamination patterns and molluscan and polychaete assemblages in two Persian (Arabian) Gulf oilfields. *Mar. Ecol.* **2016**, *37*, 907–919. [CrossRef]
66. Al-Kandari, M.; Oliver, P.; Chen, W.; Skryabin, V.; Raghu, M.; Yousif, A.; Al-Jazzaf, S.; Taqi, A.; AlHamad, A. Diversity and distribution of the intertidal Mollusca of the State of Kuwait, Arabian Gulf. *Reg. Stud. Mar. Sci.* **2020**, *33*, 100905. [CrossRef]
67. Pruden, M.; Dietl, G.; Handley, J.; Smith, J. Using molluscs to assess ecological quality status of soft-bottom habitats along the Atlantic coastline of the United States. *Ecol. Indic.* **2021**, *129*, 107910. [CrossRef]
68. El-Sorogy, A.; Alharbi, T.; Almadani, S.; Al-Hashim, M. Molluscan assemblage as pollution indicators in Al-Khobar coastal plain, Arabian Gulf, Saudi Arabia. *J. Afr. Earth Sci.* **2019**, *158*, 102564. [CrossRef]
69. Robinson, J.; Newell, R.; Seiderer, L.; Simposn, N. Impacts of aggregate dredging on sediment composition and associated benthic fauna at an offshore site in the southern North Sea. *Mar. Environ. Res.* **2005**, *60*, 51–68. [CrossRef] [PubMed]
70. Manokaran, S.; Joydas, T.; Qurban, M.; Cheruvathur, L.; Kariyathil, T.; Basali, A.; Khan, S.; Al-Suwailem, A. Baseline patterns of structural and functional diversity of benthic amphipods in the western Arabian Gulf. *Mar. Pollut. Bull.* **2021**, *164*, 112054. [CrossRef] [PubMed]
71. Naser, H. Soft-bottom crustacean assemblages influenced by anthropogenic activities in Bahrain, Arabian Gulf. In *Crustaceans: Structure, Ecology and Life Cycle*; Sisto, G., Ed.; NOVA Science Publishers Inc.: New York, NY, USA, 2013; pp. 95–112.
72. Buali, A. *Final Report of Research Project on Ecological Assessment in Support of Sustainable Development in Hawar Islands*; Deanship of Scientific Research, University of Bahrain: Sakhir, Bahrain, 2009; p. 187.
73. Guerra-Garcia, J.; Garcia-Gomez, J. Recolonization of defaunated sediments: Fine versus gross sand and dredging versus experimental trays. Estuarine. *Coast. Shelf Sci.* **2006**, *68*, 328–342. [CrossRef]
74. Guerra-Garcia, J.; Garcia-Gomez, J. Recolonization of macrofauna in unpolluted sands placed in a polluted yachting harbour: A field approach using experimental trays. Estuarine. *Coast. Shelf Sci.* **2009**, *81*, 49–58. [CrossRef]
75. Tavares, P.; Machado, M.; da Fonseca, L. Colonization process in soft-bottom macrofauna communities using azoic sediments: Comparison of two wetland systems with different organic loads. *Fundam. Appl. Limnol.* **2008**, *171*, 219–232. [CrossRef]
76. Lin, J.; Zou, X.; Huang, F. Effects of the thermal discharge from an offshore power plant on plankton and macrobenthic communities in subtropical China. *Mar. Pollut. Bull.* **2018**, *131*, 106–114. [CrossRef]
77. Shou, L.; Huang, Y.; Zeng, J.; Gao, A.; Liao, Y.; Chen, Q. Seasonal changes of macrobenthos distribution and diversity in Zhoushan sea area. *Aquat. Ecosyst. Health Manag.* **2009**, *12*, 110–115. [CrossRef]
78. Jickells, T.; Andrews, J.; Parkes, D. Direct and indirect effects of estuarine reclamation on nutrient and metal fluxes in the global coastal zone. *Aquat. Geochem.* **2016**, *22*, 337–348. [CrossRef]
79. Waye-Barker, G.; McIlwaine, P.; Lozach, S.; Cooper, K. The effects of marine sand and gravel extraction on the sediment composition and macrofaunal community of a commercial dredging site (15 years post-dredging). *Mar. Pollut. Bull.* **2015**, *99*, 207–215. [CrossRef] [PubMed]
80. Coles, S.; MacCain, J. Environmental factors affecting benthic infaunal communities of the western Arabian Gulf. *Mar. Environ. Res.* **1990**, *29*, 289–315. [CrossRef]
81. Wei, C.; Rowe, G.; Al-Ansi, M.; Al-Maslamani, I.; Soliman, Y.; Nour El-Din, N.; Al-Ansari, I.; Al-Shaikh, I.; Quigg, A.; Nunnally, C.; et al. Macrobenthos in the central Arabian Gulf: A reflection of climate extremes and variability. *Hydrobiologia* **2016**, *770*, 53–72. [CrossRef]
82. Naser, H. The role of environmental impact assessment in protecting coastal and marine environments in rapidly developing islands: The case of Bahrain, Arabian Gulf. *Ocean. Coast. Manag.* **2015**, *104*, 159–169. [CrossRef]
83. Pancrazi, I.; Ahmed, H.; Cerrano, C.; Montefalcone, M. Synergic effect of global thermal anomalies and local dredging local activities on coral reefs of the Maldives. *Mar. Pollut. Bull.* **2020**, *160*, 111585. [CrossRef]
84. Caia, Y.; Lianga, J.; Zhanga, P.; Wanga, Q.; Wub, Y.; Dinga, Y.; Wangc, H.; Fub, C.; Sund, J. Review on strategies of close-to-nature wetland restoration and a brief case plan for a typical wetland in northern China. *Chemosphere* **2021**, *285*, 131534. [CrossRef]

85. Butler, J.; Purkis, S.; Yousif, R.; Al-Shaikh, I.; Warren, C. A high-resolution remotely sensed benthic habitat map of the Qatari coastal zone. *Mar. Pollut. Bull.* **2020**, *160*, 111634. [CrossRef] [PubMed]
86. Butler, J.; Purkis, L.; Purkis, S.; Yousif, R.; Al-Shaikh, I. A benthic habitat sensitivity analysis of Qatar's coastal zone. *Mar. Pollut. Bull.* **2021**, *167*, 112333. [CrossRef]