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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 nornaxia 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 Paraprionospia cordifolia (20.03%) dominated during hypoxia whereas Tharyx sp. (22.63%) dominated in nornaxia 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 mgL^{-1}, mild hypoxia 2.1-2.8 mgL^{-1}, and hypoxia is ≤ 2 mgL^{-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 southward 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 Sukti* at SIM and on FORV *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.

Physio-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/m^2) was determined by 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 individual per square meter under stereo-microscope.

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 log^2). For multivariate analysis, a square-root transformation of biological abundance data was carry 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.

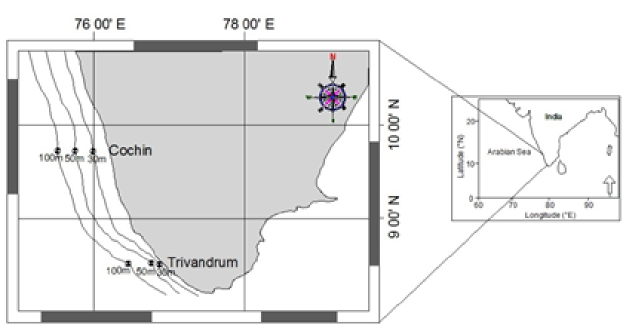

Figure 1: Map showing the study area and sampling locations for macrobenthos in Southeastern Coast of Arabian Sea.

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* sp. (10.48%) at SIM (Table 3). On the other hand *P. cordifolia* (20.03%) and *Cirriformia* sp. (12.19%) showed major dominance in benthic community during SM. The overall mean abundance was 3383 individuals' m^{-2} with minimal value Cochin 100 m depth (650 individuals m^{-2} and 8 taxa) and polychaeta groups were contributing 86.8% on benthic faunal abundance. Among these families, highest contributions of Spionidae and Crustacean were dominated (56.45% and 11.58% 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 of 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	SM	SIM	SM
Cochin	30	30.46±0.5	22.77±0.8	35.71±0.4	35.05±0.3	4.70±0.7	0.04±0.8	91	1
	50	28.47±0.7	21.72±0.5	35.48±0.3	35.03±0.9	4.45±0.8	0.14±0.7	83	2
	100	20.30±0.3	19.59±0.3	35.37±0.4	34.95±0.5	5.13±0.3	0.16±0.9	82	3
Trivandrum	30	29.74±0.8	23.46±0.9	34.76±0.9	35.01±0.4	4.38±0.3	0.80±0.7	84	14
	50	27.60±0.3	22.61±1.2	35.27±1.1	35.01±0.8	5.50±0.4	0.36±0.4	101	6
	100	24.63±0.9	20.71±1.5	35.34±0.7	34.93±1.3	4.75±0.9	0.21±0.4	82	3

Note: Mean ± SD (n=3)

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

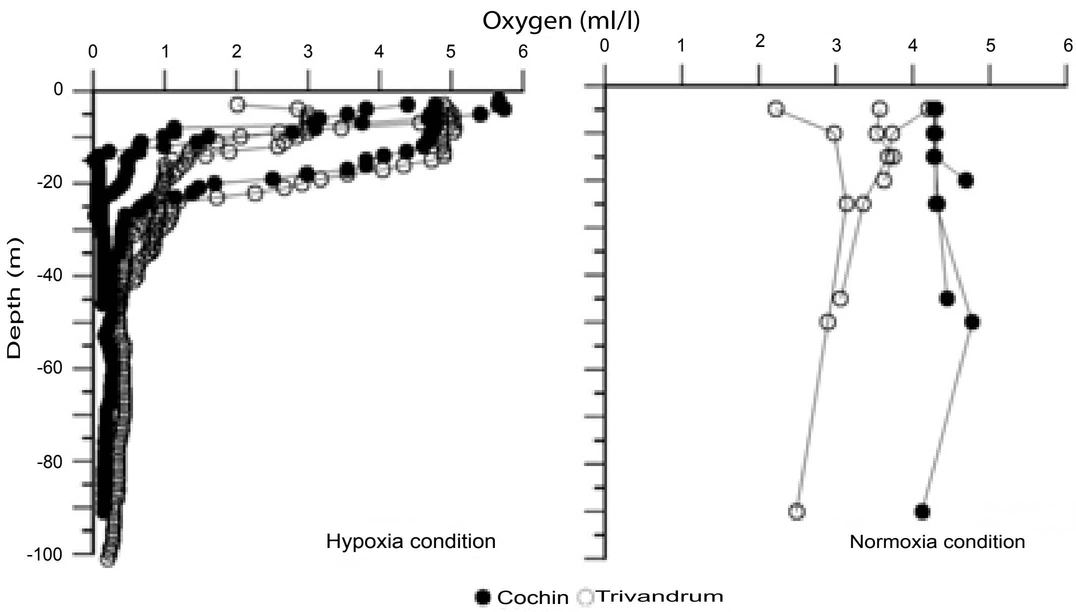

Figure 2: Season-wise distribution of DO (mL^{-1}) during SIM and SM conditions.

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})	1499	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'(log^2)	2.89	3.61	3.29	3.55	2.81	3.12	3.54	3.28	3.61	3.65	3.46	3.78

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

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

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)

Hypoxic intolerant species (SIM)	Composition (%)	Hypoxic tolerant species(SM)	Composition (%)
Tharyx sp.	22.63	*Paraprionospio cordifolia*	20.03
Mediomastus sp.	10.48	*Prionospio pygmaea*	13.04
Lumbrineris sp.	6.34	*Cirriformia* sp.	12.19
Prinospia cirrifera	5.45	*Prinospia cirrifera*	10.86
Paraprinospia cordifolia	3.74	*Glycera alba*	10.26
Prionospio aucklandica	3.3	*Prionospio steenstrupi*	4.89
Aricidea sp.	3.18	*Magelona* sp.	4.16
Nepthys sp.	2.73	*Lumbrineris* sp.	1.45

Table 3: Comparison of similarity of macro fauna observed among the dominant species from normoxic and hypoxic condition.

Hypoxic intolerant (SIM)	%	Hypoxic tolerant (SM)	%
Cirrtulidae	39.81	Spionidae	56.45
Spionidae	14.20	Crustacea	11.58
Capitellidae	5.37	Chaetopteridae	5.00
Paraonidae	4.21	Orbiniidae	4.63
Gastropoda	2.85	Sabellidae	4.17
Bivalvia	2.80	Glyceridae	3.41
Nereididae	2.56	Cirrtulidae	3.17

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

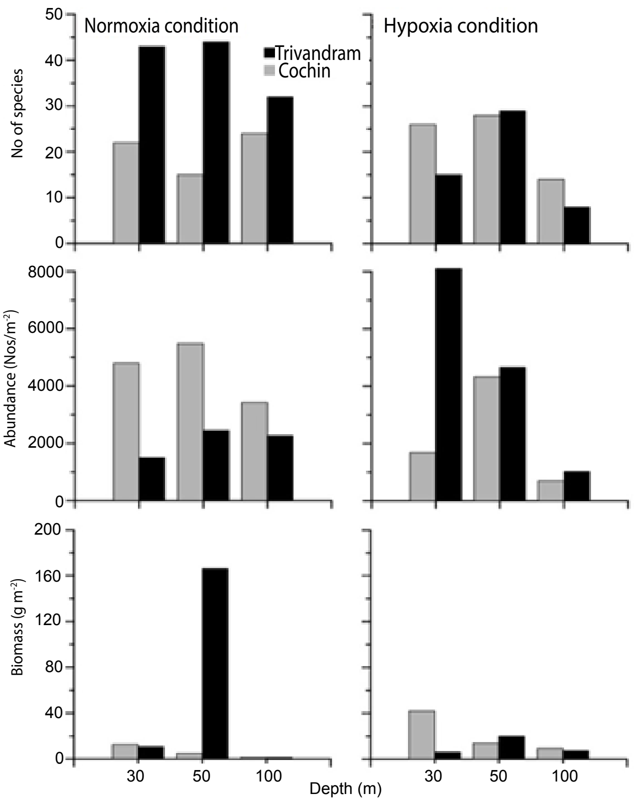

Figure 3: Season-wise distributions of macrofaunal species, abundance and biomass at the southeastern Arabian Sea.

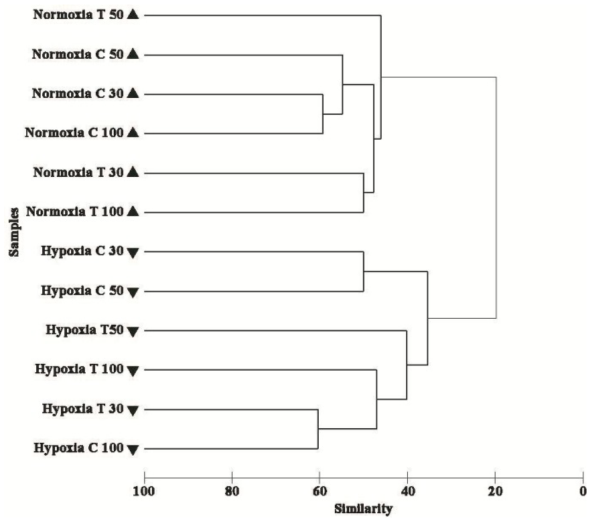

Figure 4: Dendrograms and MDS plots based on the macrobenthos abundance data.

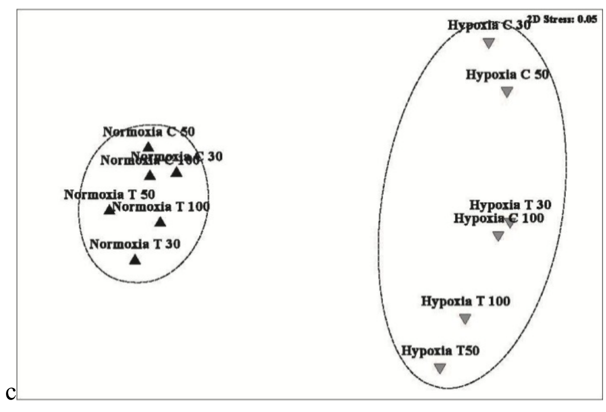

Figure 5: Bray-Curtis similarity for seasonal conditions (normoxia and hypoxia).

is found for a combination of factors: Abundance; Temperature; DO.

Multivariate (MDS) analysis of macrofaunal community structure

The MDS plot based on the abundance of macrofauna communities shows two different groups at dissimilarity (84.59%) in this study area (Figure 6). The SIM group was differentiated by *Tharyx* sp. and *Mediomastus* sp. whereas SM group were 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

Number of variables	Best variable combinations	Correlation(ρ_w)
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 (ρ_{normal}).

Lumbrineris sp. Another cluster was formed due to the abundance of *P. cordifolia, Prionospio pygmaea* and *Cirriformia* sp. included carnivore polychaeta such as *Glycera alba*.

Distribution of polychaeta feeding type

The surface deposit feeder was dominant feeding type (dwelling polychaeta) 78.5% with carnivores (17%) in the hypoxia zone (SM). The both surface and subsurface feeder existed 74.3% with carnivore (12%) in the normoxia condition. *P. cordifolia* was highest dominated as well as it also feeder tolerated at low oxygen condition; consequently the suspension of deposit feeder or filler feeders (4.6%) were uncommon in low oxygen zone (SM) (Table 6). There is also a common propensity for suspended feeders to be replaced by deposit feeders, in contest that second order opportunistic species were dominated during SM. The low oxygen condition showed highest representation of carnivores (17%) on the surface of bottom than carnivores (12%) at SIM conditions.

Discussion

The seasonal upwelling may have influence on the biological productive region in and around the Arabian Sea. The nutrient rich in upwelled water causes oxygen shortage in the subsurface water along the SEAS during SM. The observed high DO values on the normoxia zone and low DO values in the hypoxic zone were in agreement with earlier studies of the west coast of India (Muni Krishna 2008). The lowest DO value ranged from 0.04-0.8 ml.L^{-1} SM, whereas high DO values (4.38-5.5 ml.L^{-1}) observed along the normoxia conditions SIM and high tolerance in low oxygen levels has moderately connected with continuously low temperature and oxygen deficiency apt to promoted with decreasing temperature [34-36]. During the SM (June to September) the wind pattern has favored the upwelling along the west coast of Indian. However, the end of the SM indicates that the process cannot be driven by winds alone, but may be remotely forced to a large extent [10]. Studies implied increased intensity of upwelling processes in Cochin during July and creating the drop in sea level as well as surface temperature.

P. cordifolia and *Tharyx* sp. are opportunistic species belonging to the families of Spionidae and Capitellidae. Both the species are surface deposit feeder and propagate in high organic enrichment sediments [37]. However, Spionidae and Capitellidae contributed to 68% of the total polychaete species during SM and rich organic content of sediment can support the tolerant species and reduce sensitive species [37]. Among the Polychaetes, two species namely *P cordifolia* and *Prionospio pygmaea,* 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., *Ancistrosyllis* 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 *Megalomma* 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 concepection. 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 Cossuridae 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

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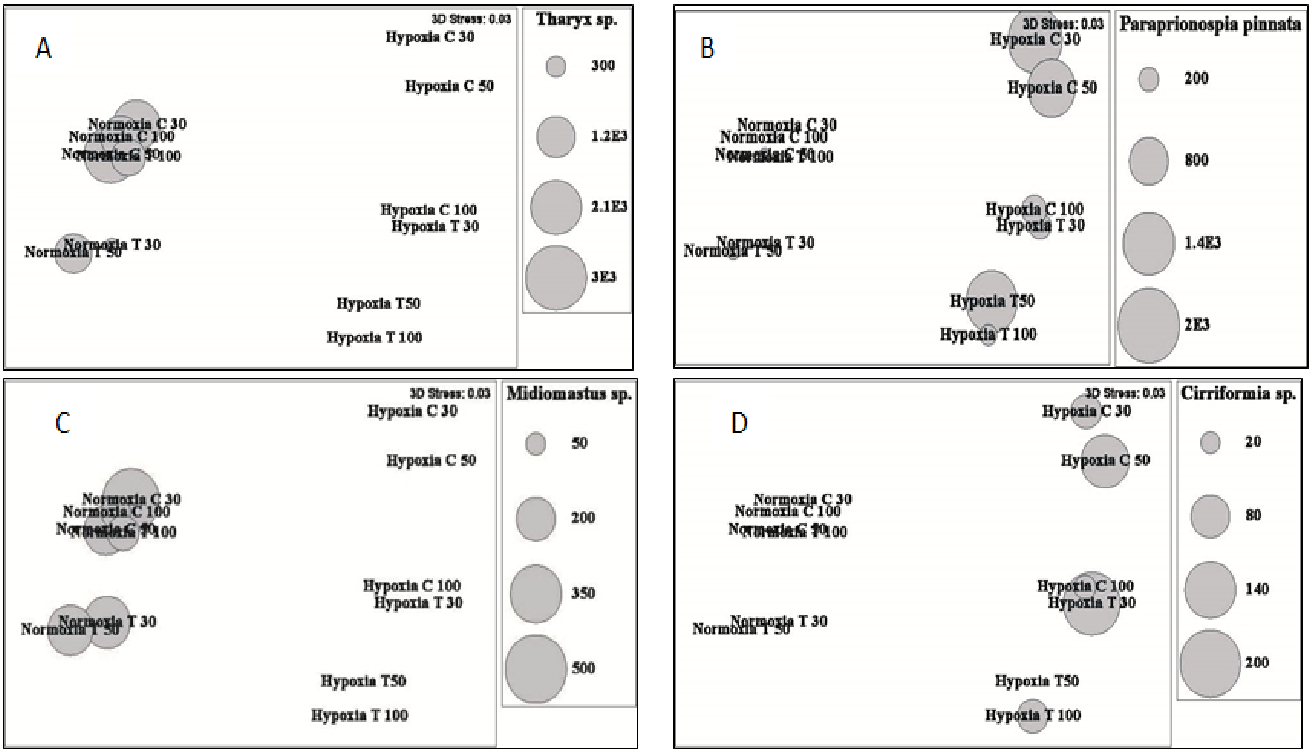

Figure 6: Seasonal distribution of species and abundance pattern.

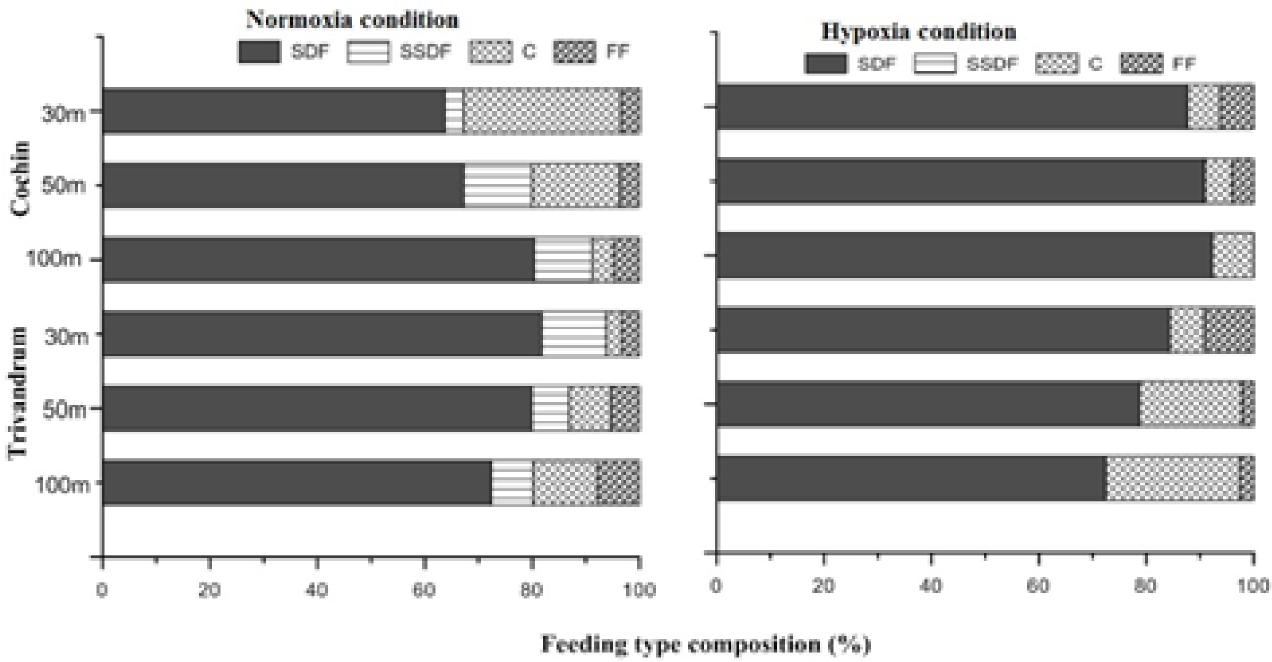

Figure 7: Seasonal distributions of feeding types of macrofauna occurred in southwest coast of Arabian Sea (SDF: surface deposit feeder, SSDF: subsurface deposit-feeder, C: Carnivores and FF: suspension feeder or filter feeder).

Group	Family	Species name	Normoxia zone (SIM)						Hypoxia zone (SM)					
			Cochin			Trivandrum			Trivandrum			Cochin		
			Water depth (m)											
			30	50	100	30	50	100	30	50	100	30	50	100
Polychaeta														
	Pilargidae													
		Synelmis sp.	5	0	0	0	0	22	0	0	0	0	0	0
		Ancystrocyllis sp.	47	22	0	15	89	0	25	50	0	0	0	25
	Ampharetidae													
		Amphicteis sp.	0	22	0	0	0	0	0	0	0	0	0	0
	Opheliidae													
		Armandia sp.	0	22	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
	Capitellidae													
		Midiomastus sp.	425	156	0	89	267	133	0	0	0	0	0	0
	Chaetopteridae													
		Chaetopterus sp.	2	22	0	0	44	0	0	1025	0	0	0	0
	Cirrtulidae													
		Cirratulidae sp.	0	0	0	44	0	22	0	0	0	0	0	0
		Cirriformia sp.	0	0	0	0	0	0	175	0	50	50	125	25
		Cirratulus sp.1	0	0	0	0	44	0	0	0	0	0	0	0
		Cirratulus sp.2	0	0	22	0	0	0	0	0	0	0	0	0
		Cirratulus sp.3	17	22	156	0	0	0	0	25	125	0	0	0
		Caulleriella sp.	0	0	0	0	0	0	0	0	0	50	0	0
		Tharyx sp.	1802	2289	1311	141	1111	955	0	0	0	25	0	0
	Cossuridae													
		Cossura sp.	0	0	0	44	0	0	0	25	75	0	0	0
	Dorvilleidae													
		Dorvillidae sp.	7	44	22	0	0	0	0	0	0	0	0	0
		Ophryotrocha sp.	0	0	0	0	0	0	25	0	0	0	0	0
	Polynoidae													
		Euphione sp.	0	0	0	0	0	0	0	0	0	0	75	0
		Eunoe sp.	0	0	0	0	0	0	0	0	0	0	50	0
	Eunicidae													
		Eunice sp.	2	111	0	0	0	0	0	0	0	25	0	0
	Glyceridae													
		Glycera alba	15	89	44	0	0	0	75	0	50	275	175	75
	Goniadidae													
		Glycinde sp.	131	0	0	0	0	22	0	0	0	50	0	0
	Goniadidae													
		Goniada sp.	0	0	0	0	0	0	0	0	0	0	0	50
	Hesionidae													
		Ophiodromus sp.	0	0	0	0	0	0	0	0	0	0	0	25
		Hesionidae sp.	0	0	22	0	0	0	0	0	0	0	0	0
	Amphinomidae													
		Pseudeurythoe sp.	15	133	89	89	0	0	0	0	0	0	0	0
		Harmothos sp.	0	0	0	0	0	0	0	0	0	0	25	0
	Sabellidae													
		Euchone sp.	0	0	0	0	0	0	0	0	0	0	75	0
		Sabellidae	0	0	0	0	0	44	0	0	0	0	0	0
		Chone sp.	0	0	0	0	0	0	0	0	0	0	0	0
		Hydroides sp.	0	0	0	0	0	0	0	25	0	0	0	0
		Megalomma sp.	0	0	0	0	0	0	0	0	0	705	0	0
		Jasmineira sp.	7	89	0	0	89	22	0	25	0	0	0	25
	Paraonidae													
		Aricidae sp.	3	111	22	9	89	22	0	25	0	0	0	0
		Levinsenia sp.	7	333	178	22	0	44	0	0	0	0	0	0
	Lumbrinereidae													
		Lumbrineris longifolia	30	44	111	89	178	44	0	125	0	0	25	25

		Ninoe nigripes	0	0	0	0	0	0	0	50	0	0	75	0
	Ampharetidae													
		Melinna sp.	0	0	0	0	0	0	0	25	0	0	0	0
		Amage sp.	12	89	0	17	0	111	0	25	0	0	0	0
	Magelonidae													
		Magelona cincta	10	44	0	0	0	133	75	175	0	100	0	25
	Nephtyidae													
		Nepthys inermis	0	89	0	0	0	0	0	0	0	0	0	0
		Nepthys sp.	0	22	0	267	133	0	0	0	0	0	0	0
	Nereididae													
		Micronereides sp.	0	89	0	0	0	0	0	0	0	0	0	0
		Neries sp.	0	0	0	0	0	0	150	0	0	0	0	0
	Onuphide													
		Onuphis sp.	79	0	22	22	0	0	0	25	0	0	0	0
	Pisionidae													
		Pisionidens sp.	0	0	0	0	0	0	0	0	0	0	50	0
	Phyllodocidae													
		Eteone sp.	0	0	0	0	0	0	0	25	0	25	50	0
		Phyllodoce sp.	40	44	0	2	0	22	0	0	0	75	75	0
	Spionidae													
		Prionospia steenstrupi	0	0	0	0	0	0	150	350	0	0	0	200
		Prionospia cirrifera	706	44	178	178	0	89	275	25	200	950	1350	25
		Prionospia pygmaea	10	0	22	22	0	22	125	25	75	600	350	125
		Paraprionospia cordifolia	5	67	22	22	89	22	250	1375	50	1550	1200	325
		Prionospia cirrobranchiata	2	0	0	22	0	0	0	450	50	0	0	0
		Prionospio sp.	168	178	311	311	44	22	0	0	0	0	0	0
		Prionospio aucklandica	0	44	22	22	44	133	0	0	0	0	0	0
		Scolelepis sp.	0	0	0	0	0	0	0	0	0	0	200	0
		Spiophanes sp.	0	0	0	0	0	0	0	0	0	1000	0	0
		Streblospio sp.	0	0	0	0	0	0	175	0	0	125	0	0
	Orbiniidae													
		Scoloplos sp.	0	22	0	0	0	0	0	0	0	900	50	0
	Syllidae													
		Syllids sp.	12	0	0	0	0	0	0	0	0	0	0	0
		Exogone sp.	15	200	22	0	0	0	0	0	0	0	0	0
	Trichobranchidae													
		Trichobranchus sp.	0	0	0	0	0	0	0	25	0	0	0	0
	Terebellidae													
		Terebellides sp.	5	22	0	0	0	0	0	75	0	0	25	0
		Lanice conchilega	0	0	0	0	0	0	0	50	0	0	50	0
		Amphitrite sp.	0	0	0	0	0	0	0	0	0	25	0	0
Crustacea														
		Isopoda	0	0	0	0	0	0	0	0	0	75	50	0
		Mystidea	0	0	0	0	0	0	0	0	0	0	50	0
		Ostropoda	0	22	0	0	0	0	0	25	0	0	0	50
		Shrimp larva	32	22	0	0	0	0	0	0	25	0	75	0
		Sand dollar	0	0	0	0	0	0	0	0	0	0	225	0
		Tanaidacea	15	89	0	0	0	22	0	25	0	0	0	0
		Decapoda larva	0	0	0	0	0	0	0	0	0	0	0	25
		Cumacea	7	22	22	0	89	0	0	50	0	50	0	0
		Caperlloidea	12	0	0	0	0	22	50	50	0	775	50	0
		Ampelisca sp.		0	0	0	0		25	50	0	350	50	0
		Byblis sp.	0	0	0	0	0	0	0	0	0	150	0	0
		Lijeborgiidae	0	0	0	0	0	0	25	25	0	50	0	0
Bivalvia														
		Bivalvia	99	0	178	0	0	0	75	75	0	100	50	0
		Gnathia cerina	0	0	22	0	0	0	0	0	0	0	0	0
		Arca sp.	0	0	0	0	0	22	0	0	0	0	0	0
		Babylonia	0	22	0	0	0	0	0	0	0	0	0	0
		Corbiculidae	0	0	0	0	0	0	0	0	0	0	0	0

		Cylichna	0	0	22	0	0	0	0	0	0	0	0	0
		Glycymeridae	2	0	0	0	0	0	0	0	0	0	0	0
		Mesodesmatidae	7	67	22	0	0	0	0	0	0	0	0	0
		Nuculena	0	0	22	0	0	0	0	0	0	0	0	0
		Nucula	7	0	0	0	0	0	0	0	0	0	0	0
		Tellina	0	0	22	0	0	0	0	0	0	0	0	0
		Naticidae	0	22	0	0	0	0	0	0	0	0	0	0
		Trochidae	0	22	0	0	0	0	0	0	0	0	0	0
		Gastropoda	10	0	0	0	0	0	0	0	0	25	75	0
Minor phyla														
		Nematoda	721	244	356	53	0	178	0	0	0	0	0	0
		Nematinea	97	244	89	0	89	22	0	0	0	0	0	0
		Sipuncula	111	111	22	4	44	0	0	0	0	0	0	0
Oligochaeta														
		Oligocheata	96	67	67	15	0	111	0	0	0	0	0	0
Total abundance(Ind.m^{-2})			4795	5484	3420	1499	2443	2261	1675	4325	700	8105	4650	1025

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

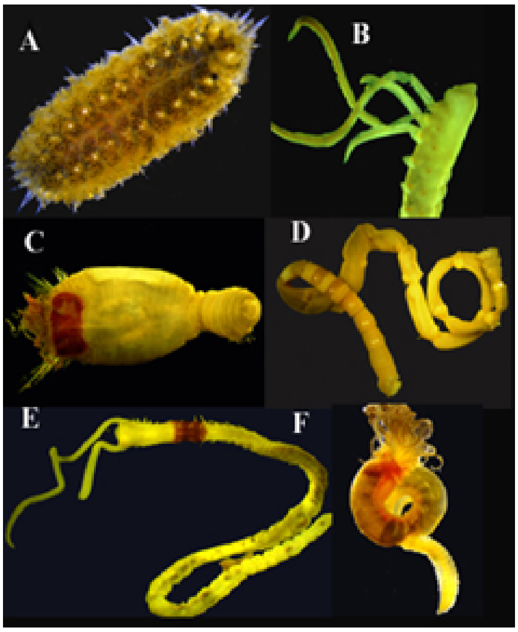

Figure 8: A: *Thormora jukesii*, B: *Paraprionospio cordifolia*, C: *sternaspis scutata,* D: *Maldanella* sp. E: *Magelona cincta* F. *Terebellides stroemi.* In figure B, E and F respiratory surface gills improved in hypoxia condition, photograph of anterior part of polychaetes with well-developed branchia.

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.

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 the 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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