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Testing the efficiency of temperate benthic biotic indices in assessing the ecological status of a tropical ecosystem

Sanitha K. Sivadas [a,*], Rahul Nagesh [a], G.V.M. Gupta [b], Udaykumar Gaonkar [a], Indranil Mukherjee [c], Darwin Ramteke [d], Baban S. Ingole [a]

[a] Biological Oceanography Division, CSIR-National Institute of Oceanography, Goa, India
[b] Centre for Marine Living Resources and Ecology, Ministry of Earth Sciences, Kochi, India
[c] Center for Ecological Research, Kyoto University, Hirano 2-509-3, Otsu 520-2113, Shiga, Japan
[d] Geological Oceanography Division, CSIR-National Institute of Oceanography, Goa, India

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ABSTRACT

The objectives of the present study were to evaluate the ecological status of tropical coastal waters using the temperate benthic indices and examine the effect of seasonal variability on the performance of benthic indices. Macrobenthic samples were collected from northwest to southeast coast of India during 2003–2012 and we tested different univariate indices, ecological strategies, indicator species and multimetric indices. AMBI and multimetric indices performed satisfactorily in evaluating the ecological status. Seasonal variability on the biotic indices was observed during the southwest monsoon and fall intermonsoon period due to recruitment. Therefore, we recommended the non-monsoon period (January–May) as a suitable time of the year to use the indices for effective assessment of the Indian coastal waters. Results show that, the temperate benthic indices are efficient in assessing the tropical environmental status. However, complementary use of different indices is suggested for accurate assessment of the environmental status.

1. Introduction

The coastal waters are subjected to a variety of changes resulting from anthropogenic and natural processes. Anthropogenic activities, such as habitat alteration, sewage discharge and overexploitation of resources have a deleterious effect on the coastal ecosystem (Halpern et al., 2008; Seitz et al., 2013). In addition to the anthropogenic stressors, the coastal ecosystems are also threatened by global climate change (Watson and Albritton, 2001). One of the main problems affecting these areas is the shift in the benthic community (Pearson and Rosenberg, 1978; Weis et al., 2004; Villnäs et al., 2012). Undisturbed systems are often dominated by *K*-selected species (large-body size, long lifespan, slow-growing) while *r*-selected species characterised by small body size, short lifespan, fast growth and variable population size represent a disturbed community (Pianka, 1970; Warwick, 1986). Changes in the community structure at any trophic level will have a cascading effect that, in turn, affects the ecosystem functioning (e.g. Hooper et al., 2005; Frank et al., 2011).

Given the increasing threat to the coastal environment, many countries worldwide have implemented legislation to assess the ecological quality of estuarine and coastal waters (Borja et al., 2008, 2015). Therefore, several methods and indices have been established to assess the impact of increasing pollution in the marine ecosystem (Borja et al., 2015). Benthic fauna have some features that make them potential candidates for evaluating the health of the coastal environment (Pearson and Rosenberg, 1978; McLusky and Elliott, 2004; Dauvin et al., 2010). Further, they play diverse roles in marine ecosystem functioning by being a primary food source for demersal fish and other benthic fauna. They also actively contribute to the marine biogeochemical cycling (Quintino et al., 2006). However, the macrobenthic community shows a spatio-temporal variation, a result of the natural functioning of the aquatic system. The marked change in the macrobenthic community pattern is reflected in the benthic indices that have often been the main criticism of its use (Reiss and Kröncke, 2005; Kröncke and Reiss, 2010). Therefore improving our understanding of the natural dynamics of indices is of primary importance when considering the use of indices for environmental monitoring and assessment (Kröncke and Reiss, 2010).

In this study, we focussed on the Indian coast, one of the fastest developing regions of the world. India, with ~8000 km long coastline, has 1,641,514 km^2 Exclusive Economic Zone (EEZ). Like the other coastal parts of the world, the Indian coast is also affected by natural and anthropogenic pressures. Major environmental stressors in the Indian coastal environment include heavy floods, sedimentation and eutrophication resulting in increase of coastal hypoxic zones. The main anthropogenic pressures affecting the coast are municipal sewage, industrial and aquaculture effluents, ports and harbours, ship building and breaking yards,

* Corresponding author.
E-mail addresses: sanitha_sivadas@yahoo.com, sanitha@nio.org (S.K. Sivadas).

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fish processing industries, salt pans, tourist resorts/beaches, solid waste dumping and overexploitation of resources (Central Pollution Control Board, Govt. of India) (http://www.cpcb.nic.in/).

Despite the considerable importance of the coastal system and threats imposed by increasing pollution, few studies have been carried out to assess the ecological status of the coastal waters of India. Some of the indices used are the Polychaete: Amphipod ratio and Abundance Biomass Comparison (ABC) curve (Ingole et al., 2006), Geometric Abundance Class and ABC curve (Ingole et al., 2009); Benthic Opportunistic Polychaete Amphipoda Index (BOPA) (Sukumaran et al., 2014), AMBI (AZTI-Marine Biotic Index) and M-AMBI (multivariate AMBI) (Ganesh et al., 2014; Khan et al., 2014; Sigamani et al., 2014, 2015). Also, like most tropical regions, the Indian coast is influenced by the monsoon system. The monsoon system leads to semi-annual reversal of ocean circulation resulting in two seasonal phytoplankton blooms followed by an organic enrichment of the benthic system (Prasannakumar et al., 2010; Ingole et al., 2014). During the Northeast monsoon (December–February), the convective mixing triggers the phytoplankton bloom while coastal upwelling characterises the Southwest monsoon (June–August); the increased runoff during the monsoon affects the physico-chemical characters of the estuaries. The macrobenthic community showed a marked temporal variation under the influence of rainfall associated changes (Alongi, 1990; Gaonkar et al., 2013; Ingole et al., 2014). In this context, the aim of the present paper is to test the applicability of different benthic indices to assess the ecological quality of the coastal waters of India. Given the strong seasonality in the region, we also examined the effect of seasonal variability on the performance of benthic indices and to identify the most suitable time of year for effective assessment of the ecological status of tropical coastal waters.

2. Methods

2.1. Study area and sampling

2.1.1. Southeast coast

Sampling in the southeast coast of India was carried out at Gulf of Mannar (GoM) and Palk Bay (PB) during March 2010 (Fig. 1 and Table 1). The GoM is located between the southern tip of India and northwest of Sri Lanka and is the first marine biosphere reserve of India. It is a large and relatively deep gulf of the Arabian Sea. On the other hand, the PB is a shallow and enclosed basin with an average depth of 5 m. In the GoM, the main sediment type consists of sand while muddy sediment dominated in the PB. Sampling was carried out at 30 stations distributed along ten transects and three depths (5, 10, 25 m) with 15 locations each in the GoM and PB (Fig. 1 and Table 1).

2.1.2. Southwest coast

Sampling was carried out in the coastal waters of Kochi (KO) along a single transect at six depths (10, 20, 30, 40, 50 and 100 m) from March–December 2012. The samples from 10, 20 30 m stations were pooled as the inner shelf, stations 40 and 50 m as mid shelf stations and the outer shelf was represented by 100 m station. Seasonal sampling was carried out at Mangalore (MG) along a single transect with six stations (10, 20, 30, 40 and 50 m). Sandy substrate dominated the southwest coast stations.

2.1.3. Northwest coast

The northwest coast of India was sampled at three different locations: (1) Goa (GO): Sampling at Goa was conducted in two major estuaries, the Mandovi (MD) and Zuari (ZU) and a single transect in the coastal region. The Mandovi-Zuari estuarine system is considered the life-line of Goa. The samples in the Mandovi estuary (MD) were collected fortnightly in 2007–2009 at a single station (Gaonkar et al., 2013). The Zuari River has a length of ~50 km and the Mormugao port is located on the southern bank of the river mouth. The Mormugao port is one of the oldest and finest major ports along the west coast of India. In the ZU, samples were collected from seven stations during 2003–2004. The first four stations were located outside the harbour (ZU estuary) and three stations (Stn 5–7) in the harbour (ZU harbour). The third sampling location in Goa was a single transect, in the coastal waters sampled during November 2009. Samples were collected from six depths (10–60 m) (2) Ratnagiri: Kalbadevi Bay (KB) is a potential placer mineral (Ilmenite) mining site along the northwest coast of India and is a relatively undisturbed area. Samples were collected from two transects with three stations (2, 5 and 10 m) each during January, May and September 2006 (Sivadas et al., 2013). Coastal samples were collected from off Ratnagiri (RT coast) during November 2009 and March 2011 at a depth of 10–50 m (five stations) (Ingole et al., 2014). (3) Mumbai (MU): The northernmost area included in the present study was the coastal region of Mumbai (Ingole et al., 2014). Sampling was carried out during November 2009 along a single transect with five stations at depth of 10–50 m. In addition, data from Ratnagiri (RT) and Karwar (KR) harbour were also used (Ingole et al., 2009). All the stations at Goa, Ratnagiri and Mumbai, were pooled based on depth as mentioned for Kochi. Clayey-silt dominated the sediment type in the northwest stations, except for KB and the ZU estuary which were dominated by sand.

2.2. Environmental data

Surface and bottom water samples were collected for temperature, salinity, pH, dissolved oxygen, biological oxygen demand, total suspended solids, nutrients, Petroleum Hydrocarbon Carbon (PHC), metals (Fe, Mn, Pb, Hg, and Cd), chlorophyll and phaeopigments. Sediment was collected for sediment texture, organic carbon, carbohydrates, proteins, lipids, PHC, metals (Fe, Mn, Pb, Hg, and Cd), chlorophyll and phaeopigments.

2.3. Biological variables

The uneven distribution of stations and seasons at each location was according to the objectives of the different projects during which the samples were collected. All the sediment samples were collected from the subtidal region using a Van Veen grab (0.04 or 0.1 m^2). Samples were sieved on a 500 μm sieve and preserved in 4% buffered formaldehyde with Rose Bengal solution. In the laboratory, the macrofaunal samples were analysed for abundance (ind m^{-2}), biomass (wet weight; g m^{-2}) and species composition. We identified the species to the lowest possible taxa. The samples were pooled to obtain a sample size of 0.1 m^2 for stations where the grab size was <0.1 m^2 (Borja et al., 2007).

2.4. Data analysis

We grouped the data into monsoon and intermonsoon seasons relevant to the Indian Ocean, i.e., December to February (Northeast Monsoon; NEM), March to May (Spring Intermonsoon; SIM), June–August (Southwest Monsoon; SWM) and September to November (Fall Intermonsoon; FIM).

2.4.1. Indices based on diversity

The classical univariate indices such as species abundance (N), species number (S), Margalef's species richness (d), Pielou's species evenness (J), Shannon species diversity (H′ log2) and Simpson's Evenness Index (1-λ′) were calculated. We also used the Hurlbert Index (ESn) which is based on the rarefaction technique of Sanders (1968) and modified by Hurlbert (1971). The Hurlbert Index is less sample size dependent compared to the evenness and species diversity. The Hurlbert Index calculates the expected number of species (ES) among a certain number of individuals. In the present study, we estimated ES for 50 individuals (ES50). The indices based on relatedness such as quantitative taxonomic diversity (Δ), taxonomic distinctness (Δ*), qualitative Average Taxonomic Distinctness (Δ^+) and Variation Taxonomic distinctness (Λ^+) were also calculated. We calculated the indices for all the replicates from each station and season using Primer v 6.1.10 software (Clarke and Gorley, 2006).