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Applying Benthic Index of Biotic Integrity in a Soft Bottom Ecosystem in North of the Persian Gulf

[1]B. Doustshenas, [1]A. Savari, [1]S.M.B. Nabavi, [2]P. Kochanian and [3]M. Sadrinasab
[1]Department of Marine Biology, Faculty of Marine Science,
[2]Department of Fisheries, Faculty of Natural Resources,
[3]Department of Physical Oceanography, Faculty of Marine Science,
Khoramshahr University of Marine Science and Technology,
P.O. Box 669, Khoramshahr, Khuzestan, Iran

Abstract: In this study, the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) was selected in an attempt to describe ecological health of soft bottom channels (Khowr-e Musa) in North of the Persian Gulf. Most of study area was found to be in degraded or severely degraded conditions. B-IBI scores were ranged between 1 and 3.86. Comparison of macrobenthos abundance and organic content between two developmental periods showed significant difference ($p<0.05$). After the establishment and development of petrochemical industries, the abundance of macrofauna decreased (809 to 239 individuals m^{-2}) and organic content increased leading to organic enrichment (15.3 to 22.4%). Three new sources of organic matter were found to be important namely industrial waste, sewage and mangrove litter. After 1999 about 6 millions *Avicennia marina* tree were planted near petrochemical zone in the area. Study area changed rapidly in the last decade and region is under severely anthropogenic impacts. The present study showed that Khowr-e Musa is under both natural stress and anthropogenic impacts and two main impacts could be attributed to the organic enrichment and to the dredging. Choice of suitable management plans and metric controls could help to the salvage of the largest tidal channel complex in Persian Gulf.

Key words: Integrity, ecological health, Persian Gulf, organic enrichment, macrofauna

INTRODUCTION

The waters of the Persian Gulf are environmentally unique with an unusual faunal assemblage (Carpenter *et al*., 1997). The Persian Gulf is a semi-closed water body connected to the Oman Sea through narrow Strait of Hormuz. The maximum width is 640 km with the average depth of 35 m (Reynolds, 1993).

Though, there are many indices for ecological health assessment, their application is limited as they have been developed for specific conditions. Most of these indices have been introduced in temperate regions by developed countries. So selecting a suitable index with high accuracy for tropical and subtropical region isn't simple (especially with less documents and historical studies in developing countries). An ecologically parsimonious approach dictates that investigators should place greater emphasis on evaluating the suitability of indices that already exist prior to developing new ones (Diaz *et al*., 2004). So the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) was selected in an attempt to describe ecological health of soft bottom channels (Khowr-e Musa) in North of the Persian Gulf. Indices such as index of biotic integrity and the Chesapeake Bay B-IBI included physiochemical factors, diversity measures, species richness, taxonomic composition and the tropic structure of the system (Jorgensen *et al*., 2005). It has been used before by several researchers (Ranasinghe *et al*., 1994; Weisberg *et al*., 1997; Van Dolah *et al*., 1999; Llansó *et al*., 2002a, b). The Chesapeake Bay B-IBI was found to be sensitive, stable, robust and statistically sound (Alden *et al*., 2002) when applied to sub-tidal unvegetated soft substrates (Llansó, 2002).

The study area, Khowr-e Musa has soft substratum, turbid water and low light penetration limiting the growth of benthic algae. This area is an important developing petrochemical industry zone in Iran. Before 1999, there were only three petrochemical plants whereas now have been established eight more large plants and many smaller in the area. In addition to this, an important pollution

Corresponding Author: Babak Doustshenas, Department of Marine Biology, College of Marine Science, Khoramshahr University of Marine Science and Technology, P.O. Box 669, Khoramshahr, Khuzestan, Iran

resource, the second largest port of Iran (Imam Khomeini Port), is situated in the North of Khowr-e Musa. Considering the possible pollution problem in the area, it was important to establish suitable indicators or to apply an existing set of indices to study the present status of the ecosystem.

MATERIALS AND METHODS

Khowr-e Musa is a complex of tidal channels in the North West part of the Persian Gulf with high temperature (exceeds 30°C in summer) and high salinity usually more than 40 psu (Fig. 1). The B-IBI for use in Khowr-e Musa has been calibrated with before 1999 (before development of the petrochemical industry) data of a 5 year study prepared by Department of Environment and a few dissertations in the region were used. The European and US directives recognize four approaches to developing biocriteria, comparison to historical conditions, comparison to present reference conditions, models and consensus professional judgment (Weisberg *et al*., 2008). Based on methods for calculating the Chesapeake Bay Benthic Index of Biotic Integrity prepared by Llansó (2002) historical data of metrics were explored and their thresholds extract by percentiles. B-IBI defines expected conditions at reference sites relatively free of anthropogenic stress and then assigns categorical values for various descriptive metrics by comparison with observations at these reference sites. The B-IBI is based upon subtidal, unvegetated, infaunal macrobenthic communities (Dauer *et al*., 2000).

Triplicate samples were collected from 18 stations using van Veen grab (0.027 m^2) from less than 35 m depth in a seasonal basis (4 times in middle of seasons). Substrates were divided in to 2 parts, the upper 5 cm of substrate and remain substrate both were sieved through a 0.5 mm mesh screen. Materials retained on the screen were transferred to 1 L labeled plastic jars and preserved in 70% alcohol and Rose Bengal stain (Holme and McIntyre, 1984; Llansó, 2002).

In the laboratory, samples were washed in fresh water and the organisms separated from detritus and sorted into major taxa. After identification of organisms to species level they were counted and prepared for the further analysis. Infaunal individuals were used for the measurement of metrics only. Ash free dry weight biomass was calculated by or each species was calculated by drying the organisms to a constant weight at 60°C followed by burning in muffle furnace at 500°C (Llansó, 2002). Species diversity was calculated with Shannon-Wiener species diversity index. The organic matter content was estimated from dried sediments as loss on ignition (Buchanan, 1984). Grain size was determined by wet sieving (Buchanan, 1984). Sorting degree of sediments was calculated with Folk and Ward equilibriums (Folk, 1974). Data of present study and before development of the area were comprised by t-test. Principal Component Analysis (PCA) was used to determine possibly correlated variables. Results visualized with Microsoft Office Excel 2003 and Primer 5.0.

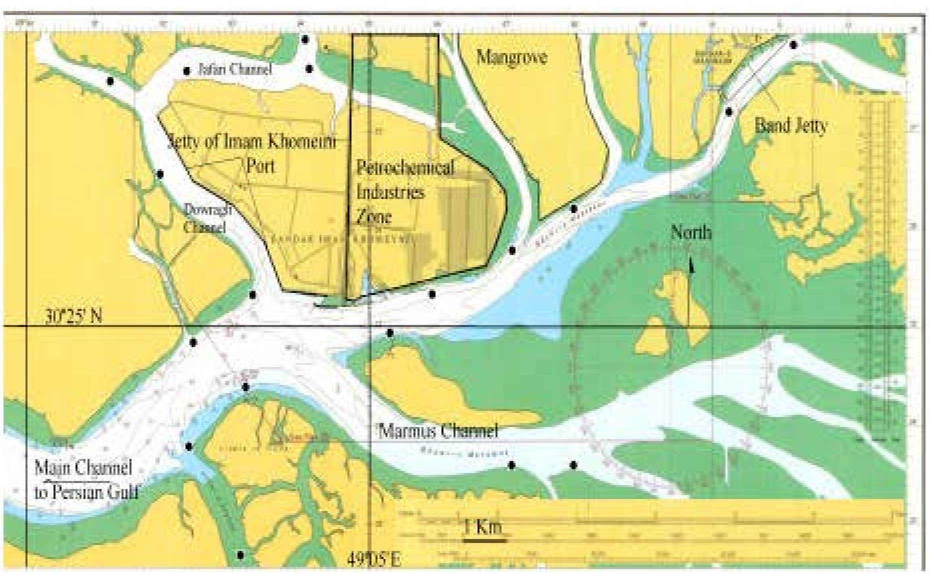

Fig. 1: Map of Khowr-e Musa including its channels showing the sampling stations in the Western coasts of Persian Gulf

RESULTS

The results showed that Khowr-e Musa were in a relative well oxygenated condition, low alkalinity, relative high variable temperature and with salinity a little higher than euhaline condition. At most stations silt and clay was higher than 80% and total organic matter more than 20% dry weight (Table 1). Dissolved oxygen was measured between 3.4 to 8.6 mg L^{-1} hence, it sometimes decreased to near critical limits (2 mg L^{-1}). Temperature varied widely and reached more than 30°C.

Total organic matter showed organically enriched conditions. The fact that the mud portion of substrate was high, could be suggest that this could bind more organic matter. Most granule sized substrate was made of broken shells. List of species in this study area is shown in Table 2. Many of species in the study area were respected to colonizing and organic enrichment indicative taxa (etc., Amphipods, Hydrozoans, Bryozoans and *Capitella capitatta*).

The three main metrics of PGB-IBI are Shannon diversity index (bits/individual), total species abundance (taxa that indicate benthic community condition) and total species biomass. We found that all the above indices were low before 1999 (Table 3). The data showed shanon index, total species abundance and total species biomass in 90% of were less than 2.1, 560 N m^{-2} and 1.8 g m^{-2}, respectively that are less than most unpolluted temperate coastal habitats. Based on these data criteria for PGB-BI metrics were calculated for the 18 stations (Fig. 2). Five stations achieved high scores and one showed marginal status. Twelve stations with low scores had degraded or severely degraded status which 9 of them were situated in main channels near industries and ports.

Table 1: Summary of chemical and physical factors for the 18 stations in Khowr-e Musa

Factors	Mean	Min	Max
Station depth (m)	13.2	2.5	35.0
Near bottom DO (mg L^{-1})	6.2	3.4	8.6
Surface DO (mg L^{-1})	6.8	4.1	9.8
Near bottom temperature (°C)	23.7	13.3	30.1
Surface temperature (°C)	24.0	13.3	30.3
Near bottom salinity (PSU)	41.6	38.3	43.9
Surface salinity (PSU)	41.5	37.5	43.8
TOM (%)	22.4	7.0	27.2
Silt and clay (%)	80.5	11.2	96.5
Near bottom pH	7.8	7.0	8.2
Surface pH	7.8	6.8	8.2

Dredging vessels dredges these channels every year. Total organic matter showed an increasing trend from 1999 onwards (before rapid development of the area) and macro invertebrate abundance decreased (Table 4).

A degrading status was observed in channels, especially near the Northern side where large jetties and petrochemical plants are situated. Taking information from nine variables (abundance N m^{-2}, biomass g m^{-2}, near bottom dissolved oxygen mg L^{-1}, water speed near bottom m sec^{-1}, mud %, granule %, sediment sorting, organic matter % and PGB-IBI score) into a PCA, PC1 accounted for 41.7% of variability in the data set and the first two components account for 73.4%. PC1 represents an axis of increasing shell particle content and sorting degree ($r = 0.43$ and $r = 0.45$, respectively), in contrast % mud and % organic matter which were negative ($r = -0.48$, $r = -0.48$). In the second axis, abundance ($r = 0.52$), biomass ($r = 0.52$) and PGB-IBI ($r = 0.51$) showed positive coefficients indicating an increase from stations near disturbance sources to none disturbed places (Fig. 3). Station 7 separated from other station due to its low contents of organic matter and fine fraction sediments (16.2 and 12.3%, respectively).

Still, 26.6% of the variability in the samples remained unexplained and were understood only with regard to PC3

Table 2: List of taxa that found in Khowr-e Musa (the Western Persian Gulf) in April 2007

Taxa	Mean (No. m^{-2})	SE	Taxa	Mean (No. m^{-2})	SE
Acme sp.	2.1	2.0	*Maera* sp.	19.1	11.80
Amphilepida sp.	4.1	4.1	*Maera tenella*	11.6	6.70
Amphiodia microplax	1.3	1.3	*Majidae*	2.1	2.00
Amphipoda (Unid.)	16.4	12.7	*Melinna palmata*	1.3	0.16
Apanthura sandalensis	0.7	0.6	*Minolia* sp.	4.1	4.00
Bivalve (Unid.)	9.6	4.8	*Mitrella blanda*	8.8	4.10
Bryozoa	13.0	13.0	*Modiulons philippinarum*	10.3	8.30
Calyptraea edgariana	4.1	4.1	*Nassarius castus*	2.1	4.00
Capitella capitatta	15.0	8.3	*Obelia dichotoma*	11.6	5.50
Cheirophotis megacheles	29.4	16.2	*Paphia gallus*	21.2	10.60
Corbula taitensis	4.1	4.0	*Penatulacea*	3.4	2.30
Eunice sp.	3.4	3.3	*Perinereis* sp.	19.8	7.50
Euphrosine sp.	2.1	2.0	*Pseudotanais* sp.	18.4	9.00
Ensiroides caesaris	7.5	7.4	*Sternapsis scutata*	2.1	4.00
Gamaropsis sp.	2.1	2.0	*Syllis* sp.	8.2	4.70
Glycera sp.	4.1	4.0	*Tellina capsoides*	10.3	10.20
Indschnopns hardmani	4.1	4.0	*Tellina wallaceae*	6.2	4.40
Maera hemigera	8.9	8.9	Total	310.4	57.50

Table 3: Percentile of three metrics for used in calculating PGB-IBI based on department of environment studies during 1994 to 1999

Percentile	H'	TSA (No. m^{-2})	TSB (g m^{-2})
5	0.7	100	0.5
10	0.8	130	0.6
25	1.2	170	0.7
50	1.5	280	0.9
75	1.9	495	1.3
90	2.1	560	1.8
95	2.2	600	2.1

H': Shannon diversity index, TSA: Total species abundance, TSB: Total species biomass

Table 4: Comparison between percentage of organic matter and macro invertebrate abundance (Mean±SE) in two developmental periods of Khowr-e Musa

Study	Organic matter (%)	Abundance of total macrofauna (No. m^{-2})	df	p-value
Present	22.44±1.4	239.7±25.6	95	0.001
1994 to 1999	15.33±0.2	809.4±34.7	109	0.001

df: Degree of freedom, p: probability

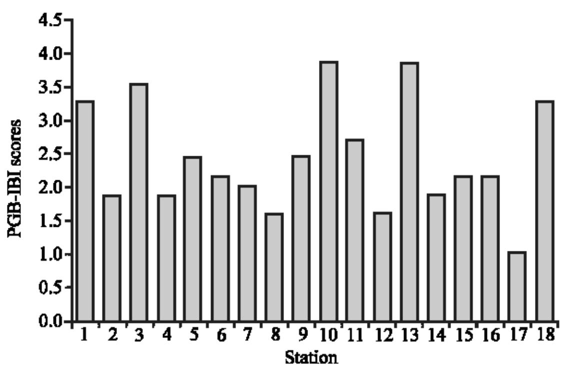

Fig. 2: PGB-IBI scores of 18 stations in the Khowr-e Musa tidal channel in spring 2007 (3-5: Natural; >2.7- <3: Marginal; 2-2.7: Degraded; <2: Severely degraded)

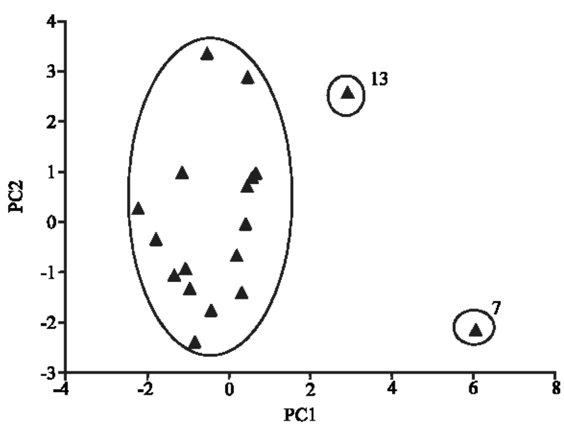

Fig. 3: PCA ordination of nine variables for 18 stations in the Khowr-e Musa (abundance No m^{-2}; biomass g m^{-2}; near bottom dissolved oxygen mg/l; near bottom water speed m sec^{-1}, mud %, granule %; sediment sorting; sediment organic matter %; PGB-IBI score)

(9.8%) and PC4 (7.2%). PC3 was dominated mostly by water current (r = 0.73) and dissolved oxygen at the bottom (r = 0.62).

DISCUSSION

The study area has had a rapid development in the last nine years. There were 3 petrochemical plants in the area before 1999 of which the largest one started full production in 1994. During the war period (1980-1988) they weren't functional and Imam Khomeini port and Mahshahr port had low activity. In the last 30 years three periods were distinguishable:

- War time and low activity between 1980 to 1988
- 1988 to 1999 with medium activity
- 1999 onwards with high activity and rapid development

There are no reliable records of benthic biotopes and community from the first period. So the best reference data of study area are related to the second period. One of most important changes in the area is the increasing organic matter load. Organic enrichment of the sediments is the best documented disturbance affecting marine macrobenthos in coastal environments (Elias, 1992). Three sources of organic mater added to the environment namely industrial waste, sewage and mangrove litter.

After 1999, the mangrove tree *Avicennia marina* was planted in about 50 ha in the Northern fringe of the Khowr-e Musa. The B-IBI uses abundance, biomass and Shannon diversity index which in turn are influenced strongly by organic matter. Analysis of data have shown significant negative correlation between organic matter contents of sediments and B-IBI (r = -0.522, p-value = 0.03). Most of sites with high level of organic matter were situated in North edge of region near developed parts (etc., station No. 2, 4, 5, 6, 14, 15, 16 and 17).

Aquatic biotic communities associated with watersheds with high agricultural and urban land use are generally characterized by lower species diversity, less trophic complexity, altered food webs and reduced habitat diversity (Conners and Naiman, 1984; Malone *et al*., 1996; Mangum, 1989; Roth *et al*., 1996). Such conditions shift environment to eutrophication. Benthos may benefit from low level of eutrophication but suffer reductions in diversity and function at higher levels of enrichment (Diaz and Rosenberg, 1995). High concentrations of tannins may hamper colonization by macrobenthos (Lee, 2000). Grapsid crabs can consume large proportions of mangrove leaf litter production and consequently, large amounts of processed material in the form of crab feces that can potentially fuel a coprophagous food chain as well as provide an alternative form of export from mangrove forests (Lee, 1997). In the artificial and recent mangrove areas there is no crab community like in the original mangrove forest and therefore circulation of organic matter and nutrients in litter aren't processed the typical way. Annual mangrove litter production for Gulf of Carpentaria, Australia 628 g m^{-2} and for Sundarbans, India 1603 g m^{-2} was recorded (Conacher *et al.*, 1996; Gosh *et al.*, 1990). Total litter biomass was recorded 1187 g m^{-2} for *Kandelia candel* and *Aegiceras corniculatum* (Tam *et al.*, 1998).

Still there are no studies in litter production for the study area. The decomposition of litters is relative slow and more than 20% remained after 10 weeks for *A. corniculatum* (Tam *et al.*, 1998). Therefore, it is possible that the litter accumulating in soft anoxic sediments increase the organic content. Twilley *et al.* (1986) observed that differences in litter tannin content might contribute to differences in mangrove leaf decomposition rate due to microbial colonization. But no data on *A. marina* tannin concentrations in the study area were available. In warm waters like Khowr-e Musa oxygen consumption by organisms is higher than colder waters. Hence it is possible those dissolve oxygen concentrations reaches critical levels at higher values and affect benthic community (Diaz and Rosenberg, 1995). In Chesapeake Bay it was recorded that events of low dissolved oxygen levels were spatially extensive and strongly correlated with benthic community condition, explaining 42% of the variation in the B-IBI (Dauer *et al.*, 2000). In the study area, oxygen concentration and current at bottom had positive correlation with PC3. These observations could also be influenced by high rates of vertical water movement due to surface evaporation and semidiurnal high amplitude (4 m or more) tides. Hence, it isn't possible to judge the ecosystem health accurately until more detail studies are under taken. There are reports indicating pollution by metals (Ni, Zn and Cd) and oil in the study area (Department of environment, 1994). Finally it could be said that the area is under both natural stress and anthropogenic impacts and is degraded in most places. Choice of suitable management plans and metric controls could help save the largest tidal channel complex in Persian Gulf.

CONCLUSION

Rapid development is an important impacting factor in the region. Usually data collection in such regions with fast development is slower than changing in the environment. So, judgment about relative effects of impacts and determination of the most important affecting factors is difficult. In the area two main impacts are organic enrichment and dredging.

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