Macrobenthic Community Structure Response to Coastal Hypoxia off Southeastern Arabian Sea

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Abstract

The analysis of changes in macrobenthic community using multivariate statistical techniques has been applied to find the structure by the environmental condition. The aim of the study was to evaluate macrofaunal community patterns between natural occurrence of coastal hypoxia condition (30 to 100 m depth) and normoxic bottom waters over the Southeastern Arabian Sea (SEAS). The macrofaunal communities patterns were analyzed by using various statistical methods (e.g. rank correlation, hierarchical clustering, nMDS, BIO-ENV). A clear seasonal difference was found in macrofaunal abundance, biomass, taxonomic composition, diversity and their relation to environmental conditions. Multivariate analysis of Non Multidimensional Scaling (nMDS) showed two major groups macrofaunal communities and ANOSIM results showed a significant difference between macrofaunal community structure in between normoxia and hypoxia conditions (R=0.913). Spearman rank correlation (using BIO-ENV procedure included in PRIMER, V.6) showed the highest correlation of dissolved oxygen (R=0.678) with community structure. The SIMPER analysis illustrated community pattern changed seasonally with Paraprinoplosia cordifolia (20.03%) dominated during hypoxia whereas Tharyx sp. (22.63%) dominated in normoxia conditions. The macrofaunal community patterns revealed contrasting pattern with two seasons, perhaps due to the dissolved oxygen (DO).

Keywords: Hypoxia; Normoxia; Macrobenthos; Community structure; Dissolved oxygen

Introduction

Changes in the structure and composition of macrobenthic communities driven by environmental condition may have marked effects on biogeochemical cycles and benthic ecosystem processes and functions. They are sedentary and trophically diverse [1] and their communities mix the effects of water and sediment changes over time. In addition, macrobenthic fauna play an important ecological role within food webs. They are a direct and indirect food source for many animals, including large crustaceans, fishes, marine birds and marine mammals [2]. Macrobenthic communities can also alter physical and chemical conditions at the sediment–water interface, promote decomposition of sediment organic matter (OM), and are important mediators in nutrient recycling from the sediments to the water column through bioturbation and suspension feeding activities [3,4]. Therefore, changes in macrobenthic community composition, abundances and diversity can affect the functioning of the entire ecosystem [5].

Macrobenthic communities are composed of sedentary organisms capable of integrating long-term environmental conditions at a particular site [6]. Large areas of high productivity induced by natural upwelling and limited mixing led to decrease in the Dissolved Oxygen (DO) concentration at coastal regions [7,8]. Studies defined that DO concentration at normoxia is >2.8 mg L⁻¹, mild hypoxia 2.1-2.8 mg L⁻¹, and hypoxia is ≤ 2 mg L⁻¹. The lower concentration of DO has a major impact on structure and functioning of biogeochemical processes such as the carbon, nitrogen cycles [9,10] and benthic ecology [11,12].

During the southwest monsoon the southwestern movement of the West Indian coastal current influences the upwelling and it causes the hypoxia condition in the Arabian Sea [13]. During southwest monsoon the coastal upwelling occurs along west coast of India between 7°N and 14°N [14-16].

Hypoxia is the most intense marine environments based on harshness conditions in sediment and water flux; also it alters the marine benthic communities. The effects of hypoxia condition on biological community are frequent and related to different levels of dwelling and tolerance. Such responses may change to the feeding habit and also reduced the predator population [17,18]. Hypoxia conditions leads to changes in macrofaunal community structure marine benthic ecosystem due to physiological changes such as stratification and mixing [7,19-23]. Hypoxic events will increase the susceptibility of coastal marine ecosystems to further hypoxia through alteration of ecosystem functioning of the sediments and show that this has already occurred in a number of coastal marine ecosystems [22].

The effect of hypoxia conditions on macrobenthic community have been studied by many researchers [24-26]. The macrobenthic abundance has been reduced in the Arabian Sea due to deceased levels of DO during winter. Many of the inshore regions exhibit poor water quality due to extensive domestic and industrial waste disposal; very low dissolved oxygen occurs during post monsoon in fall, which is mainly due to anoxia developing along the open coastal [23]. There is no study so far in the coastal SEAS explaining the effect of very low dissolved oxygen on macrofauna. However, it is known that macrofaunal communities may response in a different way to the normoxia and hypoxia condition and thus DO play a vital role in benthic ecosystem functioning. The aim of the present study is to assess the macrofaunal structural changes between normoxia and hypoxia conditions and to predict spatio-temporal variation of benthic biodiversity.

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Materials and Methods

Study area

The study was carried out at two fixed Transects, off Cochin (9° 56’N and 76° 12’E) and off Trivandrum (8° 28’N and 76° 54’E) along the coastal water of SEAS perpendicular to western Ghats which receives bulk of rain fall during tropical South-West monsoon regime (Figure 1). The sampling was carried out with the CORV Sagar Sampada during for coastal upwelling during the peak of the South-West monsoon season. In each transect, three stations (bottom depth 30, 50 and 100 m) were chosen for studying the various environmental parameters and macrofauna community structure.

Physico-chemical characteristics

In order to measure the bottom dissolved oxygen concentration, a modified Niskin type water sampler which is capable of collecting bottom water above 20 cm from the surface sediment was used. Dissolved oxygen was analyzed by Winkler’s method [27]. Water depth, salinity and temperature of water column were measured using a CTD meter (SBE-19, Sea-Bird Electronics).

Macrofaunal sampling and analysis

The sediment samples were collected using Smith-McIntyre grab of 0.2 sq.m surface areas, triplicate grab samples were collected, and sieved through a 0.5 mm mesh screen, and the retained organisms were preserved in 10% buffered formalin with Rose Bengal solution in plastic bags. Once the samples brought to laboratory, macrofauna were carefully washed again and sorted into major taxonomic groups (phylum, order or class) and preserved in 5% buffered formalin. The faunal counts from individual grabs were averaged and converted to individual per sq. meter. The faunal counts from the water overlying the grabs were divided by the number of sub-cores taken. Biomass (g/m²) was determined using the wet weight method after blotting. The biomass (shell on) was estimated similarly and converted to g.m⁻² (wet weight). As polychaeta were dominated taxa, then were identified up to species [28,29] level if possible and their number was counted as weight). As polychaeta were dominated taxa, then were identified up to species [28,29] level if possible and their number was counted as weight). As polychaeta were dominated taxa, then were identified up to species [28,29] level if possible and their number was counted as weight).

Statistical analysis

Macrobenthos data were subjected to univariate analyses to study community structure using Margalef’s index [30] for species richness (d), Pielou’s index [31] for species evenness (J), and the Shannon-Wiener index [32] for species diversity (H’ by using log2). For multivariate analysis, a square-root transformation of biological abundance data was carried out and contributed most to the observed differences among groups were found by means of SIMPER (similarity percentage) and cluster analysis and nMDS (Non-metric multidimensional scaling) ordination stand on the Bray-Curtis similarity matrix were attained using the PRIMER 6 package (Plymouth Routines in Multivariate Ecological Research) [33]. Similarity profile (SIMPROF) test was carried out to detect the significant of the clusters. The null hypothesis of no inside group structures of occupied samples was rejected when significance level of P<0.05. ANOVA analysis was carried to find out the significance of spatial and temporal variation on the environmental and biological parameters. Types of feeding were assigned to polychaetes based on the previous reports.

Results

Environmental characteristics

Physico-chemical characteristics such as temperature, salinity and DO (DO saturation %) along SEAS during SM and SIM conditions are shown in Table 1. The results showed that cold and low oxygen condition in the bottom water during SM. Notable feature was observed that the bottom water salinity did not vary along different water depths, whereas temperature showed variation between seasons range from 20.3 to 30.4°C in SIM and 19.6 and 23.5°C during SM (ANOVA, P<0.05). DO deficient of near bottom-water during the SM showed ranged from 0.038 to 0.804 mg.L⁻¹, while oxygen saturated conditions during SIM DO ranged from 4.38 to 5.5 mg.L⁻¹ (Figure 2) and significantly differed between both season (ANOVA, P<0.05).

Macrofaunal composition

The highest number of taxa (68) was identified in the SIM, and Polychaeta was dominated group, contributing 86.21% to total fauna abundance. Macrofaunal abundance decreased from depths 30-100 m in Cochin (5556 - 3520 individuals m⁻²), then increased from shallow depth to deep on Trivandrum (1529-2493 individuals m⁻²) and average abundance 3412 individuals m⁻² were in the SIM (Table 2). Moreover, 25 polychaete families were found in the SIM, in which Cirratulidae family were showed highest contribution (39.81%) followed by Spionidae (14.2%) and Capitellidae (5.37%). The SIMPER analyses showed that benthic community was dominated by Tharyx sp. (22.63%) and Mediomastus (20.03%) and Cirriformia (12.19%) showed highest contributions of Spionidae and Crustacean were dominated (56.45% and 11.38% respectively) followed by Chaetopteridae (5%), Orbiniidae (4.63%), Sabellidae (4.17%) and Glyceridae (3.41%) (Table 4). The Amphipoda was most abundance group among the crustaceans, contributing 8.05% to total macrofaunal diversity. However, the low abundance of Echinodermada and Fish larva were observed at the low oxygen conditions. The average biomass showed that the higher biomass value (16.5 g.m⁻²) found at low oxygen environmental conditions (Figure 3).

Diversity indices

Margalef’s index (d) showed that species richness (d) was varied from 2.4 to 7.4 during SIM, while hypoxia zone (SM) was recorded lower d value from 1.7 to 4.98 (Figure 4). The species evenness (J) varied from 0.87 to 0.95 in high oxygen conditions, whereas in low oxygen conditions species evenness range from 0.93 to 0.98. However, highest value of Shannon diversity index (H’) varied from 3.72 to 5.19.
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| Transect | Depth (m) | Temp (°C) | Salinity PSU | Dissolved oxygen (ml L⁻¹) | Dissolved oxygen (saturation %) |
|----------|-----------|-----------|--------------|---------------------------|--------------------------------|
|          | SIM       | SM        | SIM          | SM                        | SIM                            |
| Cochin   | 30        | 30.46±0.5 | 22.77±0.8    | 35.71±0.4                 | 4.70±0.7                       |
|          | 50        | 28.47±0.7 | 21.72±0.5    | 35.48±0.3                 | 4.45±0.8                       |
|          | 100       | 20.30±0.3 | 19.59±0.3    | 35.37±0.4                 | 5.13±0.3                       |
| Trivandrum| 30        | 29.74±0.8 | 23.46±0.9    | 34.76±0.9                 | 4.38±0.3                       |
|          | 50        | 27.60±0.3 | 22.61±1.2    | 35.27±1.1                 | 5.50±0.4                       |
|          | 100       | 24.63±0.9 | 20.71±1.5    | 35.34±0.7                 | 4.75±0.9                       |

Note: Mean ± SD (n=3)

**Table 1**: Physico-chemical characteristic of habitats study (mean± SD) on the southeastern Arabian Sea.

![Oxygen (ml/l) vs Depth (m) graph](image)

**Figure 2**: Season-wise distribution of DO (ml L⁻¹) during SIM and SM conditions.

| Zones            | Spring Inter Monsoon | Summer Monsoon |
|------------------|----------------------|----------------|
| Transects        | Cochin               | Trivandrum     | Trivandrum               | Cochin |
| Water Depth (m)  | 30 50 100            | 30 50 100      | 30 50 100                | 30 50 100 |
| Total abundance (Ind. m⁻²) | 1498 2443 2261 | 4814 5506 3954 | 1675 4475 650 | 7450 5025 1025 |
| Total number of species | 38 39 27 | 21 14 22 | 15 29 15 | 25 27 22 |
| Total Biomass (wet wt. g m⁻²) | 12.66 4.82 1.34 | 10.7 166.2 1.30 | 6.06 20.02 7.45 | 42.03 14.03 9.39 |
| Most dominant species* (comprising >10% of the density) | 1802 2289 1311 | 311 1111 955 | 1550 3550 325 | 275 1375 200 |
| Dominant feeding types | SDF SDF SDF | SDF SDF SDF | SDF SDF SDF | SDF SDF SDF |
| d                | 4.46 4.45 3.25 | 2.75 1.67 2.75 | 1.89 3.34 1.99 | 2.67 3.08 2.94 |
| J                | 0.55 0.68 0.69 | 0.80 0.74 0.70 | 0.90 0.68 0.92 | 0.79 0.73 0.85 |
| H'(log₂)         | 2.89 3.61 3.29 | 3.55 2.81 3.12 | 3.54 3.28 3.61 | 3.65 3.46 3.76 |

**Table 2**: Comparison of community parameters studied along the two transects during two different seasons at SIM and SM.

Note: (Dominant species**1**: Paraprinospia cordifolia, 2: Prinospia cirrifera, 3: Tharyx sp.), SDF: Surface deposit feeder

in SIM, whereas in SM value ranged from 2.93 to 4.52.

**Linking macrofauna community structure to environmental variables - bio-env**

The BIO-ENV procedure was explained on a species assemblage similarity matrix attuned for two sites and the resemblance matrices created using one various transformations of primary environmental 106-by-3 matrix (Temperature, salinity and DO are log-transformed prior to the normal transformation). The Spearman correlation coefficient (r) was selected as a rank correlation measure. For the normal transformed environmental matrix, DO revealed the best association with the abundance, (r=0.709). It was followed by J (r=0.590) (Figure 5). Those variables were liable for most of the similarity between the biotic and abiotic matrices (Table 5). The highest correlation (r=0.597)
### Table 3: Comparison of similarity of macro fauna observed among the dominant species from normoxic and hypoxic condition.

| Hypoxic intolerant (SIM) % | Hypoxic tolerant (SM) % |
|---------------------------|-------------------------|
| Cirtulidae 39.81           | Spionidae 56.45         |
| Spionidae 14.20            | Capitellidae 5.37       |
| Capitellidae 5.37          | Paraonidae 4.21         |
| Gastropoda 2.85            | Sabellidae 4.17         |
| Bivalvia 2.80              | Glyceridae 3.41         |
| Nereididae 2.56            | Nereididae 2.56         |

### Table 4: Dominant macrobenthic taxa tolerating from SIM and SM seasons.

- Mediomastus sp. was dominated by *P. cordifolia* and *Cirriformia* sp. (Table 3). An ANOSIM (R=0.913) test shows the significant differences between season (SIM and SM) and Bray-Curtis analysis explains two distinct clusters at 20% similarity (Figure 7). Most of the surface and subsurface deposit feeder in cluster was mainly from the oxygen saturated conditions and they were also showed low abundance in the hypoxia conditions. The surface deposit feeder of polychaete such as *Tharyx* sp. and subsurface deposit feeder of *Mediomastus* sp. were abundant along with carnivore species.

**Figure 3:** Season-wise distributions of macrofaunal species, abundance and biomass at the southeastern Arabian Sea.

**Figure 4:** Dendrograms and MDS plots based on the macrobenthos abundance data.

**Figure 5:** Bray-Curtis similarity for seasonal conditions (normoxia and hypoxia).
values (4.38-5.5 ml.L−1) observed along the normoxia conditions. SIM lowest DO value ranged from 0.04-0.8 ml.L−1 SM, whereas high DO earlier studies of the west coast of India (Muni Krishna 2008). The zone and low DO values in the hypoxic zone were in agreement with SEAS during SM. The observed high DO values on the normoxia productive region in and around the Arabian Sea. The nutrient rich in P. cordifolia in the normoxia condition.

Both surface and subsurface feeder existed 74.3% with carnivore (12%) on the surface of bottom than carnivores (12%) at SIM conditions. Oxygen condition showed highest representation of carnivores (17%) for suspended feeders to be replaced by deposit feeders, in contest that in low oxygen zone (SM) (Table 6). There is also a common propensity polychaeta such as Glycera alba. processes in Cochin during July and creating the drop in sea level as to a large extent [10]. Studies implied increased intensity of upwelling process cannot be driven by winds alone, but may be remotely forced promoted with decreasing temperature [34-36]. During the SM (June and high tolerance in low oxygen levels has moderately connected among the Polychaetes, two species namely P cordifolia and Prionospio pgymaea, belonging to the Spionidae family and one species of Cirriformia sp. under the Cirratulidae family were abundant on the low oxygen conditions (SM). These surface deposit feeders were replaced by more carnivorous species including Lumbrineris sp., Ancistrostylis sp., Syllis sp., Notomastus sp. and Cirratulis sp. [38]. Echinoderms are typically more sensitive to hypoxia with lower oxygen thresholds, than annelids, Sipuncula, Molluscs and Cnidarians. Moreover, as shown by the SIMPER analyses, the Spionidae contributed most of the difference between the hypoxic and normoxic conditions. Our results showed that the highest density of the subsurface feeder Mediomastus sp. and Oligochaeta at the normoxia conditions SIM, further the presence of the suspension feeder Megalommia sp. was restricted to the hypoxia conditions.

Although many omnivores are opportunistic and capable to switch prey depending on food availability, thus it is expected that they will balance their diet as a result of nutritional needs, food quality and availability of alternate foods [39]. On contrary, Tharyx sp. and Mediomastus sp. were found at low density during hypoxia conditions. The P. cordifolia was dominant macrobenthic species in this DO (≤ 2 mg L−1) depleted areas [12,40,41]. The macrobenthos presented in normoxia condition did not cluster with hypoxia group, because of high abundance of P. cordifolia (Figure 8). This species is well-known to tolerated hypoxia conditions [42,43]. In addition, study reported that the dominance of P.cordifolia within OMZ off conception. The rich organic matter in study area was strongly influence on evenness and dominance of macrofauna community. Therefore, it is often complicated to eminent effects of oxygen depletion from those of decreased pH on taxonomic composition [11].

The low density of macrofauna was observed at Cochin (30 and 100 m) during SM, which falls within the site of seasonal sulphate reduction [10]. Typically, the first disappear of crustaceans and echinoderms, with annelids and selected molluscs exhibiting greatest tolerance to hypoxia [19,44]. The important taxa of Spionidae and Cosuridae were found in low oxygen level [26]. However, coastal systems are become saturated through organic matter which leads to develop hypoxia condition and reduction in the biomass [45]. The present studies shows that macrofaunal species were interrelated to surroundings conditions and various environmental factors which are playing major role for the changes on macrofauna structural. The surface deposit feeders and low-oxygen tolerant species are dominated over the suspension feeders. However, the low biodiversity were observed mostly sensitive to the hypoxia conditions. According to studies classification of polychaete feeding types during SIM were dominated by surface deposit-feeding with subsurface deposit-feeding fauna playing a major role in the normoxia conditions.

The macrofauna community structure showed the evidence of low biomass supported by lowest oxygen levels during SM. Rowe reported the reduced biomass within low oxygen condition was stress induced small but found that this low biomass involves high macrofaunal densities, indicating small body size. Mobile vertebrate and invertebrate taxa were observed to avoid hypoxic condition and less mobile invertebrate taxa try to escape low-oxygen conditions or even die and if they cannot escape [7]. Further, Spionidae contributed (52.8%) of the total polychaete family and responses to the hypoxia conditions depend on the duration. The low oxygen conditions to support metazoans, small size of organisms, soft-bodied invertebrates (naturally annelids) and often time of the generation short and intricate branchial structures [7,46]. In addition, the polychaetes have high gill surface area enhances respiratory surface and morphological adaptation. Moreover, the

| Number of variables | Best variable combinations | Correlation(ρ<sub>p</sub>) |
|---------------------|----------------------------|--------------------------|
| 1                   | Dissolved Oxygen           | 0.633                    |
| 2                   | Abundance-Dissolved Oxygen | 0.709                    |
|                     | J'-Dissolved Oxygen        | 0.590                    |
|                     | d-Dissolved Oxygen         | 0.588                    |
|                     | No of species-Dissolved Oxygen | 0.570            |
|                     | H'(log2)-Dissolved Oxygen  | 0.550                    |
| 3                   | Abundance-J'-Dissolved Oxygen | 0.599                |
|                     | Abundance-Temperature-Dissolved Oxygen | 0.597 |
|                     | Abundance-salinity-Dissolved Oxygen | 0.588 |
|                     | Abundance- H'(log2)-Dissolved Oxygen | 0.582  |

Table 5: BIO-ENV procedure results showed that highest Spearman rank correlation coefficients (ρ) evaluated between square root of transformed biotic similarity matrix and abiotic matrix (μ).
Figure 6: Seasonal distribution of species and abundance pattern.

Figure 7: Seasonal distributions of feeding types of macrofauna occurred in southwest coast of Arabian Sea (SDF: surface deposit feeder, SSDF: subsurface deposit-feeder, C: Carnivores and FF: suspension feeder or filter feeder).
| Group          | Family     | Species name     | Normoxia zone (SIM) | Hypoxia zone (SIM) |
|----------------|------------|------------------|---------------------|--------------------|
| Polychaeta     |            |                  | Cochin | Trivandrum | Trivandrum | Cochin |
|                | Pilargida  | Synelmis sp.     | 5 0 0 0 | 0 0 0 22 | 0 0 0 0 | 0 0 0 0 |
|                |            | Ancystrocyllis sp. | 47 22 0 | 15 89 0 | 25 50 0 | 0 0 0 25 |
|                | Ampharetida| Amphictei sp.    | 0 22 0 0 | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 |
|                | Ophelidae  | Armandia sp.     | 0 22 0 0 | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 |
|                | Maldanidae | Axiothella sp.   | 0 67 0 0 | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 |
|                | Capilidae  | Miltiona sp.     | 425 156 0 | 89 267 133 | 0 0 0 0 | 0 0 0 0 |
|                | Chaetopterida| Chaetopterus sp. | 2 22 0 0 | 44 0 0 | 0 1025 0 | 0 0 0 0 |
|                | Cirtulidae | Cirtulidae sp.   | 0 0 0 44 | 0 0 22 | 0 0 0 0 | 0 0 0 0 |
|                |            | Cinformia sp.    | 0 0 0 0 | 0 0 0 0 | 175 0 50 | 50 125 25 |
|                |            | Cirtulatum sp.1 | 0 0 0 0 | 44 0 0 | 0 0 0 0 | 0 0 0 0 |
|                |            | Cirtulatum sp.2 | 0 0 22 0 | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 |
|                |            | Cirtulatum sp.3 | 17 22 156 0 | 0 0 0 | 25 125 0 | 0 0 0 0 |
|                |            | Cautoufla sp.    | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 |
|                |            | Tharyx sp.       | 1802 2289 1311 141 1111 956 | 0 0 0 25 | 0 0 0 0 |
|                | Cossuridae | Cossura sp.      | 0 0 0 44 | 0 0 0 0 | 0 25 75 | 0 0 0 0 |
|                | Dorvilleida| Dorvilleida sp.  | 7 44 22 0 | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 |
|                |            | Ophryodrocha sp. | 0 0 0 0 | 0 0 0 0 | 25 0 0 0 | 0 0 0 0 |
|                | Polynoidae | Euphione sp.     | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 | 75 0 0 |
|                |            | Eunoe sp.        | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 | 0 0 50 0 |
|                | Eunicidae  | Eunice sp.       | 2 111 0 0 | 0 0 0 0 | 0 0 0 0 | 25 0 0 |
|                | Glyceridae | Glycerina alba   | 15 89 44 0 | 0 0 0 | 75 0 50 | 275 175 75 |
|                | Goniadidae | Glicinie sp.     | 131 0 0 0 | 0 0 22 | 0 0 0 50 | 0 0 0 0 |
|                | Hesionidae | Goniadia sp.     | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 |
|                |            | Ophiodromus sp.  | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 |
|                |            | Heslonidae sp.   | 0 0 22 0 | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 |
|                | Amphinomida| Pseudoerythoe sp.| 15 133 89 89 | 0 0 | 0 0 0 0 | 0 0 0 0 |
|                |            | Harmothoe sp.    | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 |
|                | Sabelidae  | Euchone sp.      | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 | 75 0 0 |
|                |            | Sabelidae        | 0 0 0 0 | 0 0 0 44 | 0 0 0 0 | 0 0 0 0 |
|                |            | Chone sp.        | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 |
|                |            | Hydrodoides sp.  | 0 0 0 0 | 0 0 0 0 | 0 25 0 0 | 0 0 0 0 |
|                |            | Megalomma sp.    | 0 0 0 0 | 0 0 0 0 | 0 0 0 0 | 705 0 0 |
|                | Paracnidae | Jasmineia sp.    | 7 89 0 | 0 69 22 | 0 25 0 0 | 0 0 0 25 |
|                |            | Paracnidae       | 3 111 22 9 | 89 22 | 0 25 0 0 | 0 0 0 0 |
|                | Lampitidae | Paracnidae       | 3 111 22 9 | 89 22 | 0 25 0 0 | 0 0 0 0 |
|                |            | Levinskiia sp.   | 7 333 178 22 | 0 44 | 0 0 0 0 | 0 0 0 0 |
|                | Lumbrinerida| Lumbrineriis sp. | 30 44 111 89 | 178 44 | 0 125 0 | 0 0 25 25 |
| Taxonomy       | Common Name | Abundance |
|---------------|-------------|-----------|
| Ampharetidae   | Ninoe nigripes | 50        |
|               | Melina sp.   | 0         |
|               | Anmge sp.    | 12        |
| Magelonidae    | Magelona cincta | 133       |
| Nephtyidae     | Nephsy inermis | 0         |
|               | Nephsy sp.   | 22        |
| Nereididae     | Micronereides sp. | 0         |
|               | Nephs sp.    | 89        |
| Onuph tide     | Onuphis sp.  | 79        |
| Pisidioideae   | Pisidion sp.  | 0         |
| Phyllosocidae  | Eteone sp.   | 0         |
|               | Phyllodoce sp. | 40        |
| Spionidae      | Pronospia steenstrupi | 0         |
|               | Pronospia cinerea | 706       |
|               | Pronospia pygmaea | 10        |
|               | Parapronospia cordifolia | 5         |
|               | Pronospia cirrobranchiata | 2         |
|               | Pronospia cirrifera | 706       |
|               | Pronospia pygmaea | 10        |
|               | Pronospia aucklandica | 0         |
|               | Scoloplos sp. | 0         |
| Sylidae        | Syllids sp.  | 12        |
|               | Exogone sp.  | 15        |
| Trichobranchida| Trichobranchus sp. | 0         |
| Terebellidae   | Terebellides sp. | 5         |
|               | Lanie conchilega | 0         |
| Crustacea      | Isopoda      | 0         |
|               | Mystidea     | 0         |
|               | Ostropoda    | 0         |
|               | Shrimp larva | 32        |
|               | Sand dollar  | 0         |
|               | Tanadacea    | 15        |
|               | Decapoda larva | 0         |
|               | Cumacea      | 7         |
|               | Caperloidea  | 12        |
|               | Amplexica sp. | 0         |
|               | Byblis sp.   | 0         |
|               | Lijeborgiae  | 0         |
| Bivalvia       | Bivalvia     | 99        |
|               | Gnathia cerina | 0         |
|               | Arca sp.     | 0         |
|               | Babyloniala  | 0         |
|               | Corbicipitidae | 0         |
and Tharyx with the next normoxia condition. Further, we observed that fall were composed of opportunistic species and they disappeared again wide range of low oxygen conditions. Most recruited macrofauna in hypoxic condition and heavy recruitment that could be tolerated a P. cordifolia, tolerance species with an expanded branchial structure appeared due to the adaptations at low oxygen conditions. It also suggested that branchial are importance for feeding rather than for gas exchange. Adaptations at low oxygen conditions. It also suggested that branchial structures were highly dominant when compared to suspension feeder and hypoxic tolerant species.

Conclusions

The present study reveals that macrofaunal community structure changes by natural occurrence of coastal hypoxia in the SEAS and event of hypoxia repeatedly in the SM. The species diversity showed seasonal variation and the P. cordifolia tolerated and respond to hypoxic condition and heavy recruitment that could be tolerated a wide range of low oxygen conditions. Most recruited macrofauna in fall were composed of opportunistic species and they disappeared again with the next normoxia condition. Further, we observed that Tharyx sp. and P. cordifolia could be second order opportunistic species in surface deposit-feeder. The DO and environmental variables may influence the changes in macrofauna community structural with alteration of food webs. The surface deposit feeder and hypoxic tolerant species were highly dominant when compared to suspension feeder and hypoxic intolerant species.

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Table 6: Mean abundances of macrofauna (ind.m 2) at normoxia (SIM) and hypoxia (SM) conditions.

| Taxa               | SIM  | SIM  | SIM  | SIM  | SIM  | SIM  | SIM  | SIM  | SIM  | SIM  | SIM  | SIM  |
|--------------------|------|------|------|------|------|------|------|------|------|------|------|------|
|                    |      |      |      |      |      |      |      |      |      |      |      |      |
| Total abundance(Ind.m 2) | 4795 | 5484 | 3420 | 1499 | 2443 | 2261 | 1675 | 4325 | 700  | 8105 | 4650 | 1025 |

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Figure 8: A: Thormora jukesii, B: Paraprionospio cordifolia, C: stenaspis scrutinata, D: Maldaneella sp. E: Magelona cincta F. Terebellides strombi. In figure B, E and F respiratory surface gills improved in hypoxic condition, photograph of anterior part of polychaetes with well-developed branchia.
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