Journal of Animal Diversity
Volume 4, Issue 4 (2022)
Online ISSN 2676-685X

Research Article

http://dx.doi.org/10.61186/JAD.4.4.91

Environmental factors and benthic macrofaunal distribution in the establishment of a baseline for coastal management in Chabahar Bay, Gulf of Oman, Iran

Hoda Khaledi

[1]Iranian National Institute for Oceanography and Atmospheric Science, Tehran, Iran
[*]Corresponding author: hodakhaledi@yahoo.com

Citation: Khaledi, H. (2022). Environmental factors and benthic macrofaunal distribution in the establishment of a baseline for coastal management in Chabahar Bay, Gulf of Oman, Iran. *Journal of Animal Diversity*, 4 (4): 91–99. http://dx.doi.org/10.61186/JAD.4.4.91

Received: 4 August 2022
Accepted: 10 September 2022
Published online: 31 December 2022

Abstract

Benthic macrofauna has a pivotal role in the energy flow and material cycles of marine ecosystems. Abiotic and biotic factors determine the presence and distribution of benthic macrofauna. The present study investigated possible relationships between benthic macrofauna and natural abiotic factors along the coastal region of the Gulf of Oman, including the north of Chabahar Bay, Konarak, and Tis. This was achieved through survey of the supra-littoral and intertidal zones at low tide, during the cold and warm seasons. In each zone, nine transects were sampled at random using quadrats. Then, sediment characteristics and macrofaunal abundance were determined. Mollusks and echinoderms had the highest and the lowest species richness, respectively. The average values for the Shannon–Wiener index of the transects at Tis, north of Chabahar Bay, and Konarak were 3.22, 3.28, and 3.20 in the warm season, respectively, while the index reached 3.29, 3.47, and 3.17 in the winter. Regardless of seasonality, the level of biodiversity was at a maximum in the northern part of Chabahar Bay, and Konarak showed the minimum biodiversity. The results of multi-linear regression analysis proposed that non-biological factors are suitable proxies for predicting the levels of species density in the study regions (R^2= 0.72, $F_{(6,71)}$ = 2.25, p< 0.05).

Key words: Anthropogenic changes, ecological diversity, invertebrates, macrobenthos, marine biodiversity

Introduction

Coastal areas are ecologically vulnerable zones because of extensive human activities and the high biodiversity they possess. Natural and human-induced stressors have imposed various sorts of destructive effects on such ecosystems worldwide (Da-Silva et al., 2002; Dias-Silva et al., 2010).

Sediments are important biotopes of the marine environment. They are dynamic systems in which the interchange and re-distribution of chemicals are steadily happening (Seyed Hashtroudi et al., 2022). On the other hand, sediment-dwelling organisms, and especially macrofauna, play significant roles in marine ecosystems, such as nutrient cycling, dispersion, the burial of sediments, and secondary production (Snelgrove, 1998).

Relationships between the macrobenthos and natural environmental factors can be used to characterize seabed habitats, and to establish baseline knowledge which enables the detection of their spatial and temporal variations (Bolam et al., 2008; Shumchenia and King, 2010). In general, abiotic factors determine the broad distributional patterns of benthic organisms, while abiotic and biotic factors operate together at a smaller scale (Ellingsen, 2002). Moreover, macrobenthic species are appropriate ecological indicators because most of them cannot migrate out of their habitat, and they exhibit different tolerances to environmental stress (Dauer, 1993).

Over the past few decades, anthropogenic pressures and diminishing biological diversity have increased interest in applied ecological research (Le Bris and Glémarec, 1996; Desroy et al., 2002; Ysebaert and Herman, 2002).

Applied ecological research provides information about local biodiversity and discerns damaged habitats that need protective measures and remediation efforts. In such studies, the identification of factors responsible for the spatial distribution of macrofaunal assemblages is of great importance, especially when distinguishing between natural and anthropogenic changes is a topic of interest (Ysebaert and Herman, 2002; Ellis et al., 2006; Bolam et al., 2008). In practice, it helps to manage habitats and resources much more effectively. For instance, the establishment of suitable marine protected areas can be well-scrutinized using ecosystem-based approaches (Desroy et al., 2002; Ysebaert and Herman, 2002; Fraschetti et al., 2011).

Chabahar Bay is an omega-shaped (Ω) body of shallow water (depth range= 4–22 m, mean depth = 12 m, surface area= 290 km^2) located on the northern coast of the Gulf of Oman, Iran (Seyed Hashtroudi et al., 2022) (Fig. 1). The climate of this subtropical bay is hot and humid, with harsh summers (~47 °C) and moderate winters (~20–28 °C) (Maghsoudlou et al., 2020). Periodic monsoons, originating from the Indian Ocean, generate variable amounts of precipitation (mean depth= 15 cm/year) and frequent storm surges in the Bay. In addition, there are coral communities on the bay, increasing the biodiversity levels of the area. According to the study of Maghsoudlou et al. (2020), the total macrobenthos abundance in Chabahar Bay is 7,873 ind/m^2 (mean abundance= 40.1 individuals/m^2). The species richness and the Shannon diversity indexes (H′ based on log$_2$) range from 5 to 22 taxa (mean= 11) and 1.44–3.95, respectively.

The objectives of this study were i) to determine the baseline information of the local biodiversity and ii) to rank the natural abiotic factors responsible for the soft-bottom microfaunal distribution along the coasts of Chabahar Bay. To achieve the objectives, various factors were analyzed and linked to the observed biodiversity of macrofauna in the region of interest.

Material and Methods

Sampling

This study was conducted during two well-defined seasons: a warm season between August and September (2016) and a cold season between December (2016) and February (2017). Using tidal tables presented by the Iran Hydrography website (http://www.iranhydrography.org), suitable times for sampling at Konarak, Tis, and the northern part of Chabahar Bay were selected. The location of sampling points included fishery and urban centers (Tis and Konarak), and mangal ecosystem and desalination plant (north of Chabahar Bay) (Fig. 1).

Three transect lines were selected and divided into distinct zones, i.e., supra-littoral, mid-littoral, low-littoral, and sub-littoral, with an average width of 10 m, 80 m, and 30 m, respectively. The divisions were performed to investigate possible horizontal zonation of detected macrobenthos in the region. At the sampling sites, three replicates of the sediments (~1 kg) were gathered at random using a quadrat (25 cm x 25 cm x 30 cm, penetration depth= 15 cm) and a clean shovel. The samples were stored in clean aluminum containers. The geographical coordinates of each transect (Fig. 1) were determined using a GPS-60CSX device (Garmin, USA). The samples were then put into an ice bag, and immediately transferred to the Biological Laboratory of the Iranian National Institute for Oceanography and Atmospheric Science (INIOAS).

During the laboratory work, macrobenthic fauna were isolated in several steps including sieving, staining, sorting, identification, and counting (Maghsoudlou et al., 2020). The macrofauna were separated from other materials and sediment using a 0.5 mm mesh size sieve. For improved separation, the specimens were stained with 0.5 g.L^{-1} Rose Bengal. The sorting was done under a Nikon SMZ1500 stereomicroscope. The sorted macrofauna were fixed in 70% ethanol until identification or for further use. The identification step was precisely performed with the aid of the appropriate guidelines presented by Barnes (1987), Eleftheriou and McIntyre (2005), and Fatemi and Attaran-Fariman (2015). Furthermore, six environmental variables were recorded during each sampling in both the cold and warm seasons, including salinity, temperature, turbidity, pH, electrical conductivity (EC), and organic matter (OM). To measure OM, the burning method was employed (Buchanan, 1984).

Sediment analysis

In this study, sediment particles were divided into four grain-size groups: 1. Coarse sand (> 500 µm), 2. Medium sand (500–250 µm), 3. Fine sand (250–125 µm), and 4. Mud (< 125 µm). The grain size of the sampled sediment was determined by a wet sieving method using 4 mm, 500 µm, 250 µm, 125 µm, and 63 µm sieves (Eleftheriou and McIntyre, 2005). First, 25 g oven-dried sediment of each sample (original weight) was weighed and transferred into a beaker containing 250 mL of water. Then, 10 mL of 6.2 g L^{-1} sodium hexametaphosphate $(NaPO3)_6$ was added to disperse the clay particles. The particles were broken up with a glass rod, and then stirred mechanically for 10–15 minutes. The mixture was allowed to soak overnight and stirred again for an additional 10–15 minutes. The dispersed sediment suspension was washed through the 63 µm sieve. The water was replaced at intervals and sieving and washing was continued on the sediments until no further fine particles were washed out. The sediments remaining on the 63 µm sieve were dried in the oven at 100 ºC.

The dried sediments were finally sieved through the mentioned sieve series using a mechanical shaker. The weight difference of every sieve was recorded before and after the sieving process (ΔW). In the end, the percentage of various grain sizes was calculated using the following equation. The results of mud were not used for grain size analysis according to the method (Buchanan, 1984).

$$\text{Grain size}_i\,(\%) = 100 \times \frac{\Delta W_i}{\text{original weight}}$$

Data processing and statistical analysis

The Shannon–Wiener index was used to determine biodiversity. The formula of this index is as follows:

$$H' = \sum_{i=1}^{n} \left[\frac{(ni)}{N} \times \mathrm{Ln}\left(\frac{ni}{N}\right)\right]$$

where n_i is the number of individuals in species i and N is the total number of individuals recorded (Jorgensen et al., 2005).

Descriptive statistics and the normality status of the dataset were investigated using SPSS STATISTICS 11.5 package (SPSS Inc., USA). Since the calculated Shannon–Wiener indices were normally distributed (Shapiro–Wilk test, $p > 0.05$), possible differences among the stations in various seasons were examined with a two-way analysis of variance. This examined the hypothesis whether the means of biodiversity in the two seasons are equal or not in the stations of interest. In addition, multi-linear regression analysis was performed using a forward stepwise method. It was run to quantify the possibly significant correlations between abiotic factors (predictor variables), and benthos biodiversity (response variable). In all statistical analyses, significant differences were considered within a 95 percent confidence interval ($\alpha < 0.05$).

Results

During all sampling seasons, a total of 105 specimens of macrobenthic species were collected and identified in the studied stations. Macrobenthic specimens were related to four higher-level taxa (phylum or class), including Mollusca, Arthropoda, Polychaeta, and Echinodermata. Mollusca (gastropods and bivalves) and Echinodermata had the highest and lowest species richness, respectively (Figs. 2–4).

The results of the two-way ANOVA revealed that there was a significant difference between the Tis and Konarak transects in the case of water temperature in the cold and warm seasons ($p = 0.03$, df= 8). Such a significant difference was not detected for salinity ($p = 0.1$, df= 8), pH levels ($p = 0.1$, df= 8), and electrical conductivity ($p = 0.1$, df= 8). On the other hand, organic matter ($p = 0.03$, df= 8), and water turbidity ($p = 0.02$, df= 8) showed significant differences in the regions of study.

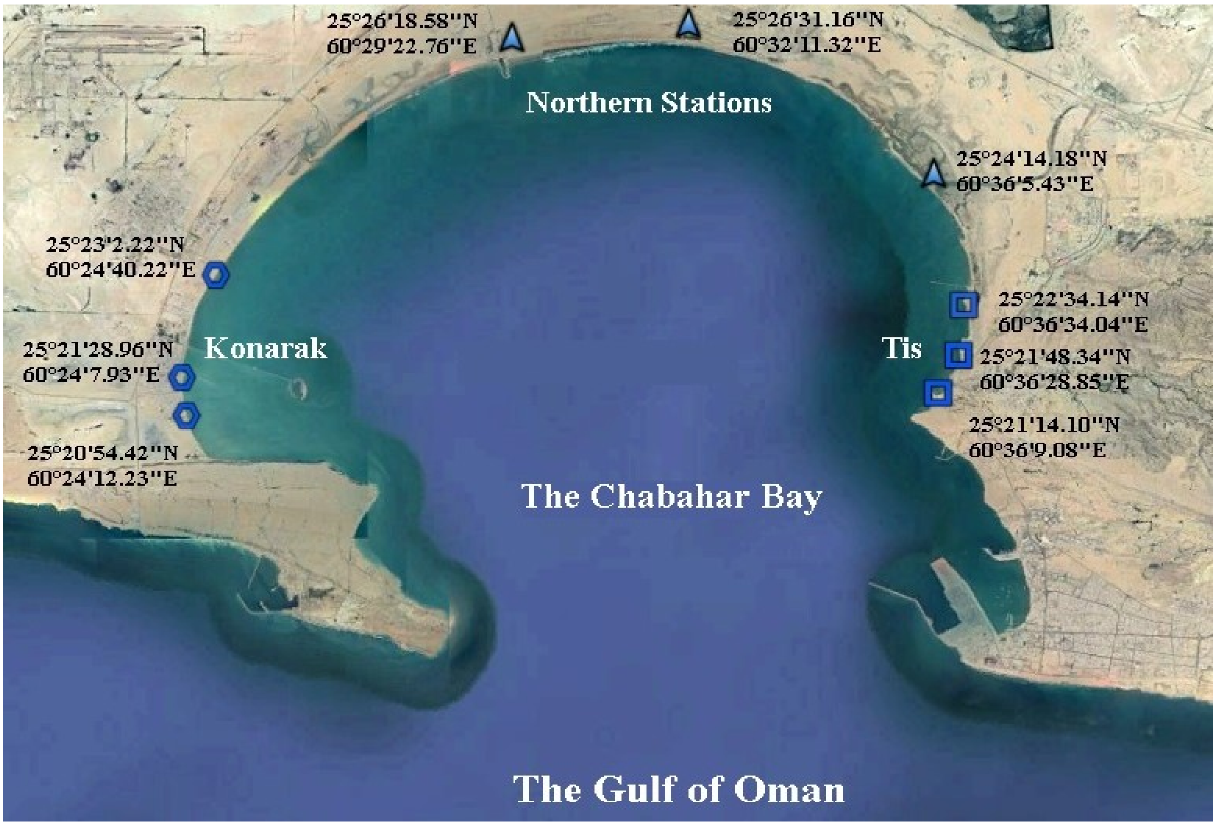

Figure 1: Spatial coordinates and map of the monitored sectors at Chabahar Bay, Gulf of Oman, Iran. (Source of Map: Google Earth).

[DOR: 20.1001.1.2676685.2022.4.4.8.4]
[DOI: 10.61186/JAD.4.4.91]

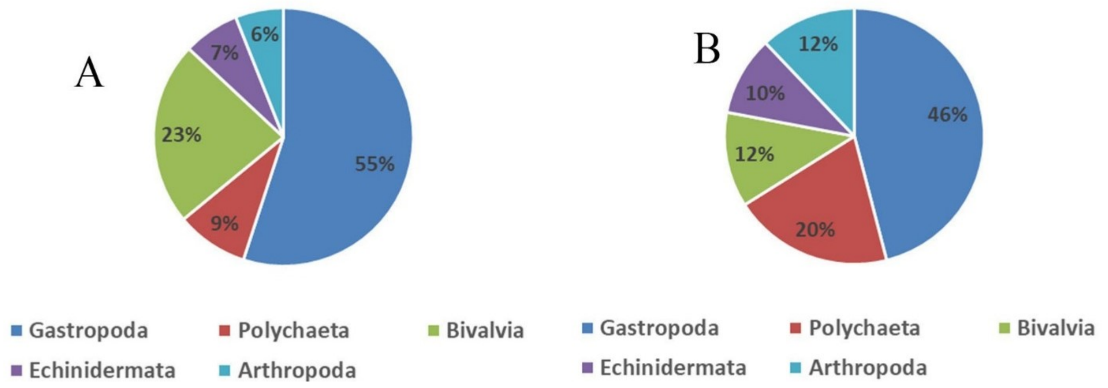

Figure 2: Percentage of frequency of taxa in samples taken at Tis, Gulf of Oman in warm (A) and cold (B) seasons.

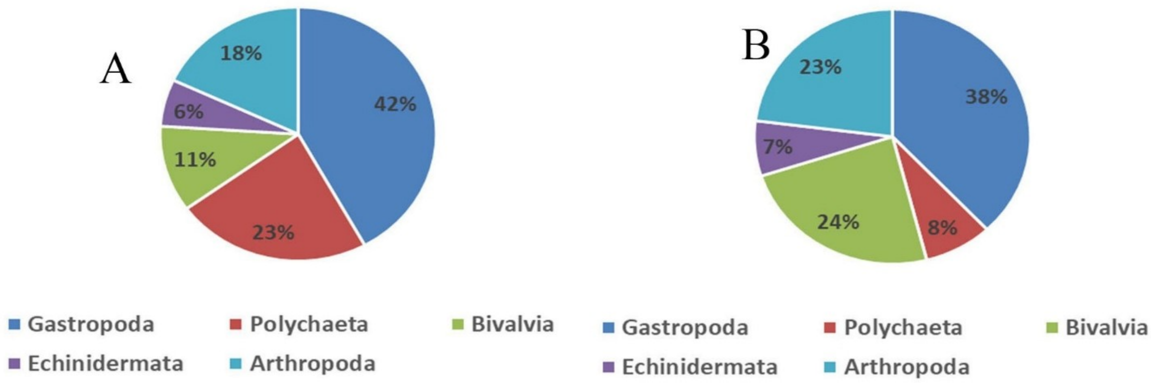

Figure 3: Percentage of frequency of taxa in samples taken at northern Chabahar Bay, Gulf of Oman in warm (A) and cold (B) seasons.

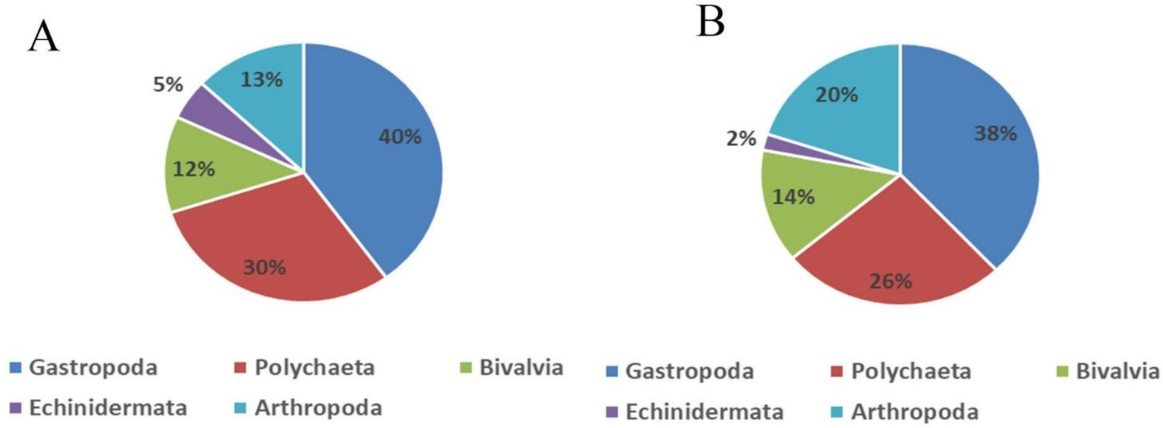

Figure 4: Percentage of frequency of taxa samples taken at Konarak, Gulf of Oman in warm (A) and cold (B) seasons.

The results of multiple regression analysis showed that there was a positive and significant relationship between species density and non-biological factors including, temperature, sedimentary organic matter, and water turbidity (R^2= 0.72, $F_{(6,71)}$= 2.25, p< 0.05) (Table 1).

The average Shannon–Wiener indices for the transects of Tis, north of Chabahar Bay, and Konarak in the warm season were 3.22, 3.28, and 3.20, respectively, while the indices reached 3.29, 3.47, and 3.17 in the winter. In both seasons, the species richness in northern Chabahar Bay showed the

[DOR: 20.1001.1.2676685.2022.4.4.8.4]
[DOI: 10.61186/JAD.4.4.91]

highest level. Conversely, the species richness was at the minimum in the Konarak region (Fig. 5).

The results of the sediment analysis are shown in Tables 2 and 3. Generally, the amount of medium and coarse sand in all stations was less than the fine sand. In almost all stations, the amount of these components was not constant among different stations. According to the following tables, the substrate type at Tis, north of Chabahar Bay, and Konarak was dominated by rock and boulders, boulders and rubble, and medium-sized sediments, respectively.

Discussion

Coastal areas are valuable habitats due to the availability of resources that highly support biodiversity. These habitats also play an important role in the production and cultivation of seafood for human consumption and other commercial activities (Naylor et al., 2000; Hejazy et al., 2023). However, due to the increasing development of economic activities, agriculture, and the entry of sewage and waste, the quality of these habitats has been diminished and their role in feeding and maintaining important fisheries species has reduced (Salm et al., 2000; Christie et al., 2000; Gallacher et al., 2016).

The design and implementation of effective management of marine protected areas such as coastal areas require ecological information (Beger et al., 2007; Perschke et al., 2023). In this study, the biodiversity sub-criterion was measured for the shores of Chabahar Bay based on the results of the Shannon–Wiener index, which expresses the difference in biodiversity for the protection of benthos habitat (Moland et al., 2013; Varnes and Olsen, 2023; Naz et al., 2016). The Shannon–Wiener index results reiterated that there is a considerable difference between biodiversity levels calculated for the warm and cold seasons in the northern Chabahar Bay and Tis transects. Such a difference, however, was not observed in the case of the Konarak transect. Moreover, the biodiversity of the Konarak transect was at the minimum in comparison. It is worth noting that the proportion of fine-grained sediments was relatively higher in this transect (Tables 2, and 3). In contrast, the dissolved oxygen levels were low in this transect. The decrease in the amount of oxygen (Wishner et al., 1990) and a significant presence of finer particles (Jegadeesan and Ayyakkannu, 1992) can possibly affect the biodiversity levels detected here. Moreover, high pollution, resulting from the wastes of barge-building activities, is evident in the Konarak region. The low diversity of Konarak benthos compared to the other transects may also be due to the presence of more fish in the sub-tidal and low-tidal areas (Clark et al., 2016; Martinetto et al., 2016). The nutritional role of fish for benthic organisms is effective in different living masses in ecosystems (Barnes, 1987). Consequently, grazing and predation can affect the macrofaunal biodiversity observed (Nikouyan and Savari, 1999).

Associations between macrobenthos and sediments have often been mentioned in terms of the range of granulometric variations tolerated by each species (Ellingsen, 2002). Based on the lifestyle, the benthos requires specific sediment characteristics for tube building, burrowing, or feeding (Dutertreet al., 2012). For example, a polychaete such as *Capitella capitata* (Fabricius) often needs a large quantity of fine particles to build its tube and to grow. Fine particles, easily re-suspended by water movements, are known to affect the feeding processes of benthic species as well (Wildish, 1977; Snelgrove, 1998). Moreover, in nearshore ecosystems, organic content tends to increase with the fineness of the particles (Gray and Elliot, 2009), thereby enhancing the food supply for many benthic species. On the other hand, the rocky substratum is the habitat of preference in the case of *Rhyssoplax peregrina* (Thiele), which needs hard surfaces to attach.

According to Li et al. (2010), the population dependence of macrobenthos is related to the size of sediment particles. There is a higher macrobenthos diversity in rock and sandy substrates than in fine-grained substrates; this may suggest that rock and sandy substrates can be more stable than fine-grained substrates. In addition, the presence of gaps and porosities (micro-habitats) helps to avoid threatening factors (Safahieh al., 2012). In the present study, we found that rocks and boulders constituted the most parts of the bed material in the Tis transect, which could provide suitable living conditions for benthos and aquatic animals. Despite having some fine-grained sediments, the north of Chabahar Bay was majorly composed of boulders and rubble, which could permit a high diversity of benthos to survive. In the Konarak transect, medium-size sediments were predominant. The presence of bedrock habitat type was also observable. This combination possibly causes compaction of the bed texture and reduces the space between the bed elements. Mclusky (1989) claimed that in fine-grained substrates, compaction between sediment particles reduces the penetration of oxygen into the substrate and leads to reduced diversity. Hence, the diminished diversity of benthos can be due or to some extent related to this kind of substratum.

The dependence of benthos to a substratum was also reported by Wildish (1977) and Snelgrove (1998). In this study, however, the substratum of the sampling points was relatively uniform, which removes their potential role in the observed overall biodiversity of macrofauna. This result should be interpreted with a consideration that the studied stations are all located on beaches of Chabahar Bay, in which seasonal monsoons are strong enough to mix the sediments throughout the year (Seyed Hashtroudi et al., 2022). This phenomenon creates a relatively uniform substratum in the region where fine sediments are at the minimum (Tables 2 and 3). On the other hand, the other abiotic factors, such as temperature, turbidity, and organic matter may have also showed significant effects on the distribution of benthos studied.

[DOR: 20.1001.1.2676685.2022.4.4.8.4]

[DOI: 10.61186/JAD.4.4.91]

Many aspects of the environmental variations in Chabahar Bay are related to the seasonal monsoon system (Seyed Hashtroudi et al., 2022). Turbidity, for example, increases in monsoon periods. The presence of sediment grains in the water column can disturb the oxygen uptake or feeding behavior of macrofauna and increases death rate of sensitive species. The high levels of organic matter (> 3%) have been attributed to impaired benthic fauna (Aghadadashi et al., 2022), while moderate levels of organic materials are of benefit for the benthos. Therefore, the level of organic materials can be a predictive factor of biodiversity.

Table 1: Multiple regression analysis between species density and non-biological factors at three stations in the Gulf of Oman, Iran.

Model	Sum of squares	df	Mean square	F	Sig.
Regression	615.987	6	102.660	2.25	0.030
Residual	7306.034	71	102.902		
Total	7924.996	71			

Table 2: Results of grain size analysis in the studied transects for the warm season in the Gulf of Oman, Iran.

Transect	Grain size	Mid-littoral	Low-littoral	Sublittoral	Supra-littoral
Tis	coarse	4.4	0	7.1	57.7
	medium	11.8	0	12.5	34.2
	fine	2.8	0	79.40	9.1
North of Chabahar Bay	coarse	6.2	1.1	0.78	30.4
	medium	31.7	24.8	11.6	10.6
	fine	5.1	3.1	88.4	2.3
Konarak	coarse	1.1	0	1	52.5
	medium	22.6	0	7.3	35.1
	fine	0	0	91.7	8.6

Table 3: Results of grain size analysis in the studied transects for the cold season in the Gulf of Oman, Iran.

Transect	Grain size	Mid-littoral	Low-littoral	Sublittoral	Supra-littoral
Tis	coarse	0	0	2.6	51.5
	medium	1.3	0	14.1	38.9
	fine	17.4	0	83.3	10.6
North of Chabahar Bay	coarse	1.4	0.68	2.1	8.4
	medium	2.3	28.5	8.8	81.7
	fine	41.8	1.5	89.1	9.9
Konarak	coarse	1.5	0	0.79	5.9
	medium	31.6	0	7.1	87.3
	fine	2.2	0	91.9	6.8

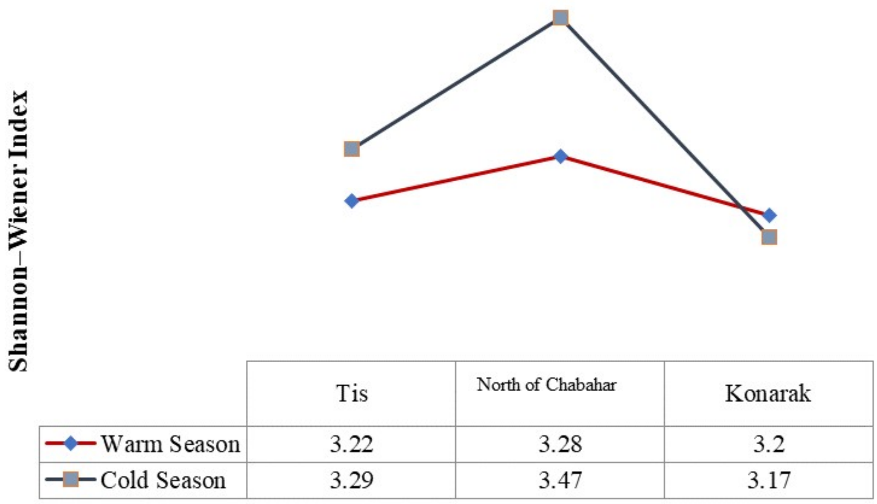

Figure 5: Shannon–Wiener index for the Tis, north of Chabahar Bay, and Konarak stations, Gulf of Oman, Iran.

Conclusions

The present study integrated local ecological surveys in order to identify and rank soft-bottom macrofaunal richness along the intertidal zones of Chabahar Bay. Use of the Shannon–Wiener index made it clear that the biodiversity levels are different between the studied seasons in two of three transects. A significant relationship between species density was also detected. While this study revealed a significant relationship between species diversity and non-biological factors (organic matter, turbidity, and temperature), the assessment methods were also proven to be useful predictors of an environment. The use of sediment analysis to determine species diversity using the Shannon–Wiener index could be considered for use in the establishment of a baseline for coastal management in general.

Acknowledgements

The author is grateful to the anonymous reviewers for reviewing various versions of this manuscript and providing insightful suggestions and corrections.

Conflict of Interest

The author declares that there are no conflicting issues related to this research article.

References

Aghadadashi, V., Molaei, S., Mehdinia, A. and Rezaei Marnani, H. (2022). Sediment characteristics and estimation of toxicity site specific criteria for sediments of Iranian Coasts, the Persian Gulf. *Advances in Oceanography and Marine Biology*, 3 (2): 2022.

Jegadeesan, P., and Ayyakkannu, K. (1992). Seasonal variation of benthic fauna in marine zone of Coleroon estuary and inshore waters, south east coast of India.

Barnes, R. D. (1987). *Invertebrate Zoology*. Sauders College Publishing. 467 pp.

Beger, M., McKenna, S. A. and Possingham, H. P. (2007). Effectiveness of surrogate taxa in the design of coral reef reserve systems in the Indo-Pacific. *Conservation Biology*, 21 (6): 1584–1593. https://doi.org/10.1111/j.1523-1739.2007.00795.x

Bolam, S. G., Eggleton, J., Smith, R., Mason, C., Vanstaen, K. and Rees, H. L. (2008). Spatial distribution of macrofaunal assemblages along the English Channel. *Journal of the Marine Biological Association of the United Kingdom*, 88: 675–687. https://doi.org/10.1017/S0025315408001276

Buchanan, J. B. (1984). Sediment analysis, *In*: Eleftheriou, A. and McIntyre, A. (Eds.), *Methods for the study of marine benthos*. Oxford Blackwell Scientific Publications. pp: 41–65.

Christie, P. (2004). Marine protected areas as biological successes and social failures in Southeast Asia. *American fisheries society symposium*, 42: 155–164.

Clark, M. R., Althaus, F., Schlacher, T. A., Williams, A., Bowden, D. A., and Rowden, A. A. (2016). The impacts of deep-sea fisheries on benthic communities: a review. *ICES Journal of Marine Science*, 73 (1): i51–i69. https://doi.org/10.1093/icesjms/fsv123

Da-Silva, E. R., Salles, F. F., and Baptista, M. D. S. (2002). As brânquias dos gêneros de Leptophlebiidae (Insecta: Ephemeroptera) ocorrentes no Estado do Rio de Janeiro. *Biota Neotropica*, 2: 1–4. https://doi.org/10.1590/S1676-06032002000200014

Dauer, D. M. (1993). Biological criteria, environmental health and estuarine macrobenthic community structure. *Marine Pollution Bulletin*, 26: 249–257. https://doi.org/10.1016/0025-326X(93)90063-P

Desroy, N., Warembourg, C., Dewarumez, J.-M. and Dauvin, J.-C. (2002). Macrobenthic resources of the shallow soft-bottom sediments in the eastern English Channel and southern North Sea. *ICES Journal of Marine Science*, 60: 120–131. https://doi.org/10.1006/jmsc.2002.1333

Dias-Silva, K., Cabette, H. S., and Juen, L. (2010). The influence of habitat integrity and physical-chemical water variables on the structure of aquatic and semi-aquatic Heteroptera. *Zoologia (Curitiba)*, 27: 918–930. https://doi.org/10.1590/S1984-46702010000600013

Dutertre, M., Hamon, D., Chevalier C. and Ehrhold, A. (2012). The use of the relationships between environmental factors and benthic macrofaunal distribution in the establishment of a baseline for coastal management. *ICES Journal of Marine Science*, 70 (2): 294–308. https://doi.org/10.1093/icesjms/fss170

Eleftheriou, A. and McIntyre, A. (2005). *Methods for the study of marine benthos*. Third Edition. Oxford Blackwell Scientific Publication. 418 pp. https://doi.org/10.1002/9780470995129

Ellingsen, K. E. (2002). Soft-sediment benthic biodiversity on the continental shelf in relation to environmental variability. *Marine Ecology Progress Series*, 232: 15–27. https://doi.org/10.3354/meps232015

Ellis, J., Ysebaert, T., Hume, T., Norkko, A., Bult, T., Herman, P., Thrush, S. and Oldman, J. (2006). Predicting macrofaunal species distributions in estuarine gradients using logistic regression and classification systems. *Marine Ecology Progress Series*, 316: 69–83. https://doi.org/10.3354/meps316069

Fatemi, Y. and Attaran-Fariman, G. (2015). Checklist of the opisthobranchs (Heterobranchia: Gastropoda) along the Iranian Coasts of the Gulf of Oman. *Journal of Biodiversity and Environmental Sciences*, 6 (3): 1–7.

Fraschetti, S., Claudet, J. and Grorud-Colvert, K. (2011). Management—transitioning from single-sector management to ecosystem-based management: what can marine protected areas offer? *In*: Claudet, J. (Ed.), *Marine Protected Areas*: *A Multidisciplinary Approach*. Cambridge University Press - Ecology, Biodiversity and Conservation Series, Cambridge, UK. pp. 11–34. https://doi.org/10.1017/CBO9781139049382.003

Gallacher, J., Simmonds, N., Fellowes, H., Brown, N., Gill, N., Clark, W., Biggs, C., and Rodwell, L. D. (2016). Evaluating the success of a marine protected area: A systematic review approach. *Journal of Environmental Management*, 183: 280–293. https://doi.org/10.1016/j.jenvman.2016.08.029

Gray, J. S. and Elliott, M. (2009). *Ecology of marine sediments: From science to management*. Second Edition. Oxford University Press, UK. 256 pp. https://doi.org/10.1093/oso/9780198569015.001.0001

Hejazy, M., Norouzi, R., Abdi, F., and Javid, F. (2023). The impact of aquaculture activities on nitrogenous and phosphorous pollution of water resources in northern Iran. *Arabian Journal of Geosciences*, 16 (4): 255. https://doi.org/10.1007/s12517-023-11347-8

Jorgensen, M., Davis, K., Kotowski, S., Aedla, P. and Dunning, K. (2005). Characteristics of Job Rotation in the Midwest US Manufacturing Sector. *Ergonomics*, 48: 1721–1733. https://doi.org/10.1080/00140130500247545

Le Bris, H. and Glémarec, M. (1996). Marine and brackish ecosystems of south Brittany (Lorient and Vilaine Bays) with particular reference to the effect of the turbidity maxima. Estuarine, *Coastal and Shelf Science*, 42: 737–753. https://doi.org/10.1006/ecss.1996.0047

Li, B., Li, X., Wang, H., Wang, J., Han, Q., Dong, C., Ma, L. and Zhang, B. (2010). The relationship between soft-bottom macrobenthic communities and environmental variables off Ningjin, eastern Shandong Peninsula. *Acta Oceanologica Sinica*, 29 (6): 73–82. https://doi.org/10.1007/s13131-010-0078-z

Maghsoudlou, A., Momtazi, F. and Seyed Hashtroudi, M. (2020). Ecological quality status (EcoQs) of Chabahar sub-tropical Bay based on multimetric macrobenthos-indexes approach: Response of bio-indexes to sediment structural/pollutant variables. *Regional Studies in Marine Science*, 40: 101524. https://doi.org/10.1016/j.rsma.2020.101524

Martinetto, P., Iribarne, O., and Palomo, G. (2005). Effect of fish predation on intertidal benthic fauna is modified by crab bioturbation. *Journal of experimental marine biology and ecology*, 318 (1): 71–84. https://doi.org/10.1016/j.jembe.2004.12.009

McLusky, D. S. (1989). The estuarine environment, *In*: *The estuarine ecosystem*. Springer, Dordrecht, Germany. pp. 1–48. https://doi.org/10.1007/978-94-011-7616-3_1

Moland, E., Olsen, E. M., Knutsen, H., Garrigou, P., Espeland, S. H., Kleiven, A. R., André, C. and Knutsen, J. A. (2013). Lobster and cod benefit from small-scale northern marine protected areas: inference from an empirical before–after control-impact study. *Proceedings of the Royal Society B: Biological Sciences*, 280 (1754): 20122679. https://doi.org/10.1098/rspb.2012.2679

Naylor, R. L., Goldburg, R. J., Primavera, J. H., Kautsky, N., Beveridge, M. C., Clay, J., Folke, C., Lubchenco, J., Mooney, H. and Troell, M. (2000). Effect of aquaculture on world fish supplies. *Nature*, 405 (6790): 1017–1024. https://doi.org/10.1038/35016500

Naz, R. A., Thivakaran, G. A., George, J., Devi, V., Nithun, L., and Suriyanarayanan, S. (2016). Comparative studies on the intertidal marine biodiversity of Macro benthos of Kachchh coastal region, Gujarat, India. *Bulletin of Environmental and Scientific Research*, 5 (3–4): 11–15.

Nikouyan, A. and Savari, A. (1999). Distribution and biomass of macrobenthic fauna in the Chabahar Bay. *Iranian Journal of Fisheries Sciences*, 1 (2): 23–39.

Perschke, M. J., Harris, L. R., Sink, K. J., and Lombard, A. T. (2023). Ecological Infrastructure as a framework for mapping ecosystem services for place-based conservation and management. *Journal for Nature Conservation*, 126389. https://doi.org/10.1016/j.jnc.2023.126389

Safahieh, A., Nabavi, M. B., Vazirizadeh, A., Ronagh, M. T. and Kamalifar, R. (2012). Horizontal zonation in macrofauna community of Bardestan mangrove Creek, Persian Gulf. *World Journal of Fish and Marine Sciences*, 4 (2): 142–149.

Salm, R. V., Clark, J. R. and Siirila, E. (2000). *Marine and Coastal Protected Areas: A guide for planners and managers*. Third Edition. IUCN, Gland, Switzerland and Cambridge, UK. 369 pp. https://doi.org/10.2305/IUCN.CH.2000.13.en

Seyed Hashtroudi, M., Aghadadashi, V., Mehdinia, A. and Fumani, N. S. (2022). Combining theoretical concepts and Geographic Information System (GIS) to highlight source, risk, and hotspots of sedimentary PAHs: A case study of Chabahar Bay. *Environmental Research*, 216 (Part 1): 114540. https://doi.org/10.1016/j.envres.2022.114540

Shumchenia, E. J. and King, J. W. (2010). Comparison of methods for integrating biological and physical data for marine habitat mapping and classification. *Continental Shelf Research*, 30: 1717–1729. https://doi.org/10.1016/j.csr.2010.07.007

Snelgrove, P. V. R. (1998). The biodiversity of macrofaunal organisms in marine sediments. *Biodiversity and Conservation*, 7: 1123–1132. https://doi.org/10.1023/A:1008867313340

Varnes, B. K., and Olsen, E. M. (2023). Fish community dynamics in a coastal no-take marine protected area compared to a harvested area before and after protection from fishing. *ICES Journal of Marine Science*, fsad074. https://doi.org/10.1093/icesjms/fsad074

Wildish, D. J. (1977). Factors controlling marine and estuarine sublittoral macrofauna. *Helgoländer Wissenschaftliche Meeresuntersuchungen*, 30 (1): 445–454. https://doi.org/10.1007/BF02207853

Wishner, K., Levin, L., Gowing, M., and Mullineaux, L. (1990). Involvement of the oxygen minimum in benthic zonation on a deep seamount. *Nature*, 346 (6279): 57–59. https://doi.org/10.1038/346057a0

Ysebaert, T. and Herman, P. M. J. (2002). Spatial and temporal variation in benthic macrofauna and relationships with environmental variables in an estuarine, intertidal soft-sediment environment. *Marine Ecology Progress Series*, 244: 105–124. https://doi.org/10.3354/meps244105