

## Macrofaunal community structure in the Western Indian Continental Margin including oxygen minimum zone

Ingole\* B.S, Sautya S., Sivadas S., Singh R., Nanajkar M

National Institute of Oceanography (Council of Scientific & Industrial Research), Dona Paula, Goa, 403004, INDIA

\*Corresponding author: [baban@nio.org](mailto:baban@nio.org);

Tel: +91 832 2450242; Fax: +91 832 2450606

### Abstract

Patterns of macrofaunal distribution were studied along the western Indian continental margin to distinguish the role of habitat heterogeneity in generating and maintaining community structure. A transect perpendicular to the coast at 14° N latitude was selected for seabed sampling. Eight stations were sampled in the depth range 34 m to 2546 m and characterized with respect to macrofaunal composition, abundance, biomass, diversity and feeding type. The sediments in the shelf region (34, 48, 100 m) and upper slope (525 m) were characterized by silty and sandy facies, whereas the mid slope (1001 m), lower slope (1524 m) and basin (2001, 2546 m) consisted of clayey silts. The highest value of sediment chlorophyll-*a* (Chl-*a*) and total organic carbon ( $C_{org}$ ) were recorded from the mid slope areas. Faunal abundance and biomass increased from the shallow to deeper depths in the shelf region, and decreased in the slope region (525-1001 m) due to the reduced bottom-water oxygen. The community parameters showed an overall increase in both the lower slope and basin areas. A total of 81 macro-invertebrate species belonging to 5 major groups represented the macrofauna of the area. Polychaeta was the major group at all depths. Among polychaete families, species of the Spionidae, particularly *Prionospio pinnata*, predominated at the oxygen minimum zone (OMZ) core and Cossuridae dominated in the lower part of the OMZ in sediments of the mid slope region (1001 m depth).

Species diversity was higher in the basin than in the slope region. Fluctuations in diversity appear to be partly due to the bottom-water dissolved oxygen (DO) gradient which includes values that are below the oxygen tolerance of many benthic species. Further, Margalef's index (*d*) and Shannon-Wiener index (*H'*) showed a significant negative ( $p < 0.01$ ) relationship between sediment Chl-*a* and  $C_{org}$ , suggesting food availability as a critical factor in species dominance. Results of multivariate analyses suggest that for continental margin fauna, different physiographic provinces and an oxygen gradient have a higher influence on the species composition and diversity than other oceanographic conditions.

**Key words:** Deep-sea; Macrofauna; Habitat heterogeneity; Continental margin; Oxygen minimum zone; Arabian Sea.

## Problem

In the past few decades, considerable attention has been given to the study of continental margin biodiversity (Flach & Thomsen 1998; Tselepidis *et al.* 2000; Palma *et al.* 2005). The continental margin, extending from the sublittoral to the abyssal zone, has various interesting habitats that can be described by geomorphological features (e.g shelf, slope, rise, marginal highs, etc.) and their related environmental conditions (e.g. depth, pressure, temperature, salinity, light, dissolved oxygen, sediment characters and other biogeochemical features). All of these features play an important role in generating and maintaining biodiversity along the continental margin.

The western Indian continental margin, located in the eastern Arabian Sea of the northern Indian Ocean, represents a series of complex environments including a permanent, oxygen depleted zone. Although the Arabian Sea covers only 2% of the surface area of the World Ocean, it is one of the most biologically productive regions (Ryther & Menzel 1965), mainly due to the upwelling of nutrients during the summer, southwest monsoon and convective mixing during the winter, northeast monsoon (Madhupratap *et al.* 1996; Wiggert *et al.* 2005). The high biological productivity combines with slow re-oxygenation to produce one of the most intense oxygen depletion zones observed anywhere in the open ocean (Swallow 1984; Naik & Naqvi 2002). This zone intercepts the continental margin at the shelf and continental slope (i.e. bathyal depths), creating extensive seafloor habitats subject to these extreme conditions, which have persisted for hundreds of thousands of years (Reichart *et al.* 1998). These oxygen-depleted zones are known as oxygen minimum zones (OMZs: defined by oxygen concentration  $<0.5 \text{ ml L}^{-1}$ ). The OMZ in the Arabian Sea is spread over  $\sim 285,000 \text{ km}^2$  of the benthic area. About 25% of the OMZ has an oxygen concentration  $< 0.5 \text{ ml L}^{-1}$  and 30% of the area has an oxygen level of  $<0.2 \text{ ml L}^{-1}$  (Helly & Levin 2004). This OMZ is the thickest found anywhere in the world and accounts for 40% of the global pelagic  $\text{N}_2$  production (Bange *et al.* 2005). According to recently published data, widespread open-ocean oxygen deficiency in this region results from the combination of a high oxygen demand arising from high biological productivity in the surface water and the limited supply of oxygen in intermediate waters (Jayakumar *et al.* 2009). This low concentration of dissolved oxygen (DO) has a major impact on biogeochemical processes such as the carbon and nitrogen cycles (Naqvi *et al.* 2006) and on benthic ecological functioning (Levin 2003).

The vertical distribution of benthic populations and their community structure is greatly influenced by the presence of OMZs (Rosenberg *et al.* 1983; Arntz *et al.* 1991; Levin 2003). The structure of macrofaunal communities in OMZs typically shows reduced diversity and high dominance in comparison with non-OMZ slope environments (Levin *et al.* 2001), although the patterns of faunal abundance are less consistent. Biomass is often reduced where oxygen levels are lowest because the

macrofauna of the OMZs are generally dominated by small-bodied polychaetes, features likely associated with the low DO, the high availability of food and the reduction in predation pressure (Levin *et al.* 2002). Previous studies of open-ocean OMZ benthos have suggested a strong lower-boundary effect, with high densities of hypoxic-tolerant faunas aggregating in the lower part of the OMZ (Thompson *et al.* 1985; Levin 2003; Hughes *et al.* 2009).

Various geomorphological features occur on the western Indian continental margin. The shelf break in this region occurs between 80 m and 110 m, is wider in the northern shelf and narrows progressively towards the south. Various physical, chemical and geological processes control the sedimentation in this region. The sedimentary input is primarily from rivers that drain from the Western Ghats mountain range. Information on the benthos of the deep eastern Arabian Sea, especially from the Indian margin, however, is not available for global comparison. Neyman (1969) studied the benthos of the eastern Arabian Sea and suggested that bottom fauna is poor between 80 m and 150 m depth due to an inflow of subsurface water with low oxygen content. Earlier studies on the Indian shelf showed a definite correlation between macrofaunal standing stocks and organic carbon as well as the nature of the substrata (Parulekar & Wagh 1975; Harkantra *et al.* 1980). The community structure and abundance of nearshore and shallow-water macrofauna is reasonably well known (Jayaraj *et al.* 2007, 2008 a, b; Ingole *et al.* 2009; Joydas & Damodaran 2009). Most of these reports highlight the influence of environmental factors on the structure of the macrobenthic community. However, most studies were based on sampling at shallow (<200 m) depths in the shelf region. As a result, information on the benthos of the western Indian slope including the OMZ and abyssal zone is not available. Recently, benthic biological and biogeochemical process within the OMZ were investigated on the Pakistan Margin of the northern Arabian Sea (Levin *et al.* 2009; Hughes *et al.* 2009; Cowie & Levin 2009; Murty *et al.* 2009; Gooday *et al.* 2009).

The aims of this paper are: 1) to generate regional biodiversity data that can be globally compared to other continental margins, 2) to study the sources of habitat heterogeneity from shallow- to deep-water regions, and 3) to identify the environmental factors responsible for changing the macrofaunal community structure on the western Indian margin.

It has been recognized that the environmental conditions of the eastern side are different from those acting on the western region of the Arabian Sea (Qasim 1982). Furthermore, the macrofaunal data show a striking contrast (especially through the OMZ core) between the western Oman margin and the eastern Pakistan margin of the northern Arabian Sea (Hughes *et al.* 2009). In recent studies, increased

productivity has been reported from the Arabian Sea as well as the west coast of India (Madhupratap *et al.* 1996; Prasanna Kumar *et al.* 2000).

Thus, on the basis of previous studies, we hypothesize that:

1. Increased productivity of the Indian margin will be reflect in standing stocks that are higher than those on the Pakistan margin.
2. Macrofaunal abundance and biomass will be high and diversity will be relatively low in the OMZ region and low DO concentration will be responsible for changing the community structure at some depths.

### **Oceanographic settings of the study area**

The surface area of the Arabian Sea, between latitudes 0° and 25° N and longitudes 50° and 80° E, is about  $6.225 \times 10^6$  km<sup>2</sup>. It is bound on the northern, eastern and western sides by the land masses of Asia and Africa. It is an area of negative water balance, where evaporation exceeds precipitation and runoff. The excess of evaporation over precipitation is highest (100 - 150 cm) off the Arabian coast and decreases steadily towards the southeast. A slight excess of precipitation over evaporation (<20 cm) occurs annually off the southwest coast of India (Venkateswaran 1956).

Surface circulation in the Arabian Sea is controlled by the seasonal variation in winds. Two types of winds blow from different directions and form two different monsoon seasons: the SW monsoon during summer (which leads to precipitation over the entire Indian peninsula) and the NE monsoon during winter. During the SW monsoon, biological productivity in the Arabian Sea lies mainly around the centers of seasonal upwelling off Arabian Peninsula, Somalia and southwest India (Qasim 1977). During this time, the upwelled waters on the southwestern margin of India are restricted by a thin (5 - 10 m) lens of low-salinity water, which originates from local precipitation and runoff from the narrow coastal plain that receives heavy rainfall (Stramma *et al.*1996).

### *Study area*

A detailed benthic sampling programme was performed on board *ORV Sagar Kanya* during August 2007 (cruise no. SK 237) in order to generate local-scale benthic data. A single transect was selected perpendicular to the coast at 14° N latitude (Fig. 1). In this region, the shelf break is located about 105 km from the coast ( $\approx$  120 m depth), followed by a 116 km wide shelf margin basin. A mid-shelf basement ridge, the dominant visible feature, divides the basin into eastern and western sections. The

bottom topography in the mid-lower slope region is strewn with prominent flat-topped marginal highs (Rao & Veerayya 2000; Chakraborty *et al.* 2006).

## **Materials and methods**

### *Sampling depth and sub-sampling*

Eight stations (Table 1) were sampled at water depths of 34 m, 48 m, 102 m, 525 m, 1001 m, 1524 m, 2001 m and 2546 m using a spade box corer (50 x 50 x 50 cm size). Two box cores were used to collect sediment samples at each depth, except at station 47 where only one box core was obtained. According to Rao & Veerayya (2000) the transect can be divided into five regions – shelf region (34 m, 48 m and 102 m), upper slope (525 m), mid slope (1001 m), lower slope (1524 m) and basin (2001 m and 2546 m). In the present study, all three slope depths were considered as a single region and therefore the study area was divided into three depth zones – shelf, slope and basin. Sub-sampling was done with a PVC core (15 cm dia) and 1-3 subcores were taken from each box core. Separate subcores were collected for organic carbon ( $C_{org}$ ), sediment chlorophyll-*a* (Chl-*a*) measurements and texture (grain sizes) analysis and frozen at  $-20^{\circ}\text{C}$ . The water overlying the box core and sub-core sediment samples was sieved through a 300- $\mu\text{m}$  mesh screen and then fixed and preserved using buffered 10% formalin to which rose Bengal was added. Bottom-water salinity and temperature data were collected using a CTD deployed down to 1524 m. CTD data from deeper depths could not be obtained due to technical problems. Bottom-water DO measurements were taken using a DO sensor attached to the CTD for depths down to 1524 m. Below this depth, water was collected using Niskin bottles and was used for DO and Chl-*a* analysis.

### *Laboratory analysis and data processing*

DO was analyzed by Winkler's method (Strickland & Parsons 1968). Chl-*a* was estimated using an acetone extraction method (Holm-Hansen 1978). Total carbon analyses were carried out on the upper 2 cm of freeze-dried sediments using a NCS 2500 (Model- EA/NA1110) CNS analyzer. Inorganic carbon was analyzed by a  $\text{CO}_2$  Culometer analyzer and the percentage of  $\text{CaCO}_3$  was calculated. Percentage of  $C_{org}$  was calculated by subtracting inorganic from total carbon. In the top 2 cm, sediment texture was determined by Malvern Laser Analyzer (Model – Hydro 2000MU).

In the laboratory, the faunal samples were washed on a 300  $\mu\text{m}$  sieve, sorted, identified and counted. Specimens were identified to the lowest possible taxon. Biomass was determined by using the wet

weight method after blotting. At each site, the faunal counts from individual subcores (1 to 6 subcores from 1, usually 2, box cores) were averaged and the mean value converted to individuals  $m^{-2}$ . The faunal counts from the water overlying the box core were divided by the number of subcores taken. The biomass (shell on) was estimated similarly and converted to  $g\ m^{-2}$  (wet weight).

The data were subjected to univariate analyses to study the benthic community structure using Margalef's index (Margalef 1968) for species richness ( $d$ ), Pielou's index (Pielou 1966) for species evenness ( $J'$ ), and the Shannon-Wiener index (Shannon & Weaver 1963) for species diversity ( $H'$  by using  $\log_e$ ). The significance of the regions outlined *a priori* was tested with multivariate analysis (Non-metric Multi-Dimensional Scaling (MDS)) and the organisms that contributed most to the observed differences among groups were found by means of SIMPER (similarity percentage) using PRIMER 6 (Clarke & Warwick 1994). Linear regression between macrofaunal diversity indices and environmental variables was tested using STATISTICA 6. Feeding types were assigned to Annelida based on information in Fauchald & Jumars (1979).

## Results

### *Environmental variables*

The physico-chemical characteristics of the study area are summarized in Table 2.

#### Bottom water

The salinity of the bottom water did not vary at different depths, whereas temperature showed variations between the bathymetric gradients. The bottom-water DO ranged from 0.08 to 2.3  $ml\ l^{-1}$  at different sampling stations. The lowest DO value was on the upper slope and increased from the lower slope reaching a peak in the basin area (Table 2). The highest bottom-water Chl-*a* was in the shelf region (48 m) and the lowest value was observed on the upper slope. In general, the Chl-*a* was low at most of the stations (Table 2).

#### Sediment

Four types of sediment textures were observed in the study area. The shelf region and upper slopes were characterized by silty and sandy facies, whereas the mid slope, lower slope and Arabian basin were characterized by clayey silts. Sediment Chl-*a* ranged from 0.2 – 2.1  $\mu g\ g^{-1}$  and showed significant

spatial variation. The middle slope showed the highest Chl-*a*, and the lowest values were recorded in the shelf (48 m depth) and basin (2546 m) region. Sediment C<sub>org</sub> was high on the mid slope (4.4%) and a low value of 0.3% was observed at the basin station (2001 m). Organic carbon was high at stations with high silt content, which was the dominant sediment type in the study area.

#### *Macrofaunal population abundance and biomass*

A total of 81 macro-invertebrate species from 5 major groups represented the macrofauna of the western Indian margin. Of the identified taxa, 67 (82.7%) were polychaetes, 4 (4.9%) crustaceans, 7 (8.6%) minor phyla and 3 (3.8%) others (e.g. Bivalvia, Arachnida and Oligochaeta). Polychaeta was by far the dominant macrofaunal group at all the water depths (Fig. 2). The maximum proportion (100%) of polychaetes was observed on the slope (1001 and 1524 m) and minimum (71.4%) in the basin (2546 m). The next most abundant group was Crustacea with maximum relative abundance (23%) at 2546 m and minimum (3.3%) at 102 m depth.

The average macrofaunal abundance increased from depths of 48 to 102 m depth, then decreased precipitously to a minimum value at the 525-m site, before increasing gradually down to basin depths (2001- 2546 m) (Fig. 3). The macrofaunal abundance was much higher at the deeper stations on the shelf (mean values ~ 2900 – 3722 ind m<sup>-2</sup>) than at the shallower site (mean value 971 ind m<sup>-2</sup>). The slope fauna was extremely sparse, with the mean ( $\pm$ SD) abundance of 528  $\pm$  156 ind m<sup>-2</sup>. The highest value was recorded on the lower slope and the lowest in the mid-slope region. Mean abundance within the basin varied from 1188 – 1244 ind m<sup>-2</sup>.

The average macrofaunal biomass showed a similar trend. The highest biomass value (13.3 g.m<sup>-2</sup>) was found at a water depth of 102 m while the lowest value (0.08 g m<sup>-2</sup>) was found at 1001 m. Biomass was higher on the upper slope than at other stations (Fig. 4).

#### Macrofaunal composition

The values for macrofaunal composition in different physiographical provinces are described below and are shown in Table 3.

##### Shelf (34, 48 and 102 m)

A total of 43 taxa were identified and Polychaeta was the dominant group, contributing 85% - 95% to the faunal abundance. Of the 28 polychaete families identified in the entire area, 24 were observed on the shelf. The family Paraonidae made the highest contribution (36.8%) followed by Spionidae (16.9%)

and Capitellidae (9.3%). Natantia and Oligochaeta were present but species of Amphipoda were not recorded. Other groups such as Bivalvia and minor phyla were found in low numbers.

Slope (525, 1001 and 1524 m)

Only two groups, Polychaeta and Crustacea were present in this depth range. The majority 80 - 100% of the macrofaunal animals were polychaetes, which were represented by 14 families. The contribution of Cossuridae was maximal (62.5%) at the mid slope area. Spionidae were predominant on the upper slope. The maximum number of families (10) was observed in the lower slope area. The only crustacean taxon present in this physiographic region was the Amphipoda.

Basin (2001 and 2546 m)

The highest number of taxa (52) was present in the basinal region. This area was marked by a lower proportion (69 - 71%) of Polychaeta than the other two regions. A total of 21 polychaete families was observed, with the Spionidae and Paraonidae being dominant (24.5% and 14% respectively). The highest contribution of Crustacea (23% at 2546 m) and minor phyla (12.1% at 2001 m) were also observed in this region. The Tanaidacea was the most abundant group among the crustaceans, contributing ~12% to the total macrofaunal community.

#### *Dominant taxa*

The three dominant species (representing 22 – 100% of the macrofaunal community) at their respective depths, together with their rank, are summarised in Table 4 and Figure 5.

Among these species, the polychaetes *Aricidea* sp., *Prionospio pinnata* and *Sternaspis* sp. were dominant at a depth of 34 m. However, their faunal contribution decreased sharply as water depth increased. At a depth of 48 m, the three top-ranked species were the polychaetes *Levinsenia* sp. 1, *P. pinnata* and *Staurocephalus* sp.; again their abundances declined with increasing water depth. *Mediomastus* sp. was dominant at 102 m, but was not observed at any other depth except for at the shallowest site (34 m), where *Prionospio pinnata* was ranked second dominant.

*Prionospio pinnata*, Cirratulidae sp. 2 and an unidentified Amphipoda species dominated in the upper slope area. Only three species were observed in the mid slope region, with *Cossura* sp. dominating. *Levinsenia* sp. 2 was present on the lower slope. The polychaete Cirratulidae sp. 2 was the only taxon restricted to the slope region.

The highest taxonomic diversity was observed in the basin. Here, Tanaidaceans were dominant at both depths (2001 and 2546 m). Tanaidaceans were also present on the shelf, but with low abundance and



were absent on the slope. At 2001 m, Spionidae sp. 1 and Paraonidae sp. 1 appeared as second and third ranked respectively. The polychaete *Prionospio* sp. occupied second rank at the 2546 m depth.

#### *Multivariate (MDS) analysis of community structure*

An MDS plot based on the average abundance of macrofauna revealed three distinct groups at 20% similarity, reflecting the three different physiographic regions (Fig. 6) in the study area. Group 1 was restricted to the shelf region and was characterized by the dominance of *P. pinnata*, *A. constricta* and *Aricidea* sp. Group 2 covered the slope region (mid and lower) and was dominated by *Cossura* sp. and Cirratulidae sp. 2. Group 3 consisted of the two deeper stations located in the Arabian basin with polychaetes *Levinsenia* sp.2, Cirratulidae sp. 3, along with and Tanaidacea, as the dominant taxa. The upper slope remained separate as it did not cluster with any of the above groups.

#### *Diversity indices*

Margalef's index ( $d$ ) varied from 0.3 to 5.5 over the study area (Fig. 7). A higher  $d$  value was recorded from the basin (2001 m) than in the mid slope. Species evenness varied from 0.6 to 0.9, with the higher value recorded at a depth of 2001 m, rather than at a shallower depth (34 m) on the shelf. Values of  $H'$  varied from 0.9 to 3.4. The highest  $H'$  value was also observed in the basin (2001 m).

#### *Distribution of polychaete feeding types*

Surface deposit-feeders (SDF) were the dominant feeding type at all the sampling depths (Fig. 8). The highest contribution of SDF was on the slope. The frequency of SDF was also high (50 – 75%) within the slope area. The mid slope showed the highest contribution (50%) of sub-surface deposit feeders (SSDF). The highest representation of carnivores was on the shelf region (particularly at 48 m). Moreover, a moderately high contribution of carnivores was observed at the two basin sites. Carnivores were not present in the in the mid slope area and filter feeders were rare across the study area.

#### *Correlation of environmental and community parameters*

The correlation between macrobenthic parameters and environmental variables were based on Pearson's correlation analyses (Table 5). Macrofaunal abundance was positively correlated with sand and  $\text{CaCO}_3$  ( $p < 0.05$ ). The  $H'$  values were negatively correlated with sediment Chl-*a* and  $C_{\text{org}}$  ( $p < 0.05$ ). Margalef's index showed a significant negative relationship between  $C_{\text{org}}$  and silt content ( $p < 0.05$ ) and a positive relationship with sand and  $\text{CaCO}_3$  ( $p < 0.05$ ). Only species evenness showed a significant negative relationship with bottom water salinity ( $p < 0.05$ ). Other environmental variables, including DO, did not show significant correlations with macrofaunal community parameters.

## Discussion

The observed high values of sediment  $C_{org}$  on the slope, and low values in the basin region, were in agreement with previous studies of the western Indian margin. According to Rao & Veerayya (2000) diverse topographic features on the slope and the associated hydrodynamic processes play an important role in the enrichment of  $C_{org}$ . DO values ranged from 0.08 to 2.3 ml l<sup>-1</sup>. The lowest DO value was measured at the upper slope station. Based on DO concentrations, the OMZ was found to extend from a water depth of 102 m to 1001 m in the study area, with the core of the OMZ located at 525 m where the lowest DO value was recorded.

### *Macrofaunal biomass*

Macrofaunal biomass increased from 34 m to 102 m, then showed an abrupt decline with the lowest value measured at 1001 m, before increasing again from 1001 m to 2546 m. Previous studies from the shelf region (Harkantra *et al.* 1980; Parulekar *et al.* 1982; Harkantra 2004) report higher biomass values at the shelf stations. The differences noted may be due to the varied sampling methods including different types of gear, water depth and the sampling season. Moreover, all the previous studies sampled at shallower depths (<200m). Although the biomass in the present study was low, the values increased on the shelf from the shallower to the deeper regions, a pattern not reported in earlier studies (Kurian 1971; Parulekar & Dwivedi 1974; Ansari *et al.* 1977; Jayaraj *et al.* 2007, 2008b).

The high benthic biomass at shallower depths in the shelf region may reflect higher food availability in the form of  $C_{org}$  and Chl-*a*. The supply of food to the sub-tidal benthic environment depends on the proximity to the shore and water depth (Levinton 1982). Sediment Chl-*a* at 34 m and 102 m was moderately high. Furthermore, biomass was higher at 102 m compared to shallower regions, due to the presence of *Natantia* and *Arenicola* sp. Although the highest  $C_{org}$  was recorded in the lower part (1001 m) of the OMZ, biomass was lower at this depth and was related to faunal abundance. Comparatively high biomass was observed at 525 m, which was not reflected in abundance. This was due to the presence of the large-sized species *P.pinnata*. There was an increase in biomass thereafter to the lower boundary of the OMZ towards the deeper region.

### *Macrofaunal abundance and composition*

Macrofaunal abundance increased from the shallow to the deeper region of the shelf, decreased to its lowest value in the lower part of OMZ and then increased towards the deeper region. Macrofaunal abundance in the western Indian OMZ core (525 m) and the lower part of the OMZ were extremely low compared to all other OMZ margins studied to date, except for the Pakistan margin located on the

northeastern side of the Arabian Sea (Table 6). In the present study, low faunal abundance was observed on the slope at depths where DO concentrations were 0.08 and 0.28 ml L<sup>-1</sup> although measurements of Chl-*a* and C<sub>org</sub> were high. Levin *et al.* (2009) suggested that oxygen thresholds for macrofaunal abundance at ~0.11 – 0.13 mL<sup>-1</sup> when the other conditions are favorable. It is possible that oxygen thresholds in our study area are higher than on the Pakistan margin.

Among the polychaetes, spionids were highly dominant within the OMZ core whereas cirratulids were the predominant taxon in other regions. Spionids and cirratulids were also the dominant families within the OMZ on the upper slope (400 – 700m) off Oman (Levin *et al.* 2000) and a shallow shelf station (140 m), the lower OMZ boundary (1200 m) and below the OMZ (1850 m) on the Pakistan margin (Hughes *et al.* 2009). In the present study, cossurids were mainly restricted to the lower part of the OMZ (1001), although they were also present on the lower slope which is located just beneath the OMZ. This polychaete group was abundant in the OMZ core (100 – 200 m) off Central Chile (Gallardo *et al.* 2004). Because these polychaetes are deposit-feeders (both surface and sub-surface), their predominance may reflect food availability (e.g. sediment C<sub>org</sub> and Chl-*a*) within the OMZ region. Paraonids were abundant at sites above and below the OMZ regions as well as the upper shelf and the basin. Similarly, paranoids were abundant at 1850 m on the Pakistan margin (Hughes *et al.* 2009).

The Cossuridae and Spionidae were important taxa where oxygen concentrations were lowest. Cossurids are common in many bathyal OMZs, including the Pakistan margin where they are present at depths of 940 m and 1200 m, both areas of high C<sub>org</sub>. Furthermore, the global bathyal data on benthic faunal abundance and biomass indicate a reduction in density at the OMZ core (Rosenberg *et al.* 1983; Mullins *et al.* 1985; Wishner *et al.* 1995) and an increase at the OMZ boundaries (Levin *et al.* 2003).

#### *Influence of habitat heterogeneity on macrofaunal community structure*

The MDS ordination based on the macrofaunal community clustered the sites into 3 groups representing three different bathymetric provinces. Group 1 comprised in stations of the shelf region, where opportunistic species such as *Aricidea* sp., *Prionospio pinnata*, *Mediomastus* sp. and *Ancistrasyllis constricta* were dominant. These polychaete species were most abundant at a depth of 102 m, where the DO concentration was low (<0.5 ml l<sup>-1</sup>). For most of these species, this tolerance of stressful conditions such as the low DO (<0.5 ml l<sup>-1</sup>) has been observed in the OMZs of the Oman margin and off central Chile (Levin *et al.* 2000; Gallardo *et al.* 2004).

Group 2 was restricted to the slope region (1001 m and 1524 m) where the SSDF species *Cossura* sp. and Cirratulidae sp. 2 predominated within the macrofaunal community. Although 1524 m was outside

the OMZ, it was close to the OMZ boundary and the measured DO was not as high, nor as stable as the values measured at deeper stations.

Group 3, the most diverse group, was dominated by different taxa, including Tanaidacea, *Levinsenia* sp. 2 and Cirratulidae sp. 2. This group was confined to the two deepest (basin) sites, of which the 2546 m region had a higher value of  $C_{org}$  (excluding those measured at the OMZ stations). The nature and variability of the organic matter supplied to the deep-sea floor influence the structure and function of the communities (Grassle & Morse-Porteous 1987). Tanaidacea are not very diverse in shallow waters but are well represented in the deep sea (Dojiri & Sieg 1997; Pavithran *et al.* 2007) where they are one of the most abundant taxa. Among the crustaceans, Isopoda and Amphipoda are also particularly abundant and diverse in the deep sea, where they are among the most typical members of the deep-sea benthic communities (Sanders *et al.* 1965; Brandt *et al.* 2007). The diversity of the Group 3 assemblage in the present study was comparable to that of 'normal' deep-sea habitats.

The OMZ core fauna did not cluster with any group. This was due to the higher abundance of *P. pinnata* (Fig.5), which is known to tolerate low oxygen concentration (Gallardo *et al.* 2004). The dominance of *P. pinnata* has also been reported within the OMZ off Concepcion (Palma *et al.* 2005). In addition, one particular morphological adaptation of this species, an expanded branchial structure has been observed only in the OMZ settings, specifically at the lowest level of oxygen concentration on the upper slope (Fig. 9) and not in any other habitat included in the present study. Some other species were restricted to specific areas. *Mediomastus* sp., *Arenicola* sp., *Levinsenia* sp.1, *Ancistrasyllis constricta* were confined to the shelf, Cirratulidae sp. 2 to the slope and *Lumbriconereis* sp.2, *Polyopthalmus* sp., Cirratulidae sp. 3 to the basin sites (Table 3). Of the non-polychaete taxa, oligochaetes were found only on the shelf and thus were also restricted to the upper portion of the OMZ. Oligochaetes have been reported from the low-oxygen zone in a basin off Peru with partially laminated sediments (Levin *et al.* 2002). During the present study, macrofaunal diversity was generally higher at shelf and basin sites than on the slope reflecting the lower concentration of oxygen in the slope region.

The bathymetric distribution of polychaete feeding types is directly related to the amount of organic matter available in the sediments, with SDF strongly dominating the slope regions. Moreover, the proportion of carnivores in the shelf and basin regions increased with depth, proportional to the decline in the deposit-feeding component. The positive relationship between  $C_{org}$  and deposit feeders, and the increase of carnivores where deposit feeders were less abundant has been observed at the Oman and Crete margins (Levin *et al.* 2000; Tselepidis *et al.* 2000).

The result of the present study suggests that macrobenthic community structure on the western Indian margin is not determined by a single factor, but instead is influenced by a combination of environmental factors. Discussing animal-sediment relationships, Snelgrove & Butman (1994) concluded that the complexity of soft-sediment communities may defy any simple paradigm with regard to any single factor controlling their settlement and colonization. The distribution of annelids within OMZs worldwide has been reviewed by Levin (2003), who has suggested the different patterns of community structure are due to changes of hydrodynamic, bathymetric or geochemical factors rather than dissolved oxygen alone. Among the biological parameters, abundance and biomass positively correlated with sand and correlated negatively with silt. This is because the sand percentage was higher in shallow water, where higher faunal abundance and biomass were also higher. Similarly, *P. pinnata*, *Cossura* sp. and *Ancistrasyllis* sp. were also observed in sandy sediment at low oxygen concentrations on the western Indian shelf (Jayaraj *et al.* 2008b). The increase of Chl-*a*, in both water and sediment, was related to the enhanced phytoplankton production in the study area.

## Summary and Conclusions

This study reveals several novel characteristics of macrofaunal communities and their response to habitat heterogeneity on the western Indian margin. The physiographic provinces and their related environmental characteristics in the study area generated habitat heterogeneity, which is summarized below together with the corresponding community characteristics.

- a) The shelf (34, 48, 102 m) was dominated by sandy sediment with low DO. It included part of the OMZ at 102 m, and had moderately high sediment  $C_{org}$  content. The shelf contained the highest abundance and biomass with moderately high diversity, species richness and SDF feeding types.
- b) The slope (525, 1001, 1524 m) was characterized by silty sediment and included the OMZ above the lower slope with higher  $C_{org}$ . Diversity and species richness were lowest and the percentage of SDF feeding types was highest here.
- c) The basin (2001, 2546 m) appears to be a normoxic region with silty texture and lower  $C_{org}$  content. This region displayed the highest diversity, species richness and presence of fauna with the maximum numbers of feeding types.

Dominant taxa and faunal composition differed along the gradient of habitat heterogeneity. In general, results from the Pakistan margin were weak predictors for macrofaunal community structure along the Indian margin. The reason for low abundance and biomass in the core and lower boundary parts of the OMZ in the western Indian margin compared to other areas is not clear. Furthermore, the results of the present study did not support our second hypothesis, as macrofaunal abundance and biomass were lower in the OMZ region, except for the in the shallowest part (48, 102 m) where abundance and biomass were high. We believe that further investigation based on seasonal sampling in the shelf region and high-resolution sampling in the OMZ region is required to understand the community interaction with seasonal, environmental changes on the western Indian continental margin.

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**Legends to the text figures:**

Fig. 1. Location map of the study area.

Fig. 2 Depth-wise distribution of macrofaunal groups

Fig. 3. Macrofaunal abundance (ind.m<sup>-2</sup>)

Fig.4. Macrofaunal biomass (g.m<sup>-2</sup>)

Fig. 5. Rank 1 species at various depths and their composition along the sampling transect

Fig. 6 MDS analysis of macrofaunal community

Fig. 7. Depth-wise distribution of community structure indices (d: Margalef index, J': evenness and H': diversity)

Fig.8. Depth-wise distribution of macrobenthic feeding types (%) (SDF: Surface deposit feeders; SSDF:Sub-surface deposit feeders; CF: Carnivore feeder; FF: Filter feeders).

Fig.9. Photograph of anterior part of *Prionospio pinnata* with well-developed branchia observed in upper the slope OMZ.

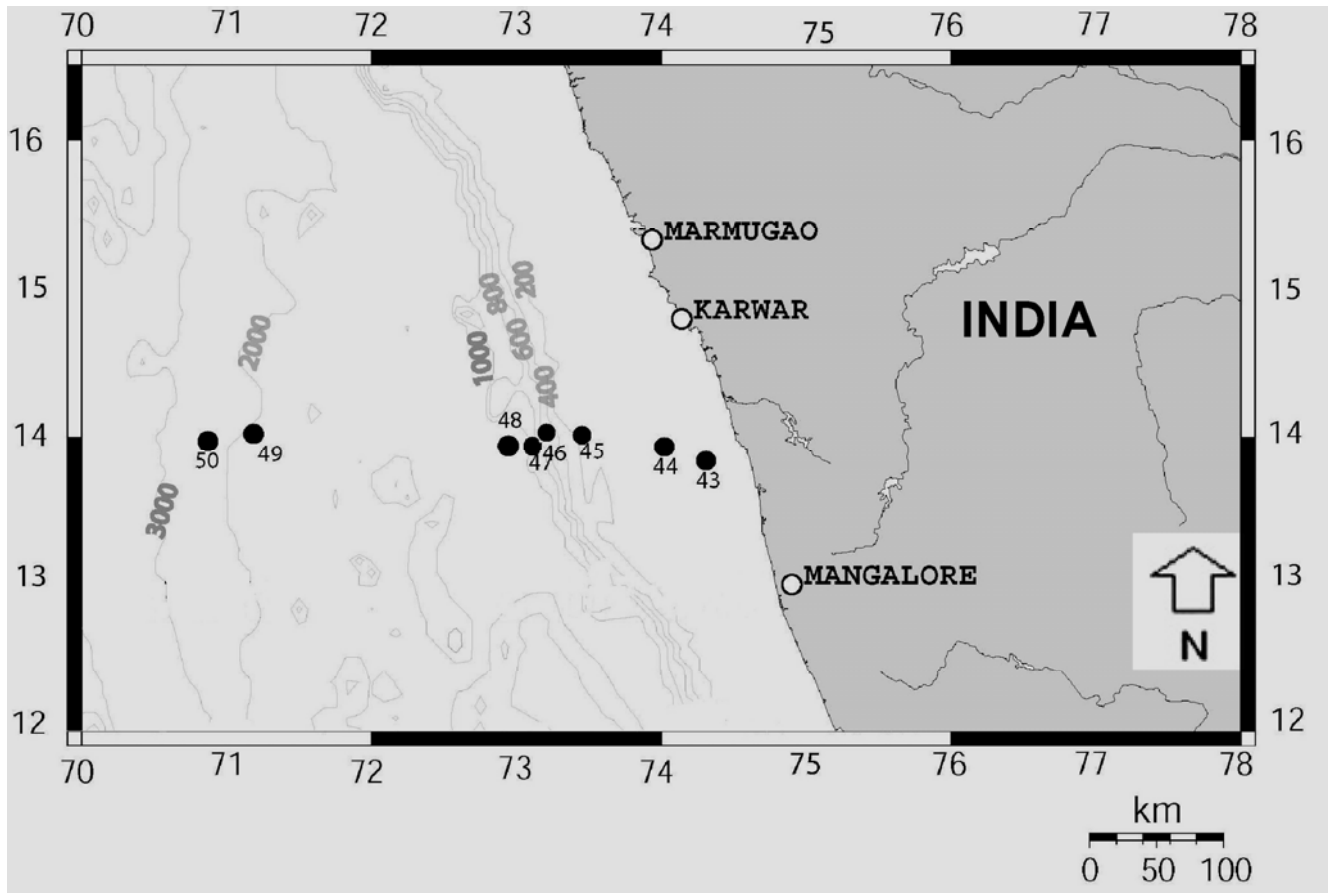


Fig.1

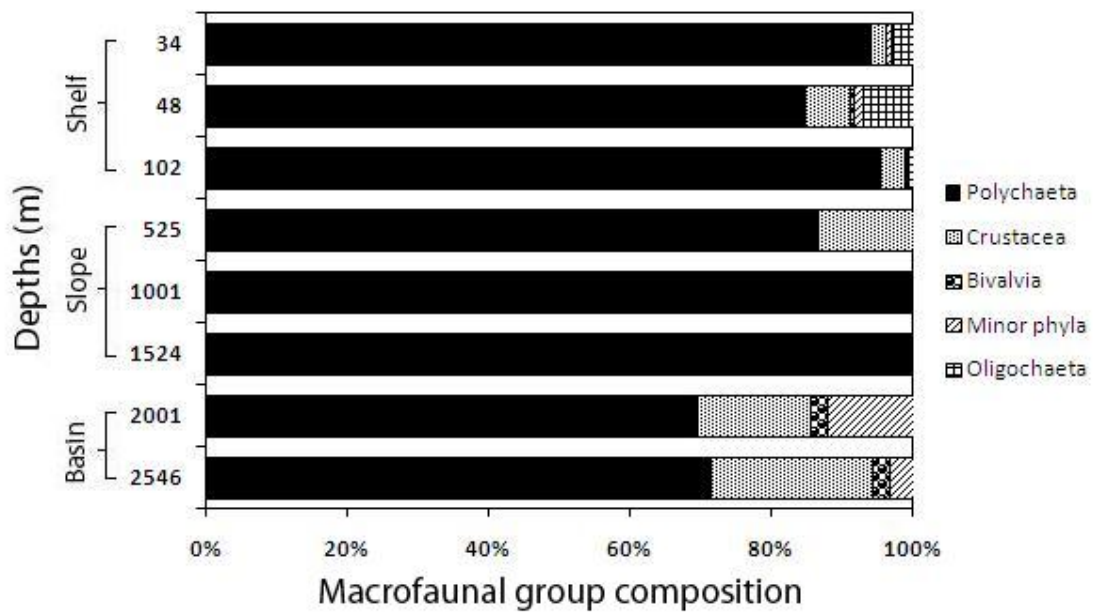


Fig.2

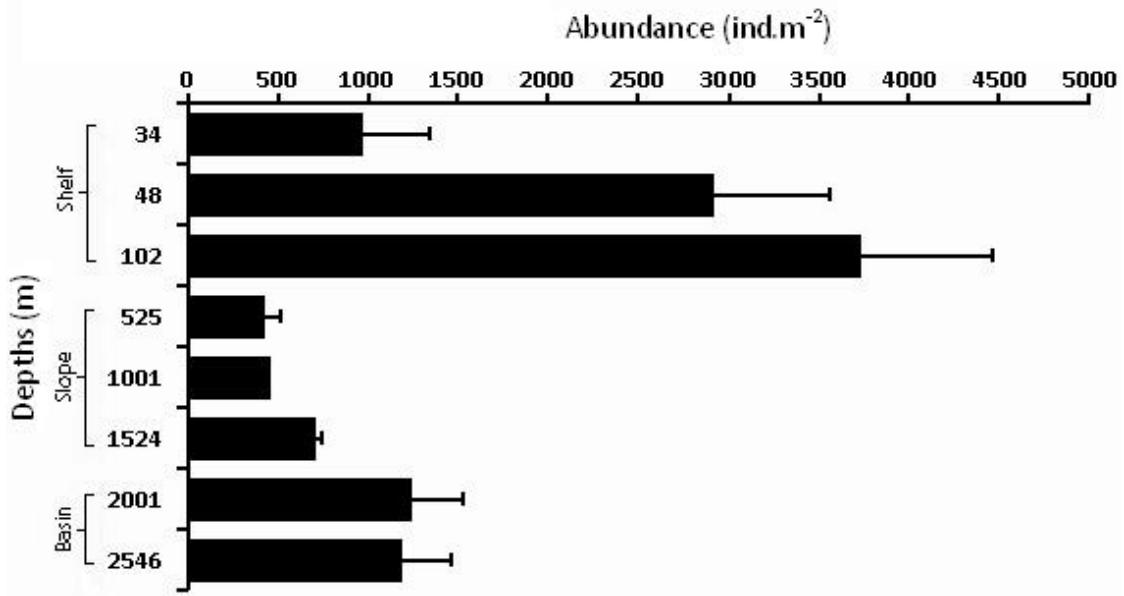


Fig. 3

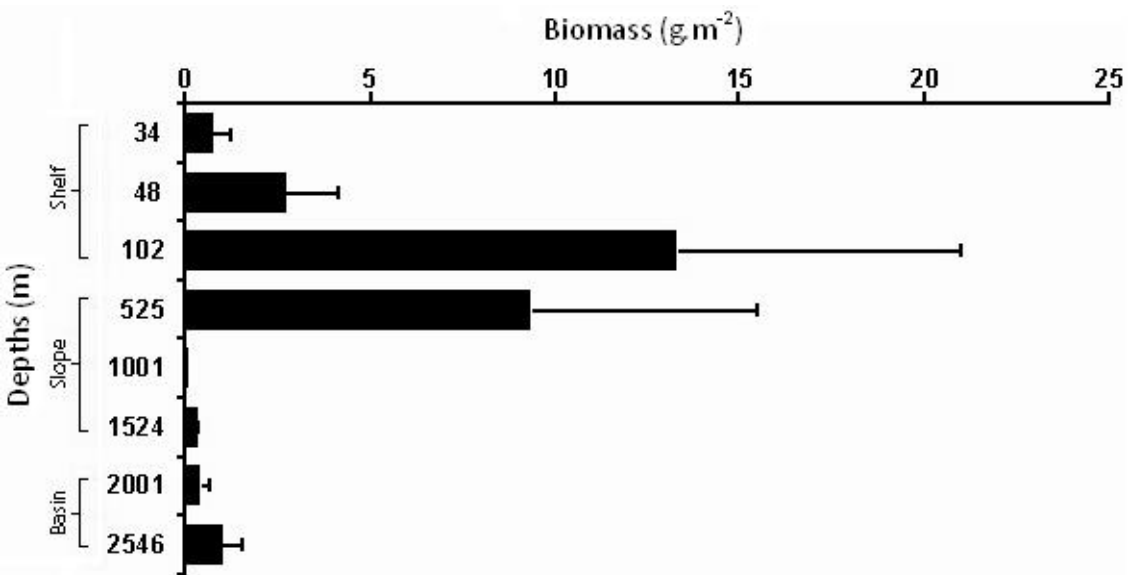


Fig. 4

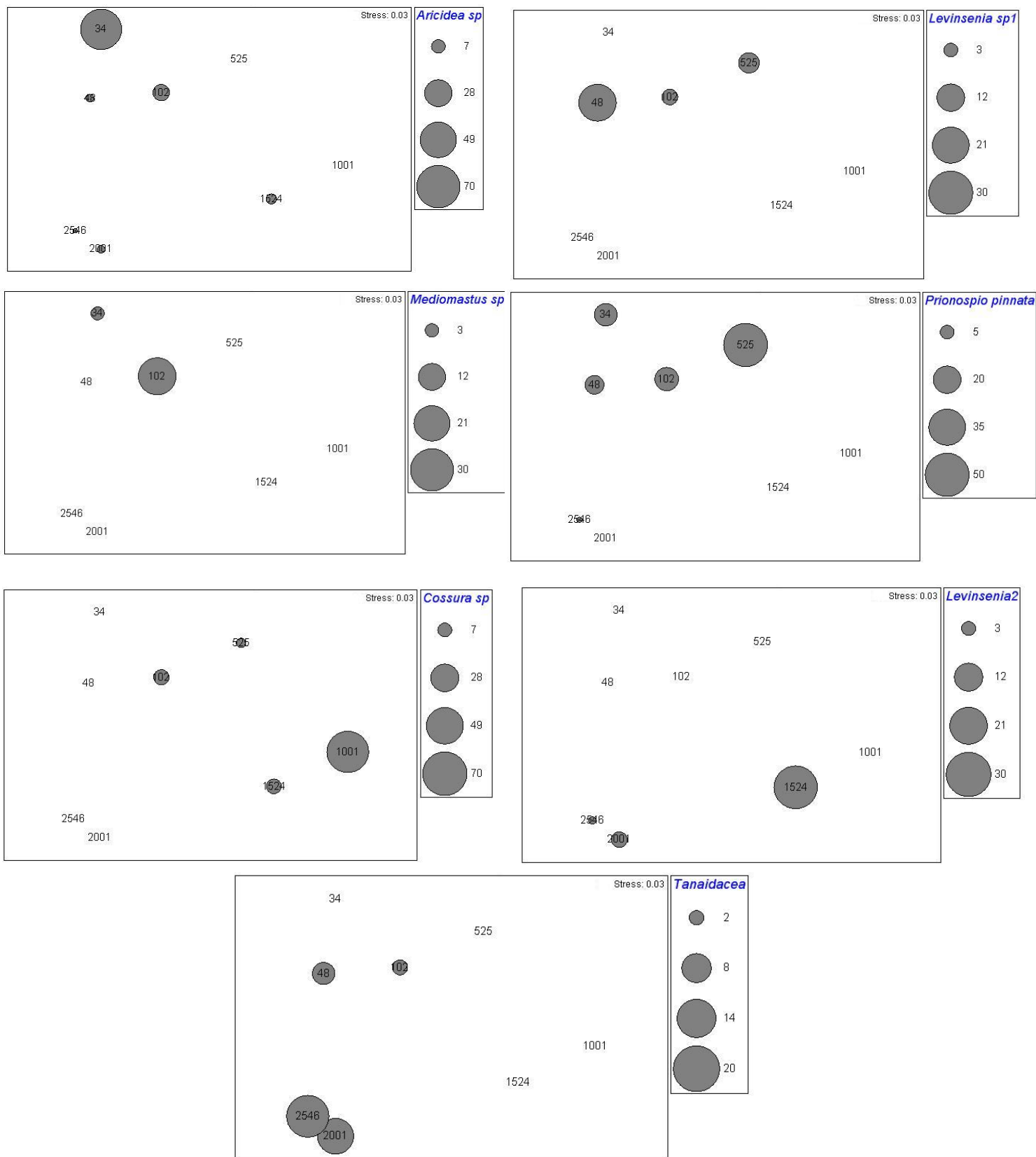


Fig. 5

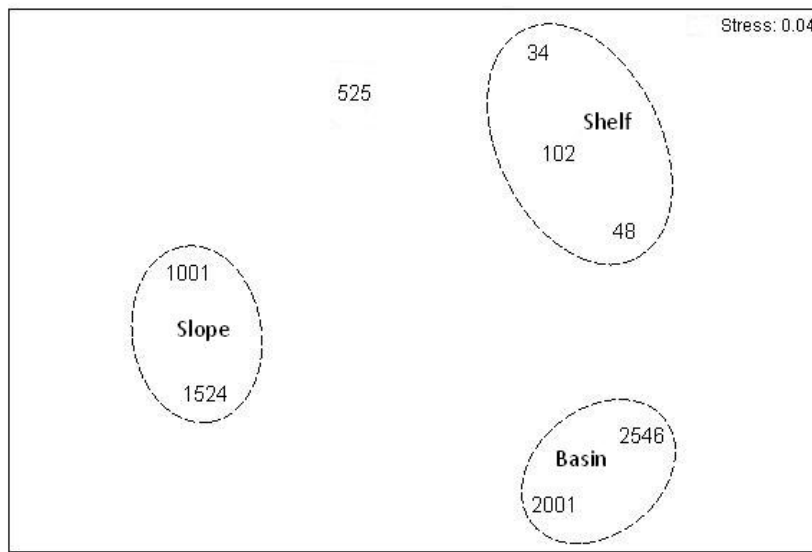


Fig. 6

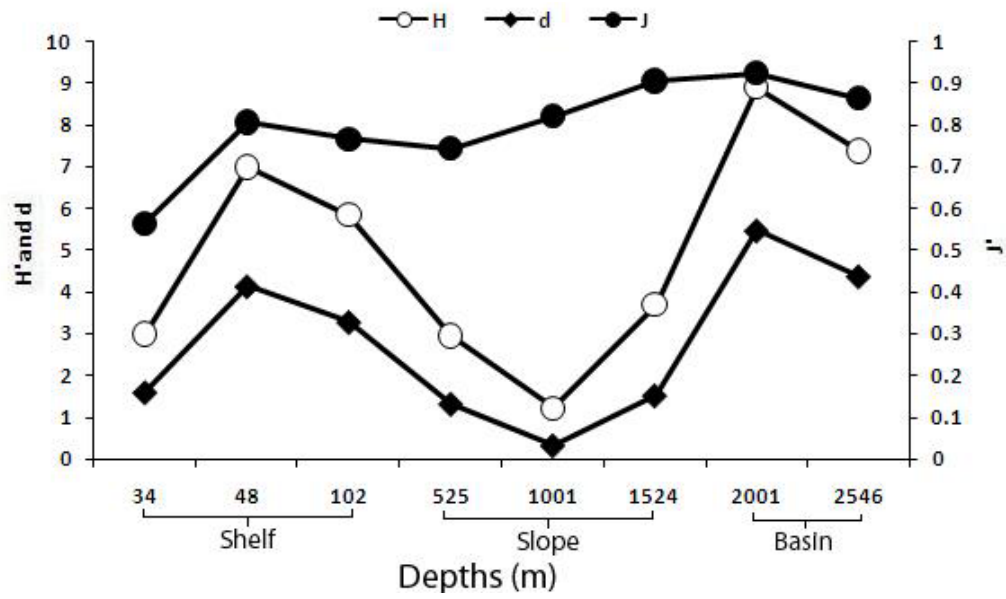


Fig. 7



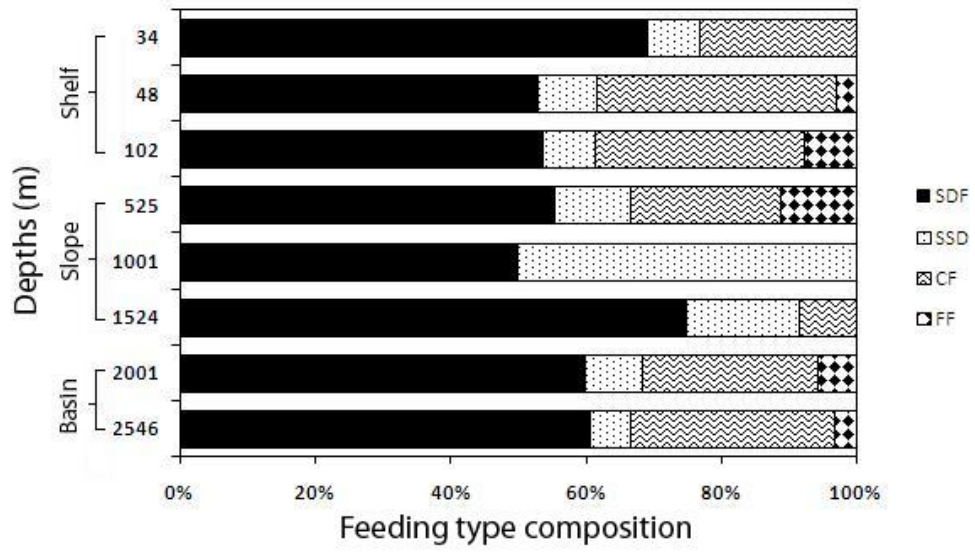


Fig. 8



Fig. 9

**Table 1. Geographical position and other information regarding sediment sampling**

Collection date	Stations	Lat(°N)	Long(°E)	Depth (m)	Number of box cores	Sub core from box core A	Sub core from box core B
11.8.07	43	13°54.26'	74°18.97'	34	2	3	3
11.8.07	44	13°59.88'	74°00.03'	48	2	3	2
11.8.07	45	14°00.29'	73°29.94'	102	2	3	2
12.8.07	46	14°00.24'	73°13.97'	525	2	2	2
12.8.07	47	14°00.25'	73°08.11'	1001	1	1	-
13.8.07	48	14°00.30'	72°57.22'	1524	2	1	1
14.8.07	49	14°00.09'	71°13.21'	2001	2	3	3
15.8.07	50	13°59.55'	70°48.40'	2546	2	3	3

**Table 2. Physico-chemical characteristics of habitats examined on the western Indian Continental Margin**

Habitat	Shelf			Slope			Basin	
Depth (m)	34	48	102	525	1001	1524	2001	2546
Bottom water								
Temperature, °C	23.2	20.84	18	10.7	7.85	5	-	-
Salinity, psu	35.8	35.5	35.1	35.3	35.2	35	-	-
DO, ml L <sup>-1</sup>	0.69	0.56	0.38	0.08	0.28	1.35	2.3	2.3
Chl a µg.l <sup>-1</sup>	0.06	0.18	0.009	0.0009	0.0004	0.0005	0.001	0.084
Sediment (0-2)								
Chl a µg.g <sup>-1</sup>	1.4	0.2	0.6	0.7	2.1	0.6	0.6	0.2
C <sub>org</sub> (%)	1.9	0.8	1.5	3.8	4.4	2.2	0.3	0.9
C:N	11.0	*	10.3	10.8	8.9	8.2	4.6	4.9
Clay (%)	8.3	9.8	3.0	12.9	13.2	8.7	15.1	15.6
Silt (%)	75.6	39.7	38.5	53.6	84.5	89.4	79.2	71.7
Sand (%)	16.0	50.5	58.5	33.5	2.3	1.9	5.7	12.7
Colour	Olive gray 5Y 4/1	Pale yellowish orange 10YR 8/6	Light olive gray 5Y 6/1	Grayish olive green 5GY 3/2	Grayish olive green 10Y 4/2	Yellowish gray 5Y 7/2	Grayish yellow 5Y 8/4	Vary pale orange 10YR 8/2
Texture	Clayey silt	Silty sand	Silty sand	Sandy silt	Clayey silt	Clayey silt	Clayey silt	Clayey silt
CaCO <sub>3</sub>	26.8	69.2	65.1	44.5	28.3	24.5	49.3	53.7

(\* N value was very low)

**Table 3. Taxon list and count data for Western Indian Continental Margin macrofauna (counts are given as number per core, 15 cm diam × 10 cm deep)**

Group	Family	Species name	Stations depth (m)																				
			34-A1	34-A2	34-A3	34-B1	34-B2	34-B3	48-A1	48-A2	48-A3	48-B1	48-B2	102-A1	102-A2	102-A3	102-B1	102-B2	525-A1	525-A2	525-B1	525-B2	1001
Polychaeta																							
	Arenicolidae																						
		<i>Arenicola</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Capitellidae																						
		<i>Mediomastus</i> sp	1	0	1	0	1	0	0	0	0	0	0	23	10	18	7	18	0	0	0	0	0
		<i>Neomediomastus</i> sp	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
		<i>Notomastus</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		<i>Capitellidae</i> sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<b>Cirratulidae</b>																						
		<i>Cirratulus</i> sp	0	0	0	0	0	0	1	1	4	1	0	1	0	0	0	5	0	0	0	0	0
		<i>Cirratulidae</i> sp. 1	0	0	1	0	0	0	0	0	0	0	1	0	9	6	2	0	0	0	0	0	0
		<i>Cirratulidae</i> sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		<i>Cirratulidae</i> sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		<i>Tharyx</i> sp	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<b>Cossuridae</b>																						
		<i>Cossura</i> sp	0	0	0	0	0	0	0	0	0	0	0	7	1	12	5	3	0	0	1	0	5
	Dorvilleidae																						
		<i>Dorvillea</i> sp	0	0	0	0	0	0	13	0	1	1	0	0	0	0	0	0	0	0	0	0	0
		<i>Staurocephalus</i> sp	0	0	0	0	0	0	1	10	6	1	3	0	0	0	0	0	0	0	0	0	0
	Flabelligeridae																						
		<i>Brada</i> sp	0	0	0	0	0	0	0	4	3	0	0	0	0	0	0	0	0	0	0	0	0
		<i>Flabelligeridae</i> sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Glyceridae																						
		<i>Glycera</i> sp	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
	Goniadidae																						

		<i>Goniada</i> sp	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hesionidae																							
		<i>Hesione</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Hesionidae sp. 1	0	0	0	0	0	0	13	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
	Lumbrineridae																							
		<i>Lumbriconereis</i> sp	1	1	1	0	1	0	0	0	3	0	1	1	1	0	0	1	0	0	0	0	0	0
		<i>Lumbriconereis</i> sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		<i>Lumbriconereis</i> sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Magelonidae																							
		<i>Magelona</i> sp	0	0	0	0	0	0	1	0	0	0	0	4	0	0	0	1	0	0	0	0	0	0
		Magelonidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Maldanidae																							
		<i>Axiothella</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Maldanidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Nephtyidae																							
		<i>Nephtys</i> sp	0	0	0	0	0	0	0	0	1	2	0	0	0	2	0	0	0	0	0	0	0	0
	Nereididae																							
		<i>Nereis</i> sp	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	Onuphidae																							
		<i>Onuphis emerita</i>	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	1	0	0	0	0	0
		<i>Onuphis</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Opheliidae																							
		<i>Polyopthalmus</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Opheliidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Orbiniidae																							
		<i>Scoloplos</i> sp	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
	Paraonidae																							
		Paraonidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	<i>Aparaonis</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Aricidea</i> sp	22	5	21	12	4	1	0	2	1	0	3	6	7	8	5	8	0	0	0	0	0	0	0
	<i>Levinsenia</i> sp. 1	0	0	0	0	0	0	9	6	4	37	0	2	2	5	2	2	0	0	2	0	0	0	
	<i>Levinsenia</i> sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Phyllodocidae																							
	<i>Phylodoce</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Pilargidae																							
	<i>Ancistrasyllis constricta</i>	0	0	0	0	0	0	0	5	9	0	0	6	3	6	5	0	0	0	0	0	0	0	
	<i>Ancistrasyllis</i> sp	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	2	0	0	1	0	0	0	
	Pisionidae																							
	<i>Pisione</i> sp	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Poecilochaetidae																							
	<i>Poecilochaetus</i> sp	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
	Sabellidae																							
	<i>Chone</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	<i>Jasmineira</i> sp	0	0	0	0	0	0	0	0	0	0	0	3	3	4	1	0	1	0	0	0	0	0	
	<i>Sabella</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	<i>Sabellidae</i> sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Sigalionidae																							
	<i>Sthenelais</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Spionidae																							
	<i>Prionospio pinnata</i>	1	3	2	6	2	0	9	1	5	8	1	22	9	5	4	8	4	2	5	4	0	0	
	<i>Prionospio polybranchiata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
	<i>Prionospio</i> sp	0	0	0	0	0	0	0	0	0	0	0	7	4	10	7	3	0	0	0	0	0	0	
	<i>Spiophanes</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Spionidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Sternaspidae																							

		<i>Sternaspis</i> sp	3	0	0	2	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0
	Syllidae																						
		<i>Syllis</i> sp	0	0	0	0	0	0	0	3	7	0	6	0	0	0	1	0	0	0	0	0	0
		Syllidae sp. 1	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0
		Syllidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Terebellidae																						
		Terebellidae sp. 1	2	1	0	0	0	0	0	0	0	1	0	0	3	2	2	1	0	0	0	0	0
		Terebellidae sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crustacea																							
		Amphipoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	2	2	0	0
		Isopoda	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Natantia	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Tanaidacea	0	0	0	0	0	0	5	5	0	2	1	2	0	3	1	0	0	0	0	0	0
		Halacarid	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalvia			0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Minor phyla																							
		<i>Dendrostomus</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		<i>Phascolion</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Echiurida	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Sipuncula sp. 1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

	Sipuncula sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sipuncula sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Nemertinia	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaete		0	0	2	1	0	0	7	2	5	2	2	2	0	1	0	0	0	0	0	0	0	0
		30	11	29	23	9	1	67	42	61	63	24	93	54	79	45	58	6	3	13	8	8	



Group	Family	Species name	1524-A2	1524-B1	2001-A1	2001-A2	2001-A3	2001-B1	2001-B2	2001-B3	2546-A1	2546-A2	2546-A3	2546-B1	2546-B2	2546-B3
Polychaeta																
	Arenicolidae															
		<i>Arenicola</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Capitellidae															
		<i>Mediomastus</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		<i>Neomediomastus</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		<i>Notomastus</i> sp	0	0	0	0	0	0	0	0	1	0	0	0	0	0
		Capitellidae sp. 1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
	<b>Cirratulidae</b>															
		<i>Cirratulus</i> sp	0	0	0	0	0	0	0	0	5	0	2	0	1	0
		Cirratulidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Cirratulidae sp. 2	2	1	0	0	0	0	0	0	0	0	0	0	0	0
		Cirratulidae sp. 3	0	0	2	2	1	0	1	0	1	2	0	3	0	1
		<i>Tharyx</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<b>Cossuridae</b>															
		<i>Cossura</i> sp	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dorvilleidae															
		<i>Dorvillea</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		<i>Staurocephalus</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Flabelligeridae															
		<i>Brada</i> sp	1	0	0	1	0	0	0	1	0	0	0	0	0	0
		Flabelligeridae sp. 1	1	2	0	0	0	0	0	0	0	0	0	0	0	0
	Glyceridae															
		<i>Glycera</i> sp	2	1	0	0	0	0	1	0	0	0	0	0	0	0
	Goniadidae															
		<i>Goniada</i> sp	0	0	1	0	0	0	1	1	0	2	1	1	3	1
	Hesionidae															
		<i>Hesione</i> sp	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Hesionidae sp. 1	0	0	0	0	2	0	0	0	0	0	0	0	0	0
	Lumbrineridae															
		<i>Lumbriconereis</i> sp	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		<i>Lumbriconereis</i> sp. 1	0	0	1	0	0	0	1	1	0	3	2	0	0	1
		<i>Lumbriconereis</i> sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Magelonidae															
		<i>Magelona</i> sp	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Magelonidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Maldanidae															
		<i>Axiothella</i> sp	0	0	0	0	0	0	0	0	0	0	2	0	0	0
		Maldanidae sp. 1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	Nephtyidae															
		<i>Nephtys</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Nereididae															
		<i>Nereis</i> sp	0	0	0	1	0	0	1	0	0	2	0	0	1	1
	Onuphidae															
		<i>Onuphis emerita</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	<i>Onuphis</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Opheliidae															
	<i>Polyophthalmus</i> sp	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Opheliidae sp. 1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Orbiniidae															
	<i>Scoloplos</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paraonidae															
	Paraonidae sp. 1	0	0	0	4	4	0	0	0	0	0	0	0	0	0
	<i>Aparaonis</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	<i>Aricidea</i> sp	0	1	0	2	0	0	1	0	0	1	0	0	0	0
	<i>Levinsenia</i> sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Levinsenia</i> sp. 2	4	3	4	1	0	0	0	0	1	0	0	0	0	0
Phyllodocidae															
	<i>Phylodoce</i> sp	0	0	2	0	0	0	0	2	0	0	0	0	0	0
Pilargidae															
	<i>Ancistrasyllis constricta</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Ancistrasyllis</i> sp	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Pisionidae															
	<i>Pisione</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poecilochaetidae															
	<i>Poecilochaetus</i> sp	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Sabellidae															
	<i>Chone</i> sp	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	<i>Jasmineira</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Sabella</i> sp	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Sabellidae sp. 1	0	0	0	1	0	0	1	0	2	1	0	0	0	0
Sigalionidae															
	<i>Sthenelais</i> sp	0	0	0	0	0	0	0	0	1	0	0	0	1	0
Spionidae															
	<i>Prionospio pinnata</i>	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	<i>Prionospio polybranchiata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Prionospio</i> sp	0	0	1	0	0	0	2	0	2	4	5	3	1	2
	<i>Spiophanes</i> sp	0	0	0	0	1	0	1	0	0	0	0	0	0	0
	Spionidae sp. 1	0	0	0	5	5	0	0	0	5	0	0	0	0	0
Sternaspidae															
	<i>Sternaspis</i> sp	0	0	0	0	0	0	0	1	0	0	2	1	1	0
Syllidae															
	<i>Syllis</i> sp	0	0	0	1	0	0	0	0	0	1	0	0	0	0
	Syllidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Syllidae sp. 2	0	0	0	1	0	0	0	0	2	0	1	0	3	1

	Terebellidae															
		Terebellidae sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Terebellidae sp. 2	0	1	0	0	1	0	0	0	0	0	0	1	2	1
		Polychaeta sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 2	0	0	0	3	1	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 3	0	0	0	4	1	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 4	0	0	0	0	4	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 5	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 6	0	0	0	5	0	0	0	0	0	0	0	0	0	0
		Polychaeta sp. 7	0	0	0	0	0	2	0	0	1	0	0	0	0	0
		Polychaeta sp. 8	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Crustacea																
		Amphipoda	0	0	0	0	0	3	1	1	1	1	0	0	0	1
		Isopoda	0	0	0	0	0	0	0	0	2	1	0	1	1	0
		Natantia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Tanaidacea	0	0	7	1	2	1	1	4	2	4	1	3	11	0
		Halacarid	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalvia			0	0	0	3	0	0	0	0	1	1	0	0	1	0
Minor phyla																
		<i>Dendrostomus</i> sp	0	0	0	0	0	4	0	0	0	0	0	0	0	0
		<i>Phascolion</i> sp	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		Echiurida	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Sipuncula sp. 1	0	0	0	0	1	0	1	1	0	0	1	0	0	0
		Sipuncula sp. 2	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Sipuncula sp. 3	0	0	0	2	0	0	0	0	0	0	0	0	0	0
		Nemertinea	0	0	0	0	2	1	0	1	2	1	0	0	0	0
Oligochaete			0	0	0	0	0	0	0	0	0	0	0	0	0	0
			12	13	19	39	31	7	19	14	30	25	17	16	28	10

**Table 4. Top three ranked taxa observed at different water depths (rank based on the species abundance) (“+” indicates the species was present but not ranked)**

Taxon	Water Depth (m)							
	34	48	102	525	1001	1524	2001	2546
<i>Aricidea</i> sp	1	+	3			+	+	+
<i>Prionospio pinnata</i>	2	2	2	1				+
<i>Sternaspis</i> sp	3	+					+	+
<i>Levinsenia</i> sp. 1		1	+					
<i>Staurocephalus</i> sp		3						
<i>Mediomastus</i> sp	+		1					
<i>Cossura</i> sp			+	+	1	2		
Amphipoda				3			+	+
Cirratulidae sp. 2				2	2	+		
Maldanidae sp. 1					3	+		+
Paraonidae sp. 1				+			3	
<i>Levinsenia</i> sp. 2						1	+	+
Flabelligeridae sp. 1	+					+		
Tanaidacea		+	+				1	1
Spionidae sp. 1							2	+
<i>Prionospio</i> sp		+	+				+	2

**Table 5. Linear regression analyzed for eight environmental variables against measures of macrofaunal community parameters at 8 stations along the study area (NS= Not significant)**

	Abundance	Biomass	d	J	H'
Depth (m)	NS	NS	NS	NS	NS
Temperature	NS	NS	NS	NS	NS
Salinity,psu	NS	NS	NS	r=-0.83, p=0.037	NS
DO	NS	NS	NS	NS	NS
Chl a	NS	NS	NS	NS	NS
Sed Chl a	NS	NS	NS	NS	r=-0.91, p=0.01
TOC	NS	NS	r=-0.87, p=0.02		r=-0.83, p=0.04
C:N	NS	NS	NS	NS	NS
Clay (%)	NS	NS	NS	NS	NS
Silt (%)	NS	NS	r=-0.81, p=0.05		NS
Sand (%)	r=0.85, p=0.02	NS	r=0.84, p=0.03		NS
CaCO <sub>3</sub>	r=0.86, p=0.02	NS	r=0.87, p=0.02		NS

**Table 6. Comparison of macrofaunal abundance (ind.m<sup>-2</sup>) in the western and eastern continental margin of the Arabian Sea**

<b>Water depth (m)</b>	<b>DO (mL.L<sup>-1</sup>)</b>	<b>Western India (present study)</b>	<b>Pakistan (Hughes <i>et al.</i> 2009)</b>	<b>Pakistan (Levin <i>et al.</i> 2009)</b>	<b>Oman (Levin <i>et al.</i> 2000)</b>
34	0.69	971			
48	0.56	2907			
102	0.45	3722			
140	2.12		14894		
	0.11		10464		
300	0.11		323		
400	0.13				12362
525	0.08	424			
700	0.16			0	16283
753	0.119			414	
803	0.122			1656	
	0.137			414	
850	0.2				19193
853	0.125			2622	
	0.14			414	
903	0.128			2967	
	0.147			6762	
940	0.13		5222		
	0.17		3380		
953	0.134			4544	
	0.156			2898	
1001	0.28	453			
	0.27				5818
1003	0.146			3726	

	0.174			4692	
1053	0.164			2208	
	0.199			690	
1200	0.35		1003		
1250	0.52				2485
1524	1.35	707			
1850	1.72		8531		
2001	2.3	1244			
2546	2.3	1188			