

## Meiofaunal Distribution across the Oxygen Minimum Zone of Continental Margin, North East Arabian Sea

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**Abstract** A quantitative study of metazoan meiofauna across the oxygen minimum zone (OMZ) of continental margin in the N-E Arabian Sea in the depth range 500-1965 m was carried out in September-November 2008. Bottom water oxygen and sediment organic carbon showed large variation between stations. The bottom water temperature and salinity was very similar in the area. The fauna was dominated by nematoda followed by harpacticoid copepoda and polychaeta. Maximum meiofaunal density of 164/10 cm<sup>2</sup> was recorded at St. 1 (500 m) and the lowest density of 25/10 cm<sup>2</sup> was observed at St. 2 (650 m) which coincided with lowest oxygen concentration. Total abundance of meiofauna was significantly lower than those reported from other areas. The average density was high (65/10 cm<sup>2</sup>) in OMZ than in non OMZ (52/10 cm<sup>2</sup>) area. Nematodes were the dominant taxon at every station. The dominance was particularly significant at those stations having very low oxygen. The meiofaunal density was positively correlated with sediment organic carbon while oxygen exhibited a negative correlation. Epibenthic Crustacean groups were more in areas of non OMZ having high oxygen. Vertical distribution revealed consistent reduction in total density and major taxa with increasing depth in sediment. Maximum density was recorded in top 0-2 cm layer. Among environmental parameters the availability of food in the form of sediment carbon appeared to be key factor in controlling meiofauna in study areas.

**Keywords** Oxygen minimum zone; Meiofauna; Distribution; Arabian Sea

## Introduction

Our understanding of the biological oceanography of the deep Arabian Sea has come largely through systematic collection of data during different oceanographic cruises (Qasim 1982; Angel, 1984). High surface productivity results in deposition of high organic carbon and nitrogen at the water-sediment interface (Gage et al., 2000). Limited sources of water replacement and high microbial activity in north eastern Arabian Sea have produced an intense and unusually deep oxygen minimum layer. It has supported one of the largest well defined OMZ where about 285000 km<sup>2</sup> of continental margin in the depth zone 100-1500 m seafloor is impacted (Helly and Levin, 2004; Stramma et al., 2008). The high organic carbon and nitrogen in the surficial sediment has helped in the development of reducing condition at intermediate depths (Cowie, 2005).

To date there are limited studies on macrofauna and meiofauna community distribution on the continental margin including the OMZ of the Arabian Sea (Cook et al., 2000; Ingole et al., 2010; Jaleel, 2012). In a recent communication Gage et al. (2000) emphasized the need for better understanding of benthic biology of the deep Arabian Sea affected by permanent OMZ. The meiofauna have a well defined three dimensional distribution based on adaptations of their species to occupy the spaces within the sediment up to several centimeters in depth (Soetaert et al., 1994). The nematodes among meiofauna particularly tend to be more tolerant than macrofauna to anoxia (Levin et al., 1991).

In comparison to temperate habitats, the ecology of meiofauna in tropical areas still needs to be widely explored, particularly in extreme regions. Oxygen minimum zones (OMZ) are stable water bodies of extreme environments where dissolved oxygen levels fall below 0.5 ml/l (Levin, 2003). We planned this study to update our understanding of the finer distribution of taxonomic composition, numerical abundance and vertical distribution

pattern metazoan meiofauna of the OMZ area in the north east Arabian Sea, the west coast of India. The data generated are based on samples collected from a submersible robotic device.

## 1 Materials and Methods

This study was carried out during the cruise 08-11 of *R.V. Yokosuka* within and outside the OMZ area of western continental margin, northern Arabian Sea (Figure 1). A total of 8 stations were covered to study the distribution and abundance of meiofauna. The stations were divided so as to get the samples from OMZ areas (501 m, 799 m, 800 m, 703 m, 900 m) and outside the OMZ (1956 m). The submersible *Shinkai 6500* was used successfully for collecting the sediment samples by using the robotic arms. The samples for metazoan meiofauna were collected using the push core device. Only one set of samples were made available due to limited number of samples. The cores collected were then sectioned onboard at an interval of 1 cm each upto a maximum depth of 20-21 cm. All sub-samples of meiofauna were preserved in 5% formaldehyde-Rose Bengal solution and brought to the laboratory for further analyses. Sediment samples were sieved using a set of two sieves, the upper 500  $\mu$  and lower 45  $\mu$ . Animals retained on finer sieve were considered for meiofauna. Animals were counted and identified to taxa level under the stereozoom microscope. All nematodes were assigned into different feeding category according to Wieser (1953): selective deposit feeders (1A), non-selective deposit feeders (1B), epigrowth feeders (2A), and predators (2B).

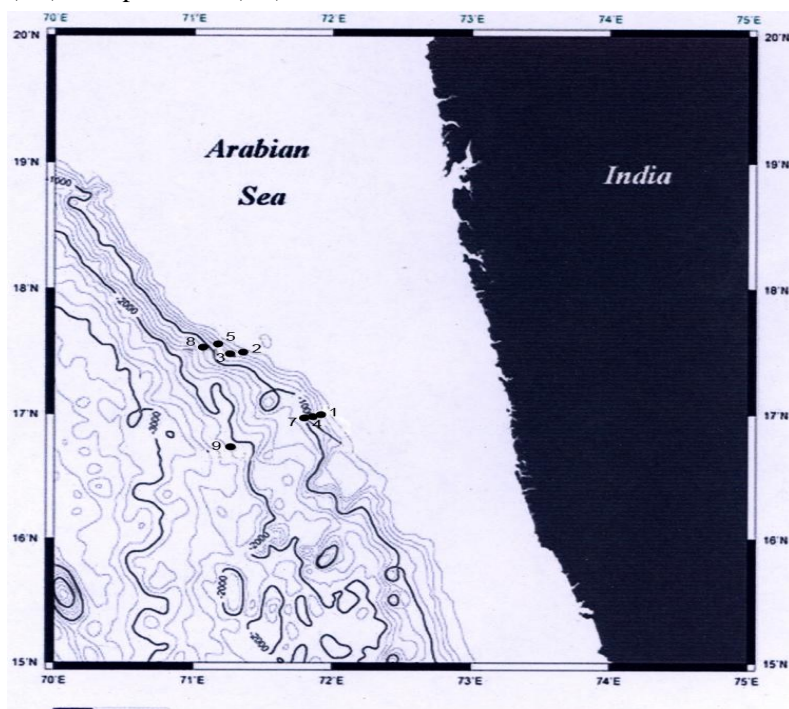


Figure 1 Bathymetry map of the study area showing stations location

## 2 Results

### 2.1 Physico-chemical parameters

The area of investigation is located in the north east Arabian Sea across the continental margin (Figure 1). Nine stations were sampled in the depth range 501–1956 m characterized by high percentage of fine silty sediment having large number of shell fragment. The environmental parameters is given in Table 1. The bottom water temperature was in the range of 3.24°C at 1956 m to 12.4°C at 500 m depth. The bottom water salinity remained high and ranged between 34.66 to 35.20 psu. The values of dissolved oxygen fluctuated widely and ranged from 0.5 to 97.2  $\mu$ m (0.08 to 2.3 ml/l). The lowest dissolved oxygen was measured at a depth of 650 m in the upper OMZ station and the highest was at a depth of 1956 m out side OMZ. Based on DO concentrations, the OMZ was found to extend from a water depth of 501-1100 m in the study area. The non OMZ area was restricted between 1100 and 1900 m. The distribution of organic carbon was related to sediment types. The values of organic carbon varied between 0.78 to 5.66%. In the upper 500-800 m of the OMZ the organic carbon was high. At continental

margin and slope (beyond 1100 m) the values reduced significantly. This zone falls outside the OMZ area. The calcium carbonate content of the sediment was in the range of 46.5 and 67.4%.

Table 1 Physico-chemical parameters of the study stations

# Station/depth	Temperature (°C)	Salinity(psu)	Dissolved Oxygen (µM)	Organic Carbon (%)	Calcium Carbonate (%)
1 (500 m)	12.4	35.18	1.3	4.30	53.8
2 (650 m)	11.84	35.20	0.5	-	-
3 (700 m)	10.59	35.14	1.0	-	-
4 (799 m)	10.36	35.12	1.2	5.66	49.7
5 (800 m)	9.86	35.09	3.0	3.11	67.4
6 (900 m)	9.24	35.02	6.2	2.18	-
7 (1100 m)	7.78	34.88	12.3	3.15	46.8
8 (H1100 m)	7.8	34.90	15.2	1.88	51.2
9 (1956 m)	3.24	34.66	97.2	0.78	46.5

## 2.2 Meiofauna

A total of fifteen taxonomic groups were recorded from the study area with different taxa showing different relative dominance (Table 2). The most abundant and widely distributed taxa were nematode (30.7-91.5%), harpacticoid copepods (4.2-31.5%), polychaeta (1.8-19.2%), turbellaria (0-4.0%), and foraminifera (0-4.0%). Other groups recorded in low number from few stations were gastrotricha, oligochaeta, amphipoda, ostracoda, kinorhyncha, cladocera, cumacea, tanaidacea and tardigrada. Total meiofauna density is shown in Figure 2. Maximum density (164/10 cm<sup>3</sup>) was recorded at St. 1 (500 m). The second highest density (87/10 cm<sup>2</sup>) was observed at 799 m. This was followed by 83/10 cm<sup>2</sup> at 900 m depth and the least density (23/10 cm<sup>3</sup>) was observed at 650 m. The highest and lowest densities were recorded in the OMZ area where the oxygen was 1.3 and 0.5 µM, respectively. The meiofauna was dominated by nematoda (8-152/10 cm<sup>2</sup>) and their contribution was 34-92% of total meiofauna. Nematode abundance was high (91.5%) in shallow region of the shelf, decreased to its lowest value in the lower part of the OMZ and then increased towards the deeper region where the oxygen concentration was high. The mean meiofaunal density in the OMZ area was 65/10 cm<sup>2</sup> while in non OMZ area it was 52/10 cm<sup>2</sup>. There was however exception where the density was not depth specific. They were followed by harpacticoida and polychaeta in the order of abundance. Greater diversity of meiofaunal taxonomic groups (10 taxa), was recorded at the deepest station (1956 m) with highest oxygen values while the least number of groups were found at 700 m where the oxygen was only 1 micromole.

Table 2 Relative (%) dominance of meiofaunal taxa at the study stations

Taxa	#1 (500 m)	#2 (650 m)	#3 (700 m)	#4 (799 m)	#5 (800 m)	#6 (900 m)	#7 (1100 m)	#8 (H1100 m)	#9 (1956 m)
Nematoda	91.5	72	68.9	78.1	71.4	68.8	30.7	48.9	42.1
Harpacticoida	4.2	8.0	17.2	5.7	7.14	12.0	23.0	27.6	31.5
Polychaeta	1.8	8.0	10.3	11.4	7.14	9.6	19.2	8.5	10.5
Turbellaria	1.2	4.0		1.2		3.6	3.8		3.5
Foraminifera	1.2	4.0		3.4		2.4			
Ostracoda						2.4	3.8		3.5
Amphipoda							7.6	2.12	
Cumacea									1.75
Cladocera							3.8		1.75
Tanaidacea									1.75
Kinorhyncha	1.2		3.4			2.4			
Bivalvia		4.0			7.14		7.6	2.12	1.75
Tardigrada									1.75
Gastrotricha								2.12	
Oligochaeta					7.14			4.25	

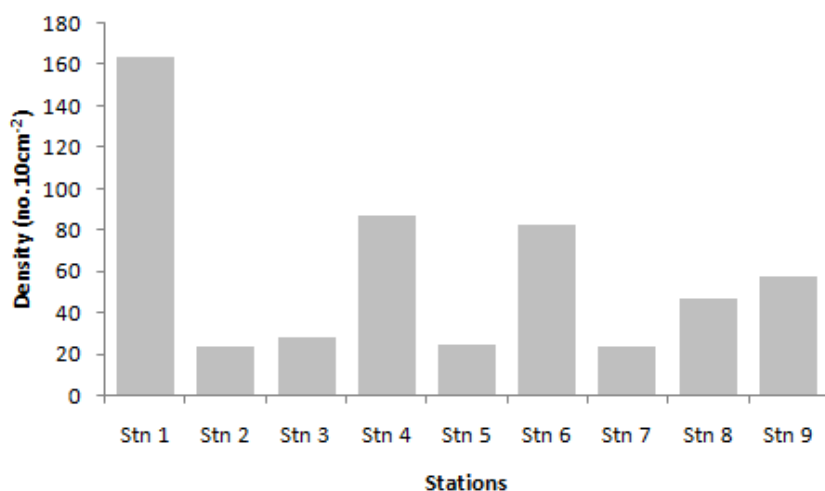


Figure 2 Total meiofaunal distribution in the study area

### 2.3 Vertical distribution

The vertical profile of the meiofaunal distribution in the sediment is given in Figure 3. More than 40% of the metazoan meiofauna occurred in the 1 cm layer except at station 3 (700 m) where the top layer contained only 10%. Vertically the faunal abundance decreased with the increasing sediment depth. Nematoda was the most dominant taxa recorded in the study area. They were vertically found throughout the sediment core from 0 to ~20 cm depth and contributed the maximum (35%-93%) to the total density at all the stations while the other groups were restricted to upper few cm only (~10 cm depth).

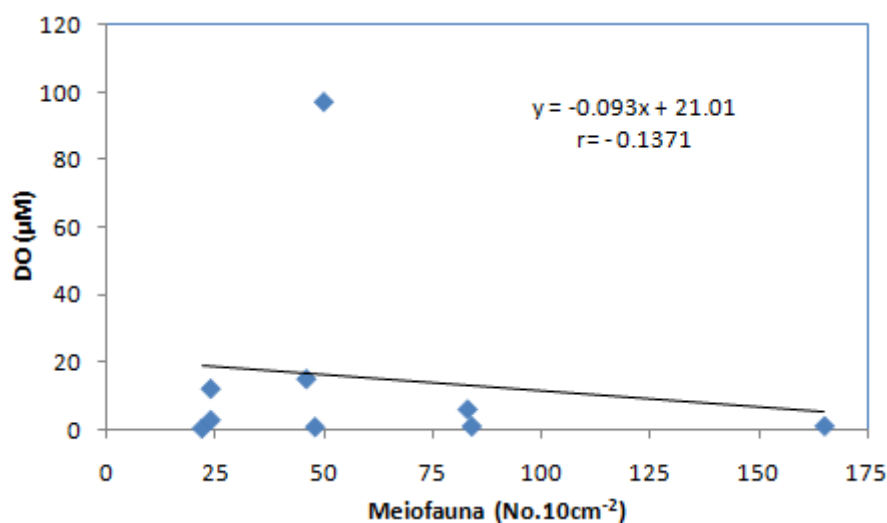


Figure 3 Correlation between meiofauna and dissolved oxygen

The meiofauna progressively decreased with increasing depth in sediment. The pattern however, differed from station to station. The 10-15 cm and 15-20 cm layer contained the least number and at some stations no fauna was recorded at 15-20 cm. The maximum number of animals was recorded in the top 0-1 cm layer (10.7-60%). At depth 650m where the oxygen was lowest (0.5 micromole) the total density recorded in the top 0-1 cm layer was 60.8.

### 2.4 Nematode feeding type

In the present study nematode feeding types varied with habitat (Table 2). The study area was dominated by a non-selective deposit feeders (1B) and predators (2B) whereas proportions of selective deposit feeders (1A) and predators (2A) were comparatively low at most stations (Table 3). The starting of OMZ was represented with maximum contribution of epigrowth feeders (more than 35%). Second dominant feeding category was non-selective feeder. This could be attributed to the presence of a high proportion of shell fragments and coarse

sand, in combination with the organic enrichment, from which these epistratum feeders scrape off bacteria and unicellular eukaryotes. Further, because of the coarser sediment at the shelf, the upper sediment layers dry out faster and are therefore disadvantageous to a deposit-feeding feeding strategy. The mid region of OMZ area was represented by a maximum contribution (35%) of omnivores and non-selective deposit feeders. The reason behind the dominance of omnivores and deposit feeders could be the high enrichment of organic material. The outside of OMZ was dominated by deposit feeders.

Table 3 Percent distribution of nematode feeding type in the study area

Depth (m)	1A	1B	2A	2B
500	18	49	5	28
650	12	38	22	28
700	27	32	25	16
799	29	19	13	39
800	27	34	18	20
900	16	40	15	29
1100	15	15	22	48
1956	32	14	24	30

The correlation of total meiofauna, and nematode with key environmental variables was attempted (Figure 3; Figure 4). There was negative insignificant correlation between total meiofauna and dissolved oxygen of the bottom water (Figure 3; Regression  $Y = -0.093X + 21.01$ ;  $r = -0.137$ ). In contrast sediment organic carbon showed a strong positive correlation with total meiofauna ( $Y = 0.017X + 1.94$ ;  $r = 0.521$ ).

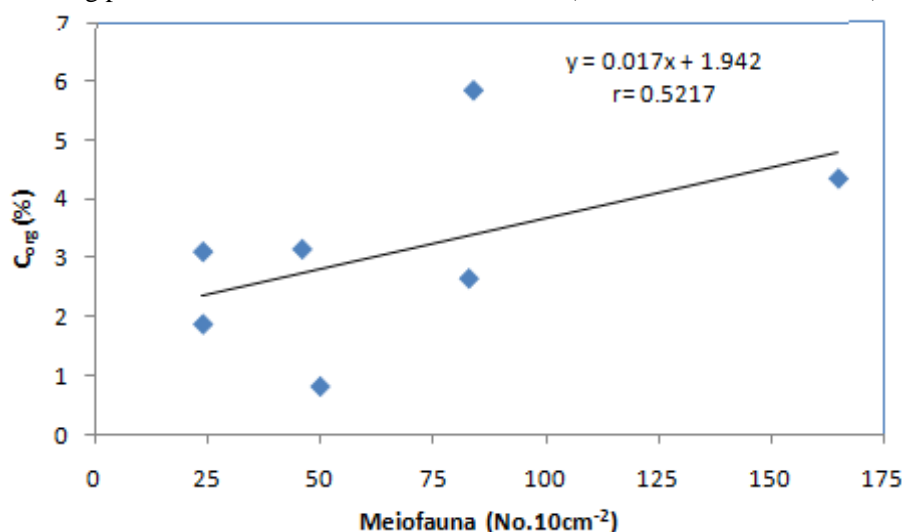


Figure 4 Correlation between meiofauna and organic carbon

### 3 Discussion

Benthos play important role in re-mineralization of organic matter and biogeochemical cycle (Jaleel, 2012). The presence of OMZ between 200 and 1200 m of western Arabian Sea has been reported by many authors (Naqvi et al., 2006; Ingole et al., 2010). The upwelling in the north east Arabian Sea typically enriches the sediment with organic matter (Qasim, 1982). The high production and seasonal deposition of organic matter in the Arabian Sea results in seasonality in high benthic microbial production that consumes the oxygen that results in the development of hypoxia at the end of south-west monsoon (Gage, 2000). The observed high values of sediment organic carbon on the slope, and low values in the basin region, were in agreement with earlier record from Arabian Sea and western Indian margin (Rao and Veeraya, 2000; Cowie, 2005).

Preliminary studies on metazoan meiofauna of Arabian Sea OMZ areas have been carried out. High to very high densities of meiofauna particularly nematode have been reported from OMZ areas (Cook et al., 2000; Neira et al., 2013) In the present study, density of 3-8 times lower was recorded. Meiofauna dissolved oxygen produced



insignificant relation suggesting that the oxygen does not control the distribution and abundance of metazoan meiofauna in OMZ. Several investigations in the world OMZ areas have observed strong correlation between food quality and abundance of meiofauna and absence of oxygen effect. Cook et al. (2000) have reported that DO has no effect on the nematode community-rather food quality appears to be the major predictor in the OMZ areas in the Arabian Sea. According to Neira et al. (2013) bottom water oxygen and sediment organic matter are two factors that exhibit steepest gradient in OMZ areas. There is however, contrasting report which emphasized the role of oxygen in structuring meiofauna communities (Neira et al., 2001). Similarly Muthambi et al. (2004) found the impact of oxygen on nematode. The oxygen limitation might directly control meiofauna composition at higher taxonomic levels within the OMZ, it is believed (Neira et al., 2001). Outside OMZ where oxygen is available, a number of oxygen sensitive group of crustacea were recorded (St. 7, 8, 9) and this also improved the overall diversity of higher taxa in the area outside OMZ. Similarly Ansari et al. (2011) high number of taxa in meiofauna of south east continental shelf of India.

The metazoan community in the present study area is characterized by two set of fauna, one for the OMZ area and the other for the non OMZ area. Whether due to sediment characters, bottom temperature, DO or food, changes in the meiofaunal taxa was recorded. In the non OMZ area of 900 m and above the temperature and sediment organic carbon remained low while the oxygen values were highest. The oxygenated water may be the influencing factor for more crustaceans groups in non OMZ. This goes against the report of Cook et al. (2000) where food is said to control nematode population in OMZ of Arabian Sea. There are report of behavioral changes and mortality in more sensitive groups such as crustacean exposed to induced hypoxia and anoxia (Miller et al., 2002; Haselmair et al., 2010). Such changes are expected in the OMZ area where very low numbers of crustaceans were recorded.

The distribution and abundance of meiofauna particularly in the OMZ area where sediment organic carbon recorded highest value, support the hypothesis of Cook et al. (2000). Several investigations on world OMZ areas have also observed strong correlation between food quality and abundance of meiofauna and absence of an oxygen effect. It is suggested that total density of meiofauna in OMZ are never reduced, rather it recorded the highest density within OMZ (Levin et al., 1991; Neira et al., 2001). These authors feel that biological interactions between the larger organisms and predation by macrofauna might be more important. There is great deal of variability in the total density of meiofauna recorded from different regions particularly in the OMZ areas. These are correlated with enhanced sedimentation regimes of particular organic matter and food supply (Sommer and Pfannkuche, 2000; Schwartz, 2007). Lamshead et al. (1994) found low nematode abundance in San Diego Trough where oxygen concentrations were in the range of 15-60  $\mu\text{mol}$ . In the present study we recorded low percentage of nematode (< 45%) at those stations having oxygen in the range of 16 to 97 micromole. In areas of permanent hypoxia specific stress responses are induced in metazoan meiofauna particularly the nematode to cope up with situation. The nematodes use high organic matter in sediment to multiply and flourish in the absence of most predators in OMZ. They are the lone group recorded in maximum number from all stations. The secret of this is that the nematodes are more tolerant to anoxia than other meiofaunal taxa (Giere, 1993). This was proved in the vertical distribution also. The higher oxygen concentration appears to be responsible for increased number of crustacean taxa which otherwise are sensitive to oxygen minima and eliminated under anoxic condition.

The meiofauna in all conditions and at all depths have shown consistent decline with increasing depth in sediment. It may be consequences of changes in abiotic and biotic factors, triggered by biogeochemical processes under highly stressed condition (Danovaro et al., 1995). The dominance of nematode particularly in the area of lower OMZ suggests their ability to adapt and survive in hypoxic condition. Such adaptation and tolerance in nematodes in the OMZ areas have been reported earlier (Levin et al., 2009). The relative proportion of each of the four feeding types in a community depends on the nature of the available food which in turn is reflected by the nature of the habitat (Platt and Warwick, 1980).

It appears that the hypoxic conditions puts additional pressure on more sensitive benthic groups and drive them away. Abundant food and absence of predators and competitors provide a more favorable condition for the nematodes to sustain. There are predictions of further decline in dissolved oxygen of the deep ocean due to global

warming. This applies to Arabian Sea also. If this happens we can expect further reduction in benthic biodiversity of the region.

#### 4 Conclusion

The meiofauna distribution and abundance recorded in this study is the baseline information derived from samples collected robotically by a submersible. The metazoan abundance was characteristically lower in the present OMZ area of north Arabian Sea than other OMZ areas of the world. However nematode remain the dominant form within oxygen-minimum zones horizontally and vertically. Vertically meiofauna showed high reduction in number with increasing sediment depth. Significant correlation with organic carbon of the sediment and no correlation with oxygen support the earlier hypothesis that meiofauna abundance is strongly enhanced by quantity and quality of food supply and virtual removal of predators and competitors by low oxygen in OMZ.

#### Authors' contributions

Z.A. Ansari is responsible for part collection of data and writing the paper. Shahin Badesab is responsible for part collection of data and analysis of sample. R. Singh is Responsible for identification of nematode feeding type. Hiroshi Kitazato is responsible for overall guidance in the sampling and preparation of manuscript.

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