Influence of Environmental Factors on Distribution of Macrobenthos along the West Coast of India

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***Abstract*: Benthos form an important component of marine food chain. The present study describes the distribution of macrobenthic community under the influence of an environmental gradient influenced by hypoxic condition of the north-west Arabian Sea. It is subjected to low oxygen (<63µM) conditions. A study of macrobenthos in this region was carried out over 31 stations distributed in the depth range of 13m to 375m. Faunal density ranged from 16 to 3642 indv.m^{-2}. A total of 58 taxa were recorded, dominated by Polychaeta and Bivalvia. The Shannon diversity index (*H'*) varied between 1.03 and 2.98, while Species richness (*S*) was found to vary between 1 and 38. The Species dominance (*D*) varied between 1 and 14.07. These community parameters were highest at 40m depth. Opportunistic and dominant polychaetes such as *Paraprionospio pinnata*, *Minuspio cirriferra*, *Cossura coasta* and *Magelona* sp. can be used as indicator species of hypoxic condition. The macrobenthic community structure in the area is comparable to other hypoxic areas. Benthos of such areas appears to be governed by a combination of environmental factors such as temperature, salinity, dissolved oxygen and sediment organic carbon acting together in this area.**

Keywords— Macrobenthos, Arabian Sea, continental shelf, Polychaeta, hypoxia, RDA

I. INTRODUCTION

The Arabian Sea, northwestern part of the Indian Ocean, covers a total area of about 3,862,000 km^2 and is located between 8 to 24^{0}N and 50 to 77^0 E. It is a biogeochemically active area characterized by high biological productivity and oxygen minimum zone (OMZ) [1-2]. The continental margin of the Arabian Sea is characterized by a wide continental shelf and narrow slope in the north and a narrow shelf and wider slope towards the south [3]. Major part of western continental shelf of India is bathed with upwelled water having < 0.5 ml l-1 oxygen concentration during the peak upwelling season in August-September. It is extended in an area of 180,000 km^2 of the eastern Arabian Sea and is the largest of all coastal hypoxic sites [4]. During the last few decades, anthropogenic inputs of excess nutrients into the coastal environment through agricultural activities and wastewater discharge have dramatically increased the occurrence of coastal eutrophication and hypoxia [5]. The sedentary and sessile macrobenthic assemblages are susceptible to anthropogenic stressors and are the first casualty of environmental disturbances [6]. Benthic Polychaeta form the major component of macrobenthos. They play significant role in the marine food web [7]. Hypoxia adversely affect benthic animals, thereby significantly affecting the ecosystem functions such as bio-irrigation and bioturbation. Although information on the benthos in general of the western continental shelf of India and OMZs of Arabian Sea are available [8-10], the detailed information on benthic polychaete community structure in relation to environmental factors especially during the hypoxia is scarce covering very limited area [11]. Therefore, in view of the increase in hypoxic condition in the western Arabian Sea this study was carried out to understand the role of hypoxia and associated environmental factors in governing the polychaete community structure.

II. MATERIALS AND METHODS

A. Description of Study area

Western continental shelf of India exhibits seasonal hypoxia due to upwelling and enhanced productivity during the southwest monsoon. The west coast of India receives the heaviest rainfall in the Indian subcontinent and because of its geography the major portion of downpour flows into the Arabian Sea through rivers [12]. The runoff along with eutrophication due to upwelled waters causes the oxygen concentration fall below 10 µM during this period on the shelf region. The sampling in the hypoxic zone at 31 stations was carried out along the western continental shelf and upper slope region between Bombay and Cochin, onboard CRV Sindhu Sankalp (SSK 024) and CRV Sagar Paschimi during September-October 2011 and SSK 046 during February 2013 (Table 1, Figure 1). The depth varied between 13 m and 375 m at these sites.

B. Sampling and Methodology

The sediment samples were collected using van Veen grab (0.1m²) in replicates. The samples were sieved through a 0.5 mm sieve on board and preserved in 4 % buffered Formalin-Rose Bengal solution and labelled. A small portion of sediment was taken from each grab for the analysis of sediment texture and organic carbon. Bottom water samples for analysis of dissolved oxygen were collected using Niskin bottles attached to the CTD rosette system from ~1m above the sea bed. Temperature and salinity data were obtained from the CTD. Dissolved oxygen (DO) was estimated by Winkler's method [13]. pH was measured using a pH meter (Thermoscientific Orion 3 star).

Stations	Station codes	Latitude ^{0}N	Longitude ^{0}E	Depth (m)	Sediment type
Bombay 1	B1	18.107	72.831	18	Silty-Clay
Bombay 3	B3	18.018	72.595	40	Silty sand
Ratnagiri 1	R1	16.73	73.241	21	Clayey-silt
Ratnagiri 3	R3	16.672	73.046	48	Silty sand
Goa 3	G3	15.52	73.718	13	Clayey-silt
Goa 4	G4	15.53	73.707	15	Clayey-silt
Goa 5	G5	15.517	73.65	25	Clayey-silt
Goa 6	G6	15.496	73.58	34	Clayey-silt
Goa 7	G7	15.48	73.5	38	Clayey-silt
Goa 8	G8	15.438	73.4	62	Silty-sand
Goa 9	G9	15.411	73.281	70	Sand
Goa 10	G10	15.3691	73.122	102	Silty-sand
Goa 11	G11	15.3466	72.9948	127	Silty-sand
Goa 12	G12	15.3	72.822	164	Clayey-sand
Karwar 2	K2	14.469	74.25	20	Clayey-silt
Karwar 3	K3	14.468	74.1688	30	Clayey-silt
Karwar 10	K10	13.799	73.09	375	Silty sand
Mangalore 1	M1	13.1166	74.6333	27	Sandy-silt
Mangalore 2	M2	13.14	74.63	22	Clayey-silt
Mangalore 3	M3	13.101	74.557	35	Clayey-silt
Mangalore 4	M4	12.95	74.3	62	Sand
Mangalore 8	M8	12.8697	74.1094	110	Silty-sand
Mangalore 9	M9	12.8679	74.0366	205	Silty sand
Cannanore 0	CN0	11.9177	75.1501	27	Sandy-silt
Cannanore 1	CN1	11.848	75.1248	40	Clayey-silt
Cannanore 5	CN5	11.65	74.56	270	Silty sand
Calicut 1	CAL1	11.337	75.6038	21	Clayey-silt
Calicut 3	CAL3	11.3373	75.17	55	Silty sand
Cochin 1	C1	10.1167	76.06	25	Silty-sand
Cochin 2	C2	9.9833	75.76	62	Sand
Cochin 0	C0	9.95	75.6333	100	Silty-sand

Table 1. Sampling locations with station code, position, depth (m) and sediment type

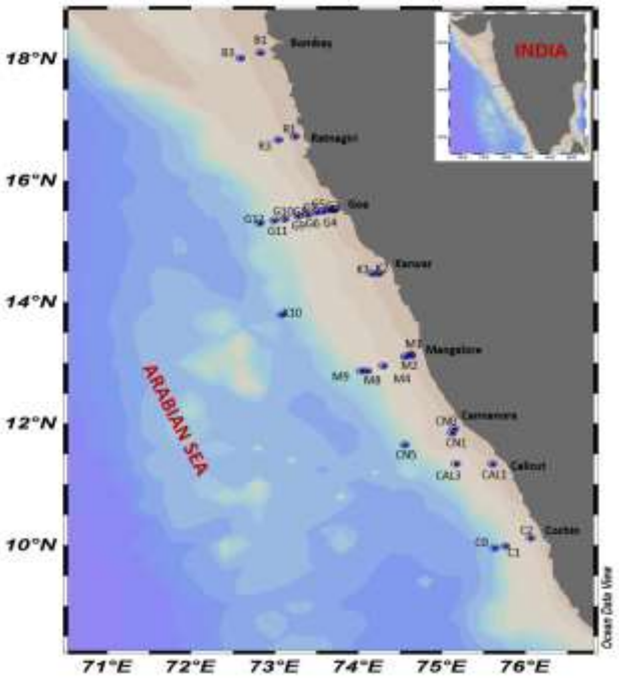

Fig. 1. Map showing study area

C. Laboratory analysis

In laboratory, organisms were sorted out and observed under binocular microscope. The organisms were separated into different groups for further identification. Wet weight was determined by using a high precision electronic balance for biomass. Polychaeta formed the major taxa and were identified as far as possible using taxonomic keys [14-15]. The taxonomic status of genera recorded was also checked and updated from the (World Register of Marine Species) website [16]. Remaining taxa were identified to possible taxonomic level. Feeding types were assigned to Polychaeta by following Fauchald and Jumars [17]. Sediment grain size was analyzed by pipette analysis [18]. Total sediment organic carbon (Corg) was estimated following wet oxidation method [19] and expressed as percentage of sediment dry weight.

D. Statistical Analysis

The univariate measures of diversity such as Species richness (*S*), Pielou's evenness (*J'*), Shannon diversity index (*H'*), Species dominance (D) were calculated using R package. Further, the influence of different environmental variables on macrofaunal groups and dominant polychaetes species was analyzed using RDA (CANOCO 4.5).

III. RESULTS

A. Physico-chemical parameters

1. Bottom water parameters

Fig. 2 (a-c) depicts variations in environmental variables at the study area. The temperature, salinity and pH showed higher values for the northern region (B1 to G9) and lower values for the southern stations (K2 to C0). Temperature at the study area ranged from 10.3 ºC at C2 to 29.18 ºC at M4. Salinity values ranged from 34.66 at M1 to 36 at G8. The pH ranged from 7.51 at CN5 to 8.23 at M1. The bottom water dissolved oxygen content ranged from below detection limit (BDL) at stations G3, G5, M2, CN0 and CAL1 to 4.44 ml l^{-1} at station B1. Anoxia was reported at CAL 1.

2. Sediment parameters

Six types of sediment texture were observed in the study area (Figure 1c). Twelve stations were dominated by clayey-silt type of sediment. Another set of twelve stations was represented by silty-sand texture. Stations G9, M4 and C2 were dominated by sandy substratum. Only two stations namely, M1 and CN0 were dominated by sandy-silt type texture. While station B1 was represented by silty-clay and G12 by clayey-sand sediment type. The sediment organic carbon (Corg) was high (4.46 %) at station K10 (375m) and low at station M4 (0.29 %).

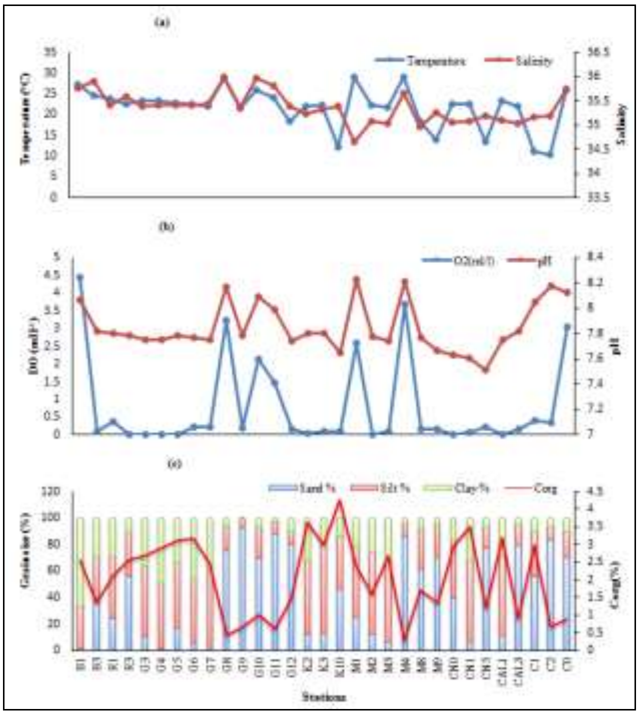

Fig. 2. Variations in environmental parameters in the study area

B. *Abundance and biomass*

The study area reported a total of 17 macrofauna groups (Figure 3). A total of 13754 macrobenthic individuals were collected during the present study. The total macrofauna abundance ranged from 16 (1± 4 indv. m^{-2}) at CN1 to 3642 (214± 815 indv. m^{-2}) at B3 (Figure 4a). No organisms were reported at stations G8, G10, G11 and G12. Polychaeta dominated the community with a contribution of 76 % to the total abundance with highest number of individuals at station B3 (3425 indv. m^{-2} , Figure 4a). It was represented by 42 species belonging to 27 families. The Spionidae family with 39 % contribution was most dominant followed by Cossuridae (8%) and the remaining contributed < 8 %. Mollusca with 9.87% was the second dominant group followed by Foraminifera (6.21 %), Crustacea (2.93 %), Nematoda (2.62 %), Oligochaeta (1.69 %), Sipuncula (0.5 %), Fish larvae (0.15 %), Nemertina (0.10%). The wet weight biomass (g m^{-2}) showed significant variations between the stations (Figure 4a). It ranged from 0.0042g m^{-2} at stations G5, G7 to 22.50 g m^{-2} 144 at station R1. Higher biomass was recorded at station R1 was mainly due to the presence of large sized bivalves. Polychaete biomass ranged from 0.0042g m^{-2} at stations G5, G7 to 10.56 g m^{-2} at station B3.

C. *Diversity*

The diversity indices showed no distinct pattern (Figure 4b & c). Species diversity (*H'*) varied from 0.45 at station CAL1 to 2.98 at station B3. Pielou's evenness (*J'*) varied from 0.65 at station CAL 1 to 1 at stations M9 and CN1. Species Richness (*S*) for macrofauna varied from 1 at station CN1 to 38 at station B3. Species dominance (*D*) varied from 1 at station 1 to 14.07 at B3.

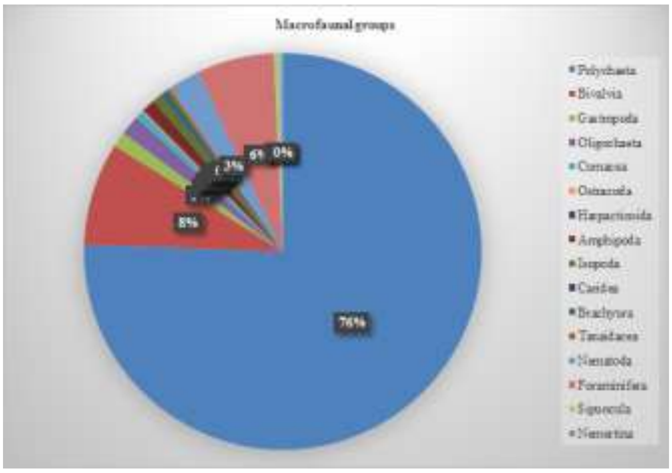

Fig. 3 Percent contribution by different macrofauna groups

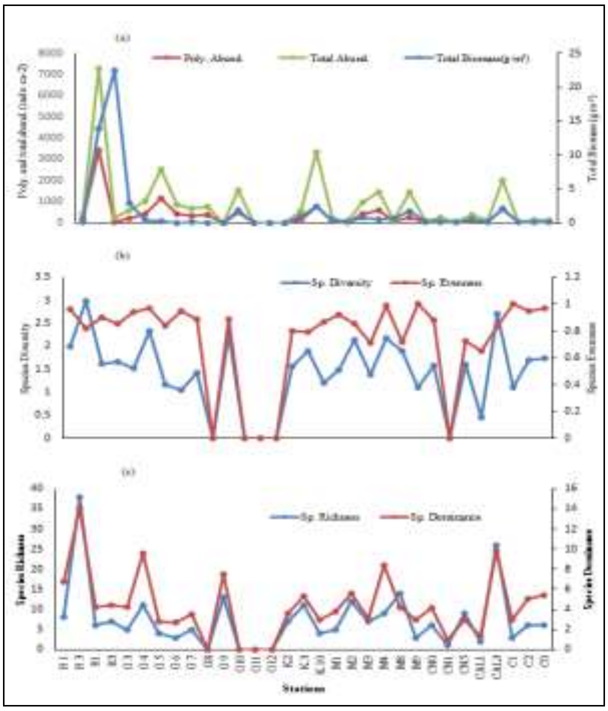

Fig. 4. Variations in macrofaunal abundance, biomass and diversity indices

D. *Polychaete feeding types*

The Polychaete community was dominated by surface deposit feeders (SDF) (62 %) and Carnivores species (CAR) (23%) (Table 2). The subsurface deposit feeders (SSDF) and filter feeders (FF) contributed 14 % and 1 % respectively. The SDF were mainly represented by *P. pinnata*, *M. cirrifera*, *Magelona* sp., *Cirratulus* sp. The Carnivores were mainly represented by *Diopatra* sp., *Sigambra* sp., *Lumbrineris sp. and Arabella* sp. The SSDF were mainly represented by *Cossura coasta*, *Euclymene* sp., *Maldane* sp. The highest surface deposit feeders were recorded at stations CN0, CN1 and CAL 1, where CN0 was represented by sandy-silt and CN1 and CN5 were both represented by clayey-silt texture. Least SDF were reported at CN5 (14%) represented by silty-sand where the subsurface deposit feeders showed maximum composition (43%). The Carnivores were present with maximum composition (56%) at B1 which was dominated by silty-clay sediment. Filter feeders were the least recorded in the study area and were present only at two stations, B3 (4%) and CAL3 (1%) dominated by silty-sand sediment.

Macrofauna taxa	Range	Feeding modes
POLYCHAETA		
Family Ampharetidae		
Amphorete sp.	0-50	SDF
Isolda sp.	0-84	SDF
Ampharetidae sp.	0-168	SDF
Family Apistobranchidae		
Apistobranchidaesp.	0-24	SDF
Family Arabellidae		
Arabella sp.	0-168	CAR
Family Capitellidae		
Capitella sp.	0-25	SSDF
Mediomastus sp.	0-13	SSDF
Notomastus sp.	0-38	SSDF
Family Cirratulidae		
Cirratulus sp.	0-213	SDF
Tharyx sp.	0-84	SDF
Chaetozone sp.	0-42	SDF
Family Cossuridae		
Cossura coasta	0-338	SSDF
Family Dorvillidae		
Dorvillea sp.	0-42	CAR
Family Eunicidae		
Diopatra sp.	0-463	CAR
Eunice sp.	0-150	CAR
Family Flabelligeridae		
Flabelligera sp.	0-25	SDF
Family Glyceridae		
Glycera sp.	0-84	CAR
Family Goniadidae		
Goniada sp.	0-13	CAR
Family Hesionidae		
Hesione sp.	0-42	CAR
Family Lumbrineridae		
Lumbrineris sp.	0-126	CAR
Family Maldanidae		
Maldane sp.	0-25	SSDF
Euclymene sp.	0-138	SSDF
Family Magelonidae sp.		
Magelona sp.	0-211	SDF
Family Nephtyidae		
Nephtys sp.	0-42	CAR
Family Nereidae		
Nereis sp.	0-42	CAR
Dendronereis sp.	0-50	CAR

Table 2. Macrofauna abundance range and polychaetes' feeding modes at the study area

Macrofauna taxa	Range	Feeding modes
POLYCHAETA		
Family Oribiniidae		
Scoloplos sp.	0-40	SSDF
Family Paraonidae		
Aricidea sp.	0-75	SDF
Paraonidae sp.	0-13	SDF
Family Phyllodocidae		
Phyllodoce sp.	0-42	CAR
Family Pilargidae		
Sigambra sp.	0-104	CAR
Family Pisionidae		
Pisionidae sp.	0-38	SSDF
Family Sabellidae		
Chone sp.	0-125	FF
Family Spionidae		
Paraprionospio pinnata	0-488	SDF
Minuspio cirrifera	0-363	SDF
Prionospio ehlersi	0-50	SDF
Spiophanes sp.	0-13	SDF
Spionidae sp.1	0-263	SDF
Spionidae sp. 2	0-25	SDF
Family Sternaspidae		
Sternaspis scutata	0-25	SSDF
Family Terebellidae		
Terebellidae sp.	0-13	SDF
Family Trochochaetidae		
Trochochaetidae sp.	0-13	SDF
BIVALVIA	0-312	-
GASTROPODA	0-40	-
OLIGOCHAETA	0-125	-
CUMACEA	0-48	-
OSTRACODA	0-13	-
HARPACTICOIDA	0-8	-
AMPHIPODA	0-50	-
ISOPODA	0-100	-
CARIDEA	0-16	-
BRACHYURA	0-42	-
TANAIDACEA	0-13	-
NEMATODA	0-168	-
FORAMINIFERA	0-3513	-
SIPUNCULA	0-50	-
NEMERTINA	0-13	-
FISH LARVAE	0-13	-

Table 3. Feeding modes: SDF-Surface Deposit Feeder, SSDF-Subsurface Deposit Feeder, CAR- Carnivores, FF- Filter Feeder

E. RDA Analysis

RDA analyses revealed the influence of environmental parameters on macrofaunal groups (Figure 5) Total sediment organic carbon (Corg), silt % exhibited strong positive impact on Polychaeta, Bivalvia, Gastropoda and Foraminifera. Salinity and Clay % showed negative impact on the Brachyura, Amphipoda and Nematoda. Also the dissolved oxygen, pH, temperature and to a lesser extent sand showed negative impact on Polychaeta, Bivalvia, Gastropoda and Foraminifera which means that lower values of these parameters were positively influencing these groups of macrofauna. Sand % and temperature were positively influencing Tanaidacea. Further, the RDA analyses to understand the impact of environmental variables on dominant polychaete species showed that their distribution and abundance was positively influenced by increase in salinity, Clay %, temperature, silt % and total sediment organic carbon. The dissolved oxygen, pH, depth and sand % showed a negative influence on the polychaete species (Figure 6). The dominant polychaetes such as *P. pinnata* (PPT), *M. cirriferra* (MCF), *Cossura coasta* (CCA), *Diopatra* sp. (DSP), *Magelona* sp. (MSP), *Ampharetidae* sp. (ASP), *Cirratulus* sp. (CSP), Spionidae sp. (SSP) and *Lumbrineris* sp. (LSP) were positively influenced by salinity, clay %, silt % to a greater extent, while temperature and total sediment organic carbon to a lesser extent. The opportunistic species such as *Prionospio pinnata*, *Minuspio cirriferra* were positively influenced by Silt %, lower dissolved oxygen, low pH and shallow depths.

IV. DISCUSSION

A. Physico-chemical parameters

The physico-chemical parameters and the productivity of the overlying water determines the distribution, abundance and diversity of benthic fauna [20]. Food availability, recruitment, hydrographic conditions and sediment stability form the important variables controlling the benthic community structure in a tropical regime [21]. The present study recorded higher water temperatures at several stations in the north and low in southern stations. Such variability in the distribution of temperature in the study area has been reported earlier [1]. Distribution of bottom water salinity followed a trend similar to temperature. The higher values in the northern region is the result of intrusion of high saline water from Arabian Sea and low in south may be the result of low saline waters entering from the Bay of Bengal [22]. The study area is characterized by low oxygen. This is reported to be the effect of eutrophication caused by upwelling during the southwest monsoon [5]. The oxygen values below detection limit at some 10 stations is the sign of anoxic condition which will affect the benthic community adversely.

The sediment in the study stations was dominated by clayey-silt and silty-sand type. The presence of finer sediment in the inner shelf is derived from low saline water laden with fine sediment discharged into the coastal waters. The mixing of low and high saline water leads to flocculation followed by deposition of fine-grained sediments. Such a deposition occurs in shallow waters within 5-50m depth [23]. The sediment organic carbon retention is mainly governed by the sediment texture [24], degree of conservation or preservation of organic carbon and rate of sedimentation. The high sediment organic carbon in the area could be the result of deposition fine

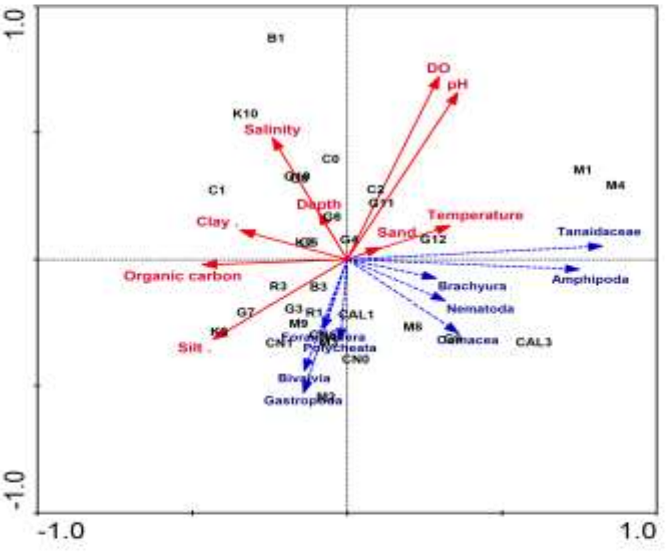

Fig. 5. RDA analyses showing influence of environmental variables on macrofauna

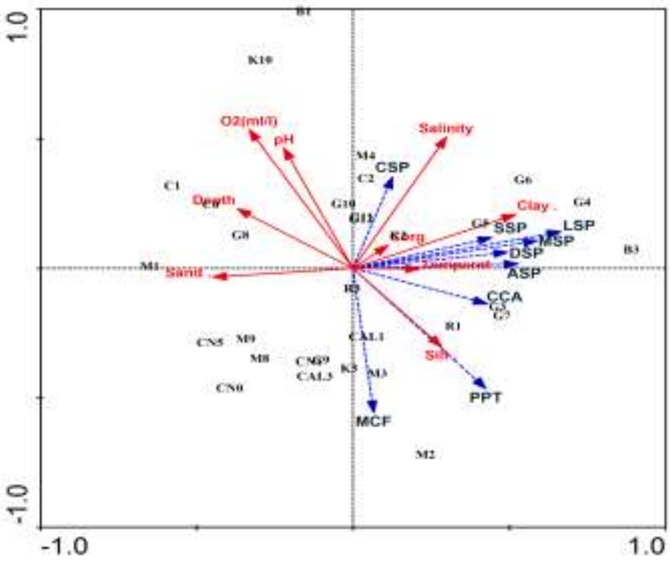

Fig. 6. RDA analyses showing influence of environmental variables on dominant polychaete species. Codes: *Paraprionospio pinnata* (PPT), *Minuspio cirriferra* (MCF), *Cossura coasta* (CCA), *Diopatra* sp. (DSP), *Magelona* sp. (MSP), *Ampharettidae* sp. (ASP), *Cirratulus* sp. (CSP), *Spionidae* sp. (SSP), *Lumbrineris* sp. (LSP).

sediment of terrestrial origin and high biological productivity [2]. The study stations fall in the hypoxic zone where low oxygen condition can lead to more organic matter accumulation and burial [25].

B. Abundance, biomass and community structure

Macrofauna plays a significant role in energy flow to the benthic ecosystem. Among the benthic organisms, polychaetes form the principal food resources of the demersal fishes [26]. Overall a low diversity observed could be because of the reduced spatial heterogeneity of food resources or enhanced environmental stress [27-28]. Low species richness, high dominance of polychaete species in this low oxygen stations was reported. Similar observations have been made in OMZ settings [29-30]. The abundance and biomass recorded in the present study was lower than reported earlier [31, 8]. This could be the combined effect of environmental factors and hydrographic condition [32] and sampling strategy. In the present study, it is observed that the stations with greater than 3 % of Corg such as G5, G6, CAL1 with exception of K2 were represented by less number of groups. While stations with low Corg were represented by higher number of groups. This may be because of avoidance of high Corg by the fauna [33, 8]. The variation in occurrence of species and other faunal groups could be related to the recruitment events, predation, competition and mortality [34]. High salinity in the northern region associated with high benthic biomass is observed in the present study and similar observations have been made earlier [35]. The distribution was related to sediment texture. Polychaetes and bivalves preferred a wider range of sediment texture while the crustaceans such as Brachyura, Cumacea, Amphipoda being epibenthic feeder were present at stations with silty-sand substratum having low Corg.

The salient feature of the present hypoxic area is the dominance of polychaeta having high percentage of surface deposit feeders in macrobenthos. Benthic trophic group thrive in areas having high organic fluxes, high organic carbon and sediment stability [36]. The detrital particle flux from pelagic to benthos takes place due to intensive sedimentation events [37]. This is particularly true for the organic fraction originating from pelagic production which forms the primary food source for benthos [1]. In other hypoxic areas of the world ocean polychaetes have contributed high to very high percentage (>90%) of fauna [38]. Study from the inner shelf and slope of Indian 12 Seas has recorded similar feature in macrobenthic distribution and polychaete abundance [32, 9]. The members of families Spionidae and Cirratulidae have also been recorded from other OMZ areas. They are the predominant taxa in areas where oxygen falls below 0.5 ml l^{-1} [38-39] Dominance of spionidae species i,e., *Paraprionospio pinnata* and *Minuspio cirrifera* in the present study corroborate the earlier reports. Polychaeta are highly opportunistic group which adapt to changing environmental conditions more effectively than other ecologically more sensitive species [40]. Their strong association with the characteristic environment along the shelf was evident from RDA analysis. The polychaete community was strongly influenced by temperature, salinity, lower dissolved oxygen, low pH, clay and silt % and Corg. Thus, the present study highlights that these macrobenthic organisms could be good indicators of anthropogenic disturbances.

V. CONCLUSION

It is inferred that the complex interaction of hydrographic parameters including coastal upwelling and hypoxia during the southwest and northeast monsoon affects macrobenthos distribution and community structure in the northeastern Arabian Sea shelf. Dissolved oxygen was an important factor for the faunal abundance. The study showed the dominance of polychaeta especially opportunistic species belonging to families Spionidae (*Paraprionospio pinnata*, *Minuspio cirrifera*) and Cossuridae (*Cossura coasta*) in very low oxygen region. The absence of crustaceans at these stations indicates their sensitivity to low oxygen. The spread of hypoxic zones due to eutrophication or the terrestrial input along the shelf is of concern as it would alter the physico-chemical variables, which in turn will affect the biology of the region. The data generated through this study represents the state of benthic community for specific time period. It has clearly demonstrated the significant influence of hypoxia and associated benthic environmental variables in structuring and controlling the macrobenthic abundance and species diversity of polychaeta.

VI. ACKNOWLEDGMENTS

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