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Research Article

Ecological quality status of stressed coastal benthic ecosystems in Nayband Bay from the Northern Persian Gulf, Iran using AMBI, M-AMBI, Bentix, and H´ indices

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Abstract

Nayband Bay has been greatly influenced by a variety of human disturbances over the last three decades. The present study was undertaken to assess the ecological quality status of macrobenthic communities in Nayband Bay sediments using four benthic indices namely AMBI, M-AMBI, BENTIX, and H´. The sediment samples were taken for macrobenthos extractions and determination of grain size analysis, Total Organic Matter (TOM), and Total Organic Carbon (TOC) using a Van Veen grab. A total of 47 macrobenthos taxa (genus and species) were identified among 34825 individuals in the sampling area. Polychaeta, Malacostraca, Bivalve, Gastropoda and Echiura were the most abundance taxon with 23 (48.9%), 11 (23.4%), 6 (12.7%), 5 (10.6%), and 2 (4.2%) species. The results showed that the macrobenthic communities were characterized by sensitive (EGI) or indifferent (EGII) species of AMBI ecological groups. The opportunistic species (EGIV and V) namely *Capitella capitata*, *Cirratulus ciratus*, and *Scolelepis* sp. were dominated at stations with high TOC. These stations were close to the beach, where the organic matter discharges and wastewater have been released from industrial outfalls. In general, the EcoQs were "good" or "acceptable", although four indices showed some differences in the EcoQs classifications for a given site. The results of the present study indicate that the complementary use of different indices, especially sensitivity/tolerance-based indices, is recommended for the ecological status assessment of the Iranian coastal waters of the Persian Gulf.

Keywords: Biotic indices, ecological quality status, Macrofauna, Nayband Bay, Persian Gulf

Introduction

Coastal areas of the marine environment are highly productive ecosystems and widely considered to be habitats for many invertebrate species. These habitats differ in terms of their hydrodynamics, structural complexity and substrate composition (Fonseca & Fisher, 1986), which structure the associated species communities (Boström & Bonsdorff, 1997; Henseler et al., 2019; Hewitt, Thrush, & Dayton, 2008). Macrobenthos is an important component and plays a vital role in the energy flow and material recycling of marine ecosystems (Hajializadeh et al., 2020; Lam-Gordillo, Baring, & Dittmann, 2020). They include a variety of biological groups (e.g., polychaetes, mollusks, and crustaceans), and most of them have a sessile or sedentary life habit on/in the surface of sediment and have a relatively long-life span (Dong, Sun, Zhang, Zhan, & Zhang, 2021). In addition, macrobenthos also display different feeding characteristics and the ability to respond to environmental disturbances and/or pollution (Gamito & Furtado, 2009). For these reasons, they are widely used as indicators for ecological quality in marine monitoring and assessment (Dong, Zhao, et al., 2021; Kosari, Mousavi Nadushan, Faremi, Ejlali Khanghah, & Mashinchian, 2021; Rahimi Moazampour, Nabavi, Mohammadi Roozbahani, & Khodadadi, 2021; Roozbahani, Nabavi, Farshchi, & Rasekh, 2010) . In recent years, several benthic biotic indices such as the AZTI's Marine Biotic Index (AMBI) (Angel Borja, Franco, & Pérez, 2000), Multivariate AZTI's Marine Biotic Index (M-AMBI) (Inigo Muxika, Borja, & Bald, 2007), BENTIX (Simboura & Zenetos, 2002) and Shannon-Wiener (H´) index of diversity have been used to assess the benthic ecological quality status (EcoQs) of coastal and estuarine waters. Nayband Bay which is located in the northern part of the Persian Gulf is an important economic development zone dominated by oil and gas activities of Pars Special Economic Energy Zone (PSEEZ) and petrochemical industries. Therefore, this study aims to assess (i) the ecological status of macrobenthic communities in the Nayband Bay sediments; (ii) to explore the suitability of four biotic indices including AMBI (Angel Borja et al., 2000), M-AMBI (Inigo Muxika et al., 2007), BENTIX (Simboura & Zenetos, 2002) and Shannon index (H´) to assess the ecological quality status (EcoQs) of the Nayband Bay coastal waters under anthropogenic disturbances; and (iii) to reveal the structure and characteristics of the macrobenthic communities of the coastal waters of Nayband Bay and to provide recommendations for similar coastal waters ecosystems.

Material and methods

Study area

The Nayband Bay (latitude: 27º 41′ 85″ N and longitude: 52º 62′ 80″ E) with an area of 19500 hectares is a marine part of Nayband National Park (an area of about 50000 hectares) located in the northern part of the Persian Gulf in Bushehr and Hormozgan provinces, 320 km south-east of Bushehr city (Fig.1). Nayband Bay is well known for its environmental setting, for which it was designated a natural protected area by the World Commission of Protected Areas (WCPA), which is a branch of the International Union of Conservation of Nature (IUCN), in 2004 (Davoodi, Gharibreza, Negarestan, Mortazavi, & Lak, 2017). The overall morphology of the coastline of Nayband Bay represents a wave-dominated shoreline wherein sandbars have been developed parallel to the shoreline (Davoodi et al., 2017). This bay encompasses a wide range of marine habitats including coral reefs, rocky, muddy and sandy shore as well as mangrove forests and seagrass meadows. At the same time land development projects, including PSEEZ industries and supportive establishments, have surrounded Nayband Bay and its coastal waters which can affect the marine benthic fauna of the bay.

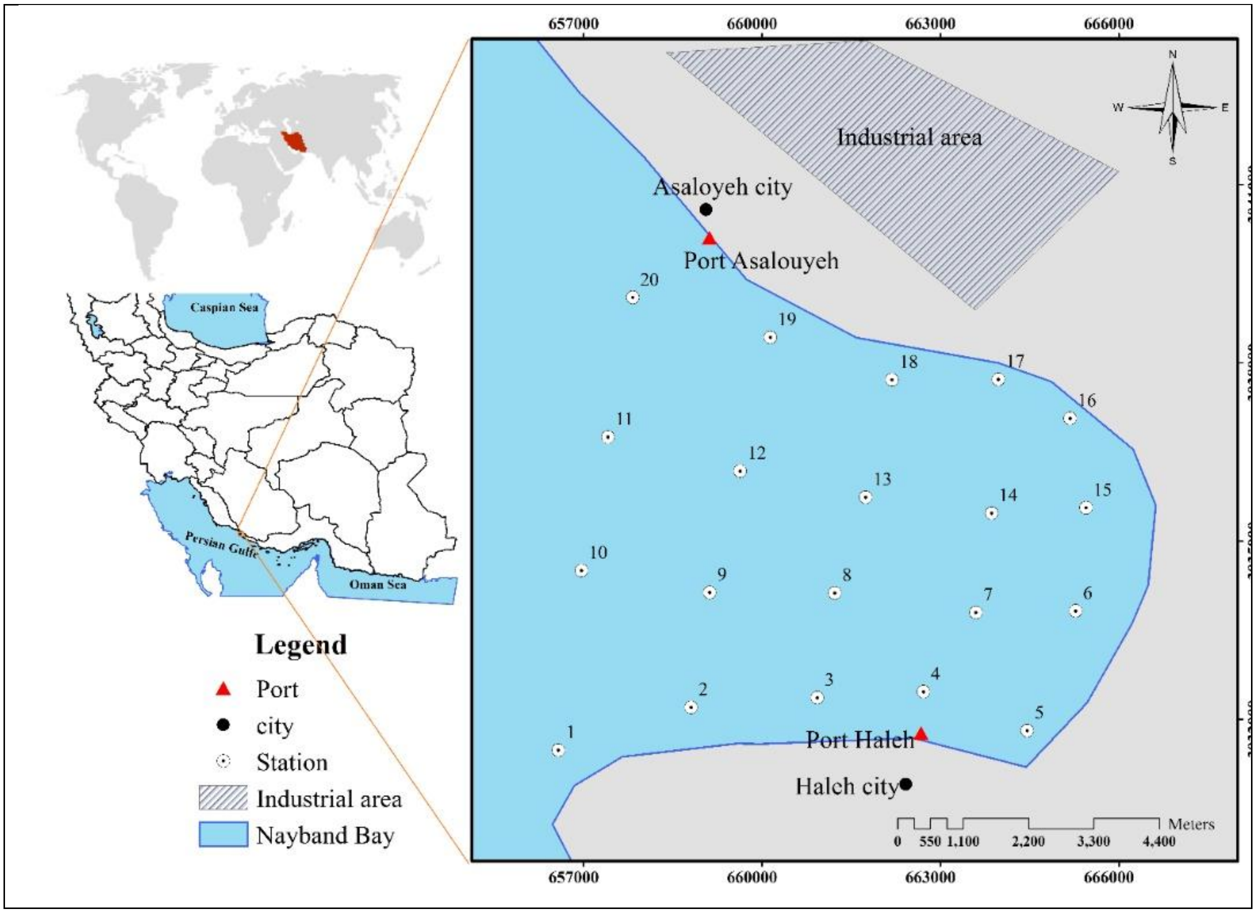

Figure 1. Map showing the location of the sampling stations

Sampling and measurements

Macrobenthic samples were collected from 20 stations in Nayband Bay in winter (February) of 2018 (Fig.1). At each station, three sediment samples were taken for macrobenthos extractions using a 0.025 m^2 Van Veen grab sampler and four sediment sample was obtained for the determination of grain size analysis, Total Organic Matter (TOM) and Total Organic Carbon (TOC) in sediments using the procedures described by (Buchanan, 1984; Holme & McIntyre, 1984) . The samples were washed and sieved over 0.5 mm mesh, and the collected macrofauna were preserved in 80% ethanol until laboratory identification to the lowest possible taxonomic level.

In the laboratory, samples were sorted after being stained with Rose Bengal and organisms were counted and identified to genus or species level. All macrobenthic abundance data were expressed as the number of individual/m^2. To obtain grain size composition, sediment samples were dried at 70ºC and a 100 g subsample was wet-sieved through a 0.063 mm sieve and dried. The remaining sediment was sieved through a seven-sieve column (4, 2, 1, 0.5, 0.25, 0.125, 0.063 mm sieves). The weight of the residue remaining in each sieve was then expressed as a percentage of the initial subsample weight and the <0.063 mm fraction was calculated from the difference between the initial subsample weight and the sum of the other fractions. A Horiba U10 multi-parameter probe was used for the in-situ measurement of dissolved oxygen, temperature, pH and salinity of the water samples close to the basin bottom using a Nansen bottle sampler. Depth was measured using a GARMIN Fish Finder 240.

Macroinvertebrate data were analyzed using four benthic indices: AMBI (Angel Borja et al., 2000), M-AMBI (Inigo Muxika et al., 2007), BENTIX (Simboura & Zenetos, 2002) and Shannon index (H´) to assess the ecological quality status (EcoQs) of the Nayband Bay according to benthic macroinvertebrate data collected. The EcoQs for each sampling station were classified to the threshold values of the AMBI, M-AMBI, BENTIX and H´ indices that were suggested by previous studies (Angel Borja et al., 2000; A Borja & Tunberg, 2011; Lu, Xu, Xu, & Liu, 2021; I Muxika, Borja, & Bonne, 2005; Simboura & Zenetos, 2002) (Table 1).

Table 1. The threshold levels of four indices for benthic ecological quality status assessment

Benthic ecological quality	AMBI[a]	M-AMBI[b]	BENTIX[c]	H´[d]
High (undisturbed)	0.0- 1.2	0.77- 1	4.5- 6.0	>4
Good (slightly disturbed)	1.2- 3.3	0.53- 0.77	3.5- 4.5	3- 4
Moderate (moderately disturbed)	3.3- 4.3	0.38- 0.53	2.5- 3.5	2- 3
Poor (heavily disturbed)	4.3- 5.5	0.20- 0.38	2.0- 2.5	1- 2
Bad (extremely disturbed)	5.5- 7.0	0.0- 0.20	0	<1

Note: The boundary of threshold was referred to: a, (Angel Borja et al., 2000; I Muxika et al., 2005) ; b, (Angel Borja et al., 2000; A Borja & Tunberg, 2011; I Muxika et al., 2005); c, (Simboura & Zenetos, 2002); d, (Lu et al., 2021).

According to the sensitivity of macrofauna response to environmental disturbance and/or pollution, all the identified taxa were assigned to five ecological groups: sensitive species (EGI), indifferent species (EGII), tolerant species (EGIII), second order opportunistic species (EGIV), and first-order opportunistic species (EGV) (Angel Borja et al., 2000).

To draw graphs and statistical analysis, Excel (Version 2019) and SPSS (Version 2016) software were used. The Kolmogorov-Smirnov normality test was applied on all variables to assess normality using mean normalization method and then one-way analysis of variance (ANOVA) with 0.05 significant level was used to test for significant differences between stations. Because of significant differences, a Tukey post-test was used for classification of data. To identify the relationship among data in sediments, pearson correlation coefficient was performed to evaluate possible correlations among the analyzed parameters and macroinvertebrate assemblages in the study area. Nonmetric multidimensional scaling (n MDS) ordination was based on the Bray-Curtis similarities of the log (X+1) transformed macrobenthic abundance data. This process was carried out in the "vegan" package (Oksanen et al., 2019). The Arc GIS (version 10) software was applied using the Jenks natural breaks classification method (Jenks, 1967) to plot the location of sampling stations, in the study area.

Results

Environmental characteristics

In the Nayband Bay waters, the sediment-related environmental variables (e.g., TOM and TOC) and depth exhibited relatively larger fluctuations than the water-related parameters (e.g., temperature, salinity and pH). In general, the study area was dominated by sand particles with higher percentage of silt and clay fractions at the two sides of the study area namely stations 18, 19, 20 at north and stations 4 and 6 at south, respectively (Fig. 2 and 3).

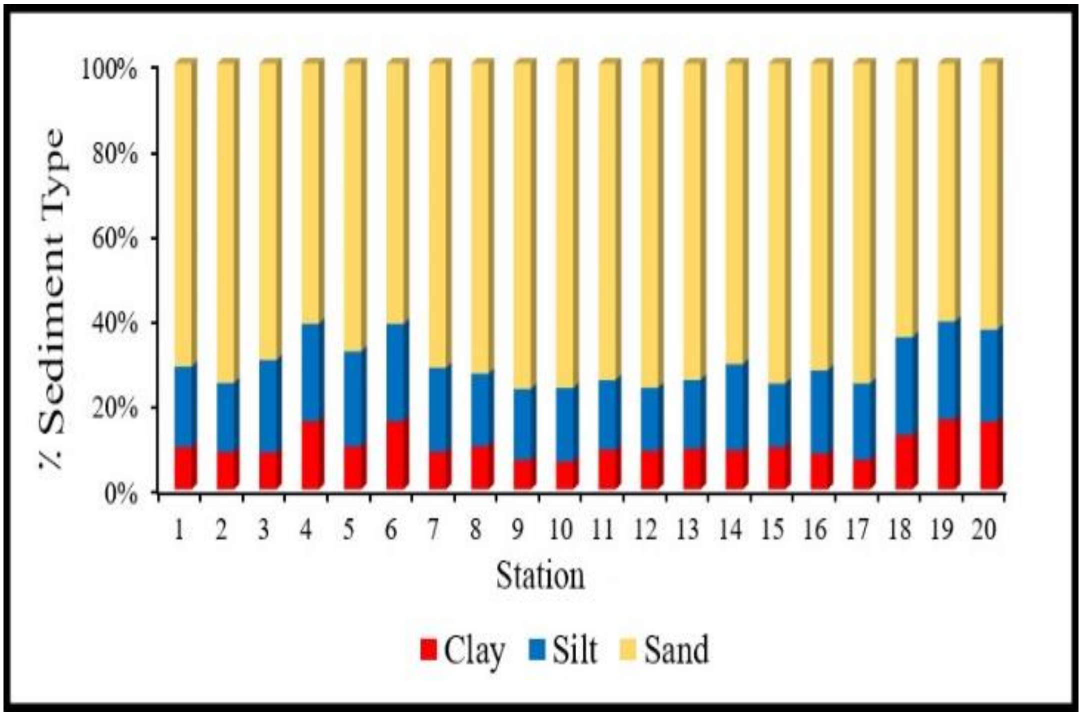

Figure 2. Percentage contribution of silt, clay and sand fractions in the sampled sediments

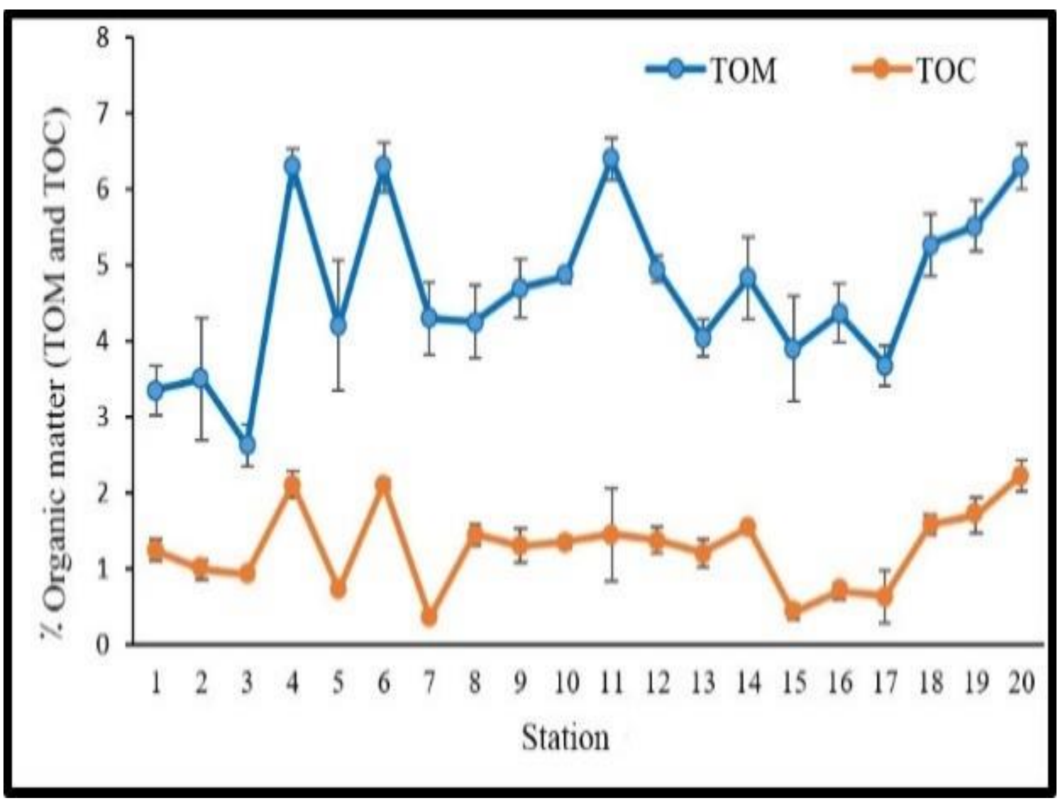

Figure 3. The comparison of means of TOM and TOC from the study area

The mean water temperature across sampling area was 23.89 ± 0.98ºC. Water temperatures ranged from 22.3ºC (st. 2) to 25.01 ºC (st. 20). pH value remained >7 throughout the study period, ranging from 7.7 (st. 1) to 8.9 (st. 19). Mean pH was 8.3 ± 0.49. The average salinity of all sampling areas was 42.06 ± 0.29 psu. The salinity was lowest in station 9 (38.5 psu) and highest in station 5 (45.8 psu). The water depth of Nayband Bay ranged from 5 m in station 3 to 25 m in station 19. Dissolved oxygen concentration was relatively high throughout the study period. Mean oxygen concentration (mg/l) was 7.41 ± 0.90, ranging from 6.1 to 8.61 mg/l in stations 7 and 4, respectively (Table 2).

Table 2. Physico-chemical characterization of water sampling stations.

St. no	Depth (m)	Do (mg/l)	pH	Salinity (psu)	Temperature (ºC)
1	5.2	6.28	7.7	44.3	22.4
2	5.2	6.98	8.7	38.7	22.3
3	5.0	6.43	8.6	41.5	23.1
4	8.6	8.61	8.8	44.1	23.3
5	8.1	8	8.5	45.8	23.4
6	8.7	8.11	8.6	41.2	23.6
7	6.8	6.14	8.2	41.7	23.5
8	7.5	6.37	8.5	41.3	23.7
9	8	8.38	8.6	38.5	24.1
10	7	6.37	8.5	41.3	23.7
11	7.8	6.96	7.9	42.4	24.4
12	7.5	7.63	8.3	39	23.4
13	8	6.99	8.8	40.4	23.9
14	7	7.39	8.1	43.9	24.7
15	8	7.42	8.5	41.8	24.7
16	15	7.51	7.8	42	24.7
17	23.9	8.08	8.7	44.3	24.6
18	24.7	7.9	7.8	44	24.7
19	25	7.79	8.9	41.7	24.9
20	24.8	8.12	7.8	40.9	25.1
Max	25	8.61	8.9	45.8	25.1
Min	5.0	6.14	7.7	38.5	22.3
Mean	10.96	7.41	8.30	42.06	23.89
SE	7.3	0.90	0.49	0.29	0.98

Macrobenthic community characteristics

A total of 47 macrobenthos taxa (genus and species) were identified among 34825 individuals in the sampling area (Table 3 and Fig 4). Polychaeta, Malacostraca, Bivalve, Gastropoda and Echiura were the most abundance taxon with 23 (48.9%), 11 (23.4%), 6 (12.7%), 5 (10.6%), and 2 (4.2%)

species. The highest and lowest abundance (ind./m^2) and the number of taxons of macroinvertebrate assemblages were found in stations 1 and 20, respectively (Figs. 4 and 5).

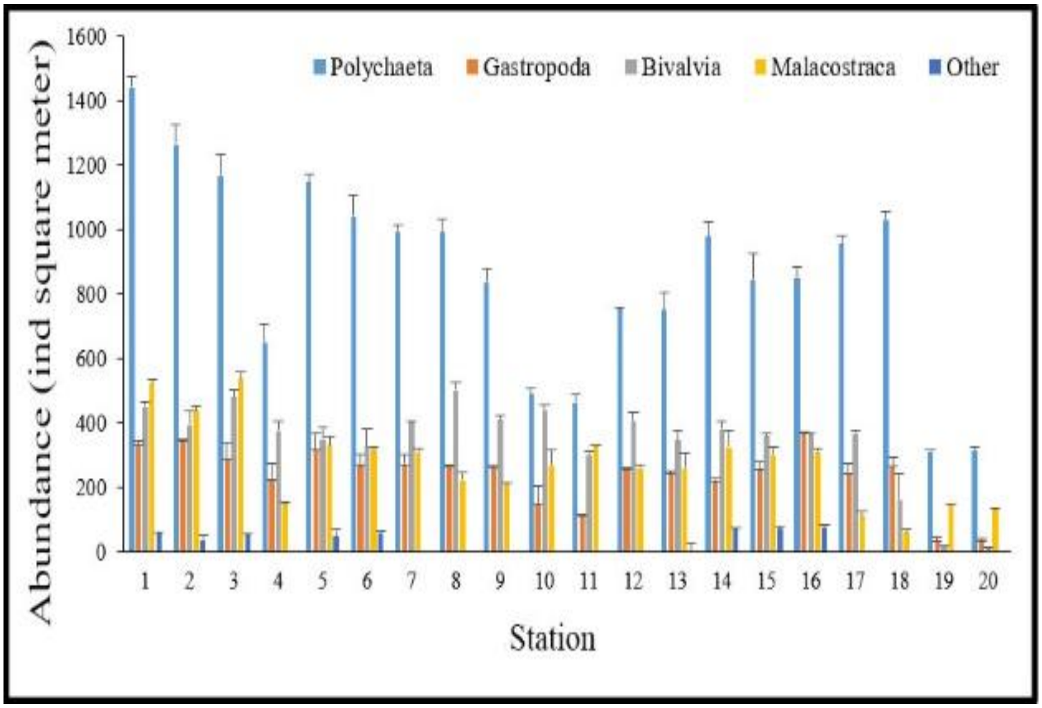

Figure 4. Mean abundance of macrofauna sampled in the coastal waters of Nayband Bay

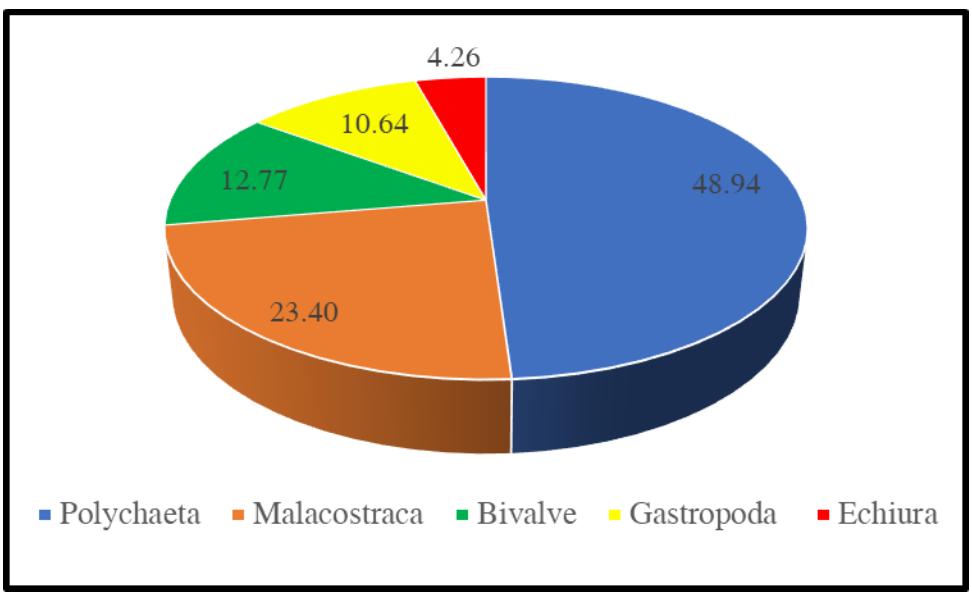

Figure 5. Percentage share of macrofauna groups collected in the study area

The AMBI value ranged from 1.63 to 2.65 and averaged 2.27. According to the AMBI threshold levels, all sampling stations were classified as having a "good" status which implied that the benthic environment had suffered slight impacts from human activities in the study area (Fig. 6). By using the species-list of December 2000 (Angel Borja et al., 2000) and expert opinion namely Dr. Angel Borja, of the 47 taxa identified in February 2018, 14 (30.0%) were not initially assigned to any ecological group. After assignment, 5 (10.6%) remained unassigned. Among the 47 macrobenthic taxa, 17 were very sensitive species (36.17%) according to (Grall & Glémarec, 1997) model, 11 were indifferent species (23.40%), 8 were tolerant species (17.02%), 4 were second-order opportunistic (8.51%), 2 were first-order opportunistic species (4.25%) and 5 were not assigned (10.64%) (Table 3).

Table 3. Species list and their ecological group assignation in Nayband Bay-Persian Gulf

	Phylum	Class	Family	Genus/Species	Ecological group (EG)
1	Annelida	Polychaeta	Aphroditidae	*Lepidonotus carinulatus*	II
2	Annelida	Polychaeta	Capitellidae	*Capitella capitata*	V
3	Annelida	Polychaeta	Cirratulidae	*Cirratulus cirratus*	IV
4	Annelida	Polychaeta	Cirratulidae	*Tharyx* sp.	IV
5	Annelida	Polychaeta	Glyceridae	*Glycera alba*	II
6	Annelida	Polychaeta	Glyceridae	*Glycera convolute*	II
7	Annelida	Polychaeta	Nephtyidae	*Nephtys cirrose*	II
8	Annelida	Polychaeta	Nephtyidae	*Nephtys dibranchis*	II
9	Annelida	Polychaeta	Nephtyidae	*Nephtys* sp.	II
10	Annelida	Polychaeta	Sabellidae	*Jasmineria* sp.	*N.A
11	Annelida	Polychaeta	Serpulidae	*Hydroides* sp.	*N.A
12	Annelida	Polychaeta	Spionidae	*Prionospio pinnata Ehlers*	IV
13	Annelida	Polychaeta	Spionidae	*Prionospio polybranchiata*	IV
14	Annelida	Polychaeta	Syllidae	*Syllis* sp.	II
15	Annelida	Polychaeta	Flabelligeridae	*Flabelligera* sp.	I
16	Annelida	Polychaeta	Maldanidae	*Petaloproctus* sp.	I
17	Annelida	Polychaeta	Nereididae	*Hediste diversicolor*	III
18	Annelida	Polychaeta	Nereididae	*Perinereis* sp.	III
19	Annelida	Polychaeta	Oweniidae	*Owenia fusiformis*	I
20	Annelida	Polychaeta	Spionidae	*Scolelepis* sp.	V
21	Annelida	Polychaeta	Sternaspidae	*Sternaspis* sp.	III
22	Annelida	Polychaeta	Nereididae	*Perinereis cultrifera*	III
23	Annelida	Polychaeta	Terebellidae	*Terebella* sp.	I
24	Mollusca	Gastropoda	Hydrobiidae	*Hydrobia ulvae*	III
25	Mollusca	Gastropoda	Potamididae	*Cerithidea cingulata*	I
26	Mollusca	Gastropoda	Obtortionidae	*Finella* sp.	II
27	Mollusca	Gastropoda	Olividae	*Ancilla* sp.	*N.A
28	Mollusca	Gastropoda	Onchidiidae	*Phasionella solida*	*N.A
29	Mollusca	Bivalvia	Veneridae	*Paphia gallus*	I
30	Mollusca	Bivalvia	Mytilidae	*Septifer bilocularis*	III
31	Mollusca	Bivalvia	Mytilidae	*Mytilus* sp.	III
32	Mollusca	Bivalvia	Mytilidae	*Callista multiradiata*	III
33	Mollusca	Bivalve	Veneridae	*Marcia opima*	I

34	Mollusca	Bivalve	Solenidae	*Solen* sp.	I
35	Arthropoda	Malacostraca	Ampeliscidae	*Ampelisca* sp.	I
36	Arthropoda	Malacostraca	Liljeborgiidae	*Liljeborgia* sp.	I
37	Arthropoda	Malacostraca	Xanthidae	*Actaea* sp.	*N.A
38	Arthropoda	Malacostraca	Ocypodidae	*Uca sindensis*	I
39	Arthropoda	Malacostraca	Anthuridae	*Apanthuras* sp.	I
40	Arthropoda	Malacostraca	Bodotriidae	*Cyclaspis* sp.	II
41	Arthropoda	Malacostraca	Bodotriidae	*Eocuma* sp.	I
42	Arthropoda	Malacostraca	Talitridae	*Diogenes* sp.	II
43	Arthropoda	Malacostraca	Gonodactylidae	*Orchestia* sp.	I
44	Arthropoda	Malacostraca	Gonodactylidae	*Gonodactylus* sp.	II
45	Arthropoda	Malacostraca	Ocypodidae	*Macrophthalmus pectinipes*	I
46	Echinodermata	Echiura	Holothuriidae	*Holothuria* sp.	I
47	Echinodermata	Echiura	Echinoidea	*Echinoidea* sp.	I

*N.A. - not assigned

The M-AMBI values ranged from 0.65 (St. 20) to 0.97 (St. 2) and averaged 0.83, which corresponded to “good” to “high” EcoQs; specifically, 15 stations (75%) corresponded to “high” EcoQs and 5 stations (25%) corresponded to “good” EcoQs, respectively. The mean BENTIX index was 5.04 ± 0.03, which indicated that the benthic EcoQs were “high” with the highest values at stations 3 and 2 and the lowest values at stations 19 and 20. The range of H´ values was 2.45-3.41. The lowest value was observed at station 18, and the highest value was at station 1. The highest H´ values occurred at stations 1, 2 and 3 in the south whereas the lowest values occurred at stations 17, 18, 19 and 20 in the north of the bay. According to the H´ threshold levels, 10 stations (50%) corresponded to “good” EcoQs and 10 stations (50%) corresponded to “moderate” EcoQs (Fig. 6). These relatively divergent results of bioindices may occur in same stations due to lack of a reference conditions for the location as it has been noted by others (Sivaraj, Murugesan, Muthuvelu, Vivekanandan, & Vijayalakshmi, 2014). The macrofauna classification analyses (using Bray-Curtis similarity) examined through nMDS show a separation of the northern from the southern and central regions (Fig.7). There are significant central and northern- southern differences between the assemblages with the highest and lowest abundance at station 1 (2798 ± 70.20 ind/m^2) and 20 (489 ± 2.64 ind/m^2), respectively (Fig. 4).

In the present study, the abundance of *Capitella capitata*, *Cirratulus ciratus* and *Scolelepis* sp. Was relatively high at some stations. These stations (stations 17-20) were evaluated as good (slightly disturbed) or moderately disturbed according to H´ index, which differed from the results of other indices. Stations 17-20 are very closed to the beach, where the organic matter discharges and wastewaters have been released from platforms conducting gas exploration and cooling towers of PSEEZ at 20 outfalls which was consistent with the results of other studies (Davoodi et al., 2017; PSEEZ, 2016).

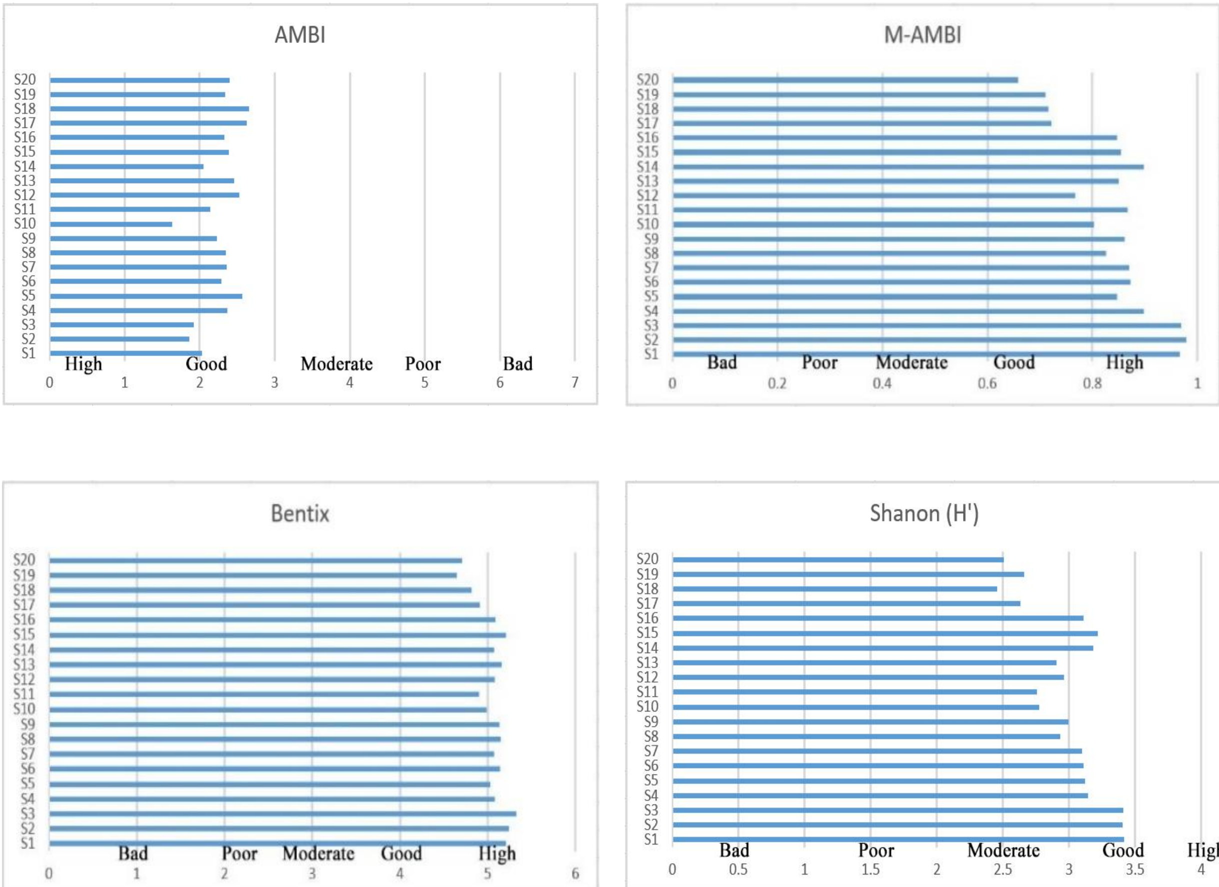

Figure 6. Ecological quality status of the coastal waters of Nayband Bay

Permutational multivariate analysis of variance (PERMANOVA) revealed significant differences in taxa compositions between the three groups ($P < 0.01$). Stations 1-3 consisted of group 1, stations 17-20 and 10-11 consisted of group 2 and the remaining stations consisted of a third group (Fig.7).

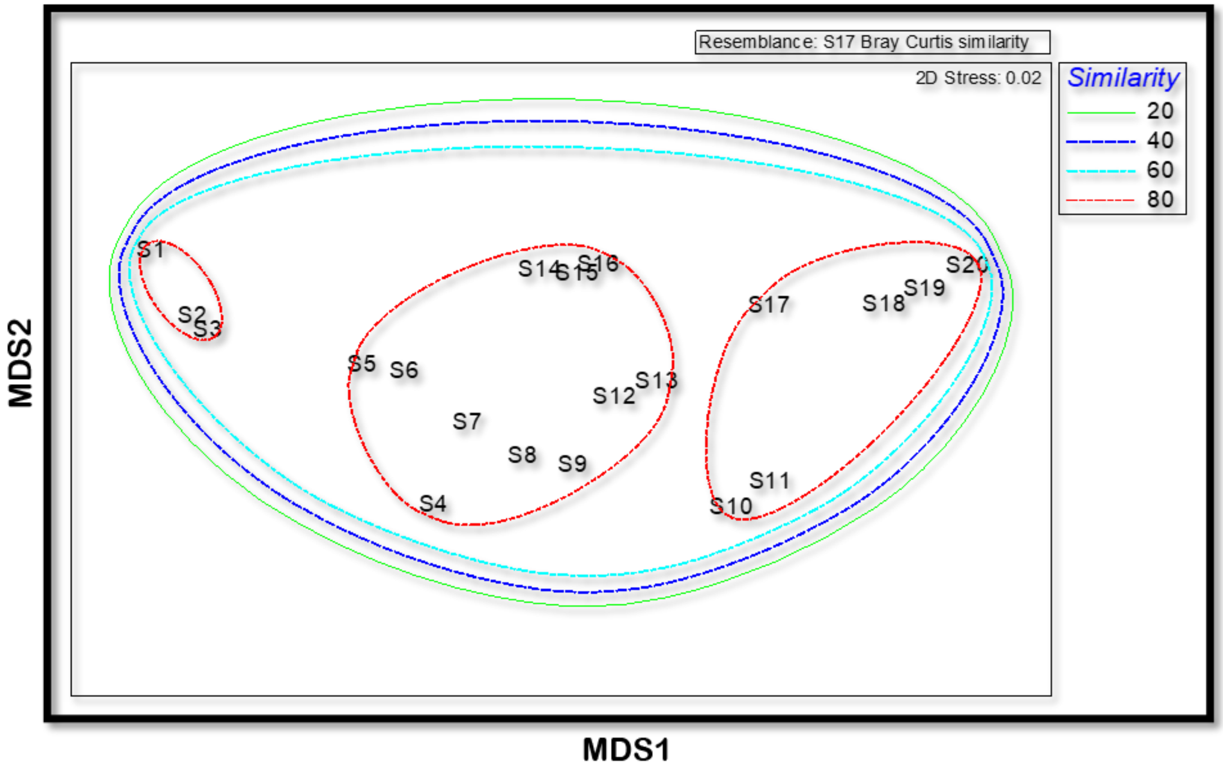

Figure 7. nMDS plots for the macrobenthic communities in the coastal waters of Nayband Bay

A pearson correlation test indicated that there was a significant positive correlation between macrofauna abundance and TOM ($p < 0.05$; r-value= 0.676*) and TOC ($p < 0.05$; r-value= 0.502*) percentages in the sediment. In general, when sedimentary TOC content is lower than 1%, it has a low impact on the environment, TOC content between 1% and 3% has medium impact and those above 3% has high impact (Baniemam, Moradi, Bakhtiari, Fatemi, & Khanghah, 2017; Wang et al., 2014) . A significant negative correlation was also observed between macrofauna abundance and temperature ($p < 0.05$; r-value= - 0.677*). There was a moderate correlation between macrofauna abundance and sand fractions ($p < 0.05$; r-value= 0.404*) and depth ($p < 0.05$, r-value= 0.503*) (Table 4) suggesting that the marine benthic environment is related to TOM, TOC, temperature and sediment type, which is similar to other studies (Ghanavati Asl, Nabavi, Rouzbahani, Alipour, & Monavari, 2022; Lu et al., 2021; Oleszczuk, Grzelak, & Kędra, 2021; Toussaint et al., 2021).

Table 4. Pearson's correlation coefficients of macrofauna abundance and physicochemical parameters.

	Abundance	%TOM	%TOC	T^{oc}	Sal (psu)	pH	Do (mg/L)	%Sand	Depth (m)
Abundance	1								
%TOM	0.67*	1							
%TOC	0.50*	0.55*	1						
T^{oc}	- 0.67*	0.41*	0.15	1					
Sal(psu)	0.07	0.05	0.11	- 0.05	1				
pH	0.006	- 0.03	0.05	0.01	- 0.04	1			
Do(mg/L)	0.002	0.09	0.05	- 0.04	- 0.02	- 0.18	1		
%Sand	0.40*	- 0.32*	- 0.40	- 0.15	- 0.110	0.09	0.02	1	
Depth(m)	0.50*	0.20	0.19	0.10	0.094	0.09	0.08	0.24	1

*Correlation is significant at the 0.05 level (2- tailed)

Discussion

In this study, the macrobentic communities in the coastal waters of Nayband Bay, were investigated. The macrobentic communities were dominated by Polychaeta followed by Crustacea and Mollusca. Most of the sampled macrobenthos were very sensitive or indifferent to organic matter enrichment, which implied that the EcoQs in the study area were in good condition. According to the results of nMDS, the macrobentos communities in the study area can be divided into three groups, and they have significant differences in taxa compositions (PERMANOVA). The pearson correlation results showed that the macrobenthic communities were affected by environmental variables, mainly TOC, TOM, Temperature, sediment texture and depth, and that these variables were also supported by the results of previous studies (Dong, Sun, et al., 2021; Dong, Zhao, et al., 2021; Kosari et al., 2021; Maghsoudlou, Momtazi, & Hashtroudi, 2020). Considering the TOC content classification proposed by (Baniemam et al., 2017; Wang et al., 2014) sediment from all sampling stations in the Nayband Bay coastline showed low impact in stations 2, 3, 5, 7, 15, 16, 17 and medium impact in stations 1, 4, 8-14 and 18-20 with the highest %TOC value at station 20. The species richness and abundance of benthic macroinvertebrates were lowest in areas were concentrations of TOC and TOM were higher (e.g. stations 18, 19, 20), suggesting that excess of TOC and TOM are having an adverse effect on benthic organisms in the Nayband Bay. In the present study, opportunistic species namely *Capitella capitata*, *Cirratulus* *ciratus* and *Scolelepis* sp. (EGIV and V) were more abundance at stations with high TOC. Grall and Glemarec (1997) and Sivaraj et al. (2014) reported that these groups were capable of proliferating in reduced sediment and also tolerate in toxic conditions (Grall & Glémarec, 1997; Sivaraj et al., 2014) .These results were agreed with previous reports elsewhere (Muniz, Venturini, Pires-Vanin, Tommasi, & Borja, 2005).

Benthic invertebrates are frequently used as bioindicators of natural stress (Bustos-Baez & Frid, 2003; Dauer, Ranasinghe, & Weisberg, 2000; Sivaraj et al., 2014). Severeal indicies have been developed using macrobenthic communities to assess the health of the ecosystem from different types of disturbance (Á. Borja et al., 2004; Eaton, 2001; Grall & Glémarec, 1997). Among these, the AMBI, M-AMBI, BEnTIX and H´ indices have been used extensively in different habitats worldwide for assessing the ecological status of benthic communities (Dong, Zhao, et al., 2021; Li, Wang, & Li, 2013; Simonini et al., 2009; Sivaraj et al., 2014).

In the present investigation, AMBI, M-AMBI, BENTIX and H´ indices were applied to the Nayband Bay coastal waters subjected to ecosystem stress due to industrial effluents. According to AMBI, the ecological status of the Nayband Bay was in the condition of good (slightly disturbed) for all sampling stations, while based on M-AMBI, the status conditions were high (undisturbed) for most of sampling stations and good (slightly disturbed) for stations 12 and 17-20. The BENTIX values indicated that the EcoQs were high in all stations, while based on H´, the status condition were good (slightly disturbed) for stations 1-7 and 14-16, and moderate (moderately disturbed) for stations 9-13 and 17-20. Most of the sampled macrobenthic communities were sensitive or indifferent to organic matter enrichment which implied that the benthic EcoQs in this area were in good (slightly disturbed) condition.

Overall, the results of the present study show that Nayband Bay is currently considered a low-pollution/disturbed area due to the development of oil, gas and petrochemical industries. These disturbance pollution conditions are higher in the stations (19-20) near PSEEZ outfalls which can be attributed to the existance of industrial units, discharge of wastewater from these units to the coast, the transit of oil carriers and emitting gaseous and partculate contaminants as fallout from several fired flares. Our findings suggest that these four benthic indices (AMBI, M-AMBI, BENTIX and H´) can be used for the EcoQs determination of the coastal waters of the Persian Gulf. The joint use of these indices for the assessment of ecological status can yield a more accurate result.

Conclusions

The benthic ecological status of the Nayband Bay was assessed using the AMBI, M-AMBI, BENTIX and H´ indices in this study. The macroinvertebrate assemblages in the Nayband Bay coastal waters are dominated by polychaeta and Crustacea and are characterized by sensitive (EGI) and intolerant (EGI) species. In this study, the macoinvertebrate assemblages showed relatively strong signs of stress in stations close to PSEEZ and petrochemical industries, as indicated by the low abundance and species diversity. Accroding to Borja et al., model, the AMBI values were clearly indicated that the study area could be characterized as being slightly disturbed benthic ecosystem, however the results of M-AMBI revealed that the stations closed to discharged points of PSEEZ were classified as good (slightly disturbed) and other stations were high (undisturbed) in condition. According to BENTIX values, the EcoQs were high in all stations, while based on H´, the status condition were slightly disturbed for stations 1-7 and 14-16, and moderately disturbed for stations 9-13 and 17-20. This is the first case study to assess the industrial enffluent stress on an ecosystem using AMBI, M-AMBI, BENTIX and H´ indices in Nayband Bay. That as a result of this study similar assessment should be made of the Iranian coastal waters so the environmental status can be assessed.

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