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Assessment of Macrofauna around Tarapur Atomic Power Station (TAPS), Maharashtra, India

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Abstract

A study was carried out to observe the macrofaunal habitation in the coastal area of India's first commercial atomic power station at Tarapur, Maharashtra. Macrobenthos are mostly sedentary as well as sessile in nature; therefore, they are used as indicator organisms to monitor health of marine ecosystem. The faunal record observed observed at experimental sites in Tarapur (TAPS1-4), consisted of 25 groups with 16 different polychaete families dominated by Nereidae, Capitellidae and Spionidae. Shannon - Wiener index (H') was highest at Varor for faunal groups (2.07) and polychaete families (2.89) while lowest at anthopogenically stressed Uchheli (faunal group - 0.74) and Nandgoan (polychaete family - 1.67). Margalef's species richness was highest at Varor (fauna -1.93 and polychaete family -1.61) and lowest at Nandgoan (fauna-1.00 and polychaete family - 0.74) due to dominance of environmental bioindicators, the polychaetes (Nereidae) as indicated by dendrogramme depicting Bray Curtis similarity and MDS Along with these observations, hydro-sedimentological parameters revealed comprehensive picture of community structure of macrobenthos and polychaetes' families. The elevated water temperature was noticed at TAPS 3 and 4 (30.1^0C) which is under permissible limit ($26\text{-}28^0C$ ±7) accompanied by pH (7.0). Dissolved oxygen was observed minimum at Uchheli ($4.1mgl\text{-}^1$) and maximum at TAPS 1and2 area ($7.5mgl\text{-}^1$).

Keywords: Diversity, Macrobenthos, Bio-indicators, TAPS.

Introduction

For the prosperity of the mankind at the global level, the peaceful use of nuclear energy in favor of electric power generation is need of the hour. The amount of nuclear energy used worldwide for electricity generation is 16 %. This amount of electricity generation from nuclear plants further needs to be enhanced in the context of global warming and climate changes aspects too. Thus recently nuclear power plants have attracted the attention due to this global warming and climatic changes, occurring at a faster pace for the fact that nuclear power is clean and environment friendly than any other forms of conventional energy production. Nuclear power is not simple energy source but it is produced through a very complex and meticulously designed nuclear plants. The world's first commercial nuclear power plant was established on June 26, 1954, at Obninsk in Russia, the APS- 1 with a net electricity output of 5 MW.

India's first commercial Atomic Power Station is located at, west coast of India (Tarapur, Maharashtra, 19^0 50' N, 72^0 41'E), about 100 km North of Mumbai and has been in operation successfully for more than last four decades. Prior to commissioning of this plant site, environmental survey was conducted to observe environmental health of marine ecosystem[1]. Panampunnayil and Desai in 1975[2], studied zooplankton whereas, Balani and Patel 1994[3], have studied radionuclide accumulation and biology of gastropods. However, specific assessment of Macrofauna is still unexplored.

Macrobenthos are a key constituent of the marine environment. They play a vital role in ecosystems' ecological processes such as decomposition of organic matter, nutrient cycling, pollutant metabolism, dispersion and burial, translocation of material and in secondary production[4-11]. Analysis of macrobenthic infauna is necessary in marine ecological monitoring programmes because macrobenthic species are comparatively sedentary[12] and have relatively long life span comprising different species that exhibit their tolerances to stress[13,14]. Among Macrofauna, polychaetes are numerically dominant and diverse in nature[15], a good indicator of anthropogenic impact with considerable saving in time and efforts for monitoring programme[16-19]. Taking consideration the uses of nuclear energy for electricity generation, the regular monitoring of environmental parameters is a necessity to observe the impacts of aquatic thermal discharge from these power plants to receiving water bodies. Therefore, during early commencement of the investigation, systematic sample collection was conducted to assess macrofauna around Tarapur Atomic Power Station (TAPS), Maharashtra, India. Physico-chemical and hydro-sedimentological parameters were also evaluated to know their impact on macrobenthos.

Methodology

Samples were taken in the vicinity of coastal area around

Tarapur Atomic Power Station (TAPS), during early commencement of the project, November 2011. The locations were fixed within 5km radius in two directions (North and South of TAPS), with the help of GPS (Figure-1). As stated by Lardicci and Rossi (1999)[20], in their study, the sampling stations at the distance within 4.5 km radius around discharge can be considered as an appropriate control station. Without replicating control sites, difference among locations cannot be unambiguously attributed to disturbance due to pollution sources[20]. In the present study, the stations, Light house (0.3 km), Ucheli (4.5 km) and Chinchani (4.5 km) were considered as control and the stations, Varror and Nandgaon which are at 8.4 km each, taken as reference points in the north east and south west directions respectively. A total 84 replicates were taken in seven transects, namely TAPS 1 and 2, TAPS 3 and 4, Light house, Chinchani, Varor, Uchheli and Nandgoan at High Water Level (HWL), Mid Water Level (MWL) and Low Water Level (LWL). All transects have stable bedrock and boulders except at Chinchani which is having sandy shore and Uchheli is situated in the creek region. Water and sediment samples were collected for physico-chemical, sedimentological and macrobenthic study. Water samples were collected in pre-cleaned plastic container and stored immediately in the ice box. The temperature was observed with the help of mercury centigrade thermometer having 0.5°C accuracy. During sampling, dissolved oxygen was fixed instantly in the field as per Winkler's method.

Sediment samples were collected by quadrate method[21], (20 cm x 20 cm) quadrate for small organisms and (1m x 1m) for large and motile organisms. Sediment for macrobenthos samples were washed with sea water through 500 µm sieve and organism retained on the sieve stained with 1% rose Bengal stain and preserved in 5% buffered formalin. Sediments for texture and organic carbon were collected in separate containers. All the preserved samples were brought to the laboratory for their further analysis.

Macrobenthos samples were rewashed in the laboratory, in running tap water to remove preservative and organisms were sorted to different groups and identified up to lowest possible taxa under stereomicroscope[22-26]. Having identified abundance of organisms it was converted into no. m^{-2} and biomass was expressed as wet weight, gm m^{-2}. Calibrated pH meter (by using the standard buffer solution) was used to record pH of seawater. The refractometer (Atago, Japan) was used to measure salinity. The modified Winkler's method illustrated by Strickland and Parsons[27], was implemented for the analysis of dissolved oxygen. The alkalinity, hardness, ammonia, nitrite, nitrate and inorganic phosphate were estimated by the methods described in Strickland and Parsons, Grasshoff and APHA[27-29]. Organic carbon was estimated by wet combustion method[30] and texture by hydrometer method[31].

Macrofauna collected from the all locations were identified and tabulated for their numerical abundance and statistical analysis. The Pearson correlation coefficient was applied for the better understanding of the relationship among the results of various hydro - sediment logical parameters such as pH, dissolved oxygen, alkalinity, hardness, nutrients, sediment composition and organic carbon by using software Statistica-7. To detect spatial distribution of community structure, the multivariate analysis methods for physico-chemical parameters with square transformed biological data were performed by using PRIMER software[32-33]. The univariate measures were applied such as, Margalef's species richness (d), Shannon–Wiener diversity (H' log) and Pielou's evenness (J'), graphical presentation like k-dominance curve and plots and multivariate tool such as Bray–Curtis similarity with square root transformed sample abundance data, classification (hierarchical agglomerative clustering by group-average linking), and ordination (multidimensional scaling, MDS) to visualize pattern in species abundance using statistical software of PRIMER v.5 (Plymouth Routines In Multivariate Ecological Research ver. 5.2).

Results and Discussion

Hydrography and sediment characteristics: Physico - chemical variables in the study area got varied across different spatial scales (Table-1). All through assessment period, average water temperature got resided as 25.3^{0} C ranging from 22.0°C (Varor) to 30.1°C (TAPS 3and4). As heated effluent from TAPS 3and4 is discharged into the pond (1 ha) near sea shore, which causes a rise in sea water temperature and it gets reduced with a increase in distance as also referred[34]. Average hydrogen ion concentration (pH) ranged from 7.5 -8.2 (8.0 ±0.3) at all locations throughout the study period. Salinity got varied from 35_0% - 37_0 % (35.7±0.8), phosphate 0.62 mgl^{-1} to 0.94 mgl^{-1} (0.76 ± 0.12), ammonia 0.02 mgl^{-1} to 1.3 mgl^{-1} (0.38± 0.53), nitrite 0.02 mgl^{-1} to 0.24 mgl^{-1} (0.09± 0.09) and nitrate 1.0 mgl^{-1} to 3.21 mgl^{-1} (1.6 ±0.7). In the present study, Uchheli showed the lowest dissolved oxygen value (4.1 mg l^{-1}) as this creek area is surrounded by villages and their household waste waters get discharged without any treatment, resulting in reduction of dissolved oxygen level[35] and maximum concentration of 7.5 mg l^{-1} at TAPS 1 and 2 may be a possibility of the increased capacity of mixing oxygen due to wave beating action at rocky substratum. No difference in sediment texture was observed at the entire stretch of study area. It was dominated by sand, 79.3 % to 92.2 % (84.63±4.58), followed by silt 3.2% to 13.2% (8.51 ± 3.82) and clay 4.4% to 7.5 % (6.85 ± 1.16). Organic carbon fluctuated from 0.2% to 1.4 % (0.48 ± 0.45).

Numerical abundance and composition of macrofauna: The benthic macrofauna was represented by Amphineura, Polychaeta, Brachyura, Amphipoda, Isopoda and Tanaidacea. Polychaeta was the most dominant taxon in terms of individuals, contributing over 53.78% of the total macrofaunal population. Their abundance varied from 219 in $d.m^{-2}$ to 8300 in $d.m^{-2}$.

They were followed by Amphipoda ranging from 44 ind. m^{-2} to 1206 ind. m^{-2}. Crustaceans were most assorted group having 13 different taxa and comprised 41.8 % of total faunal composition. Major crustaceans were enlisted as Amphipods 33.07 %, Tanaids 3.48%, Isopods 1.75 %, Brachyurns 1.07 %, Cumaceans 1.52 %, Barnacle 0.12 %, Bracyuran larvae 0.23 %, Penaeids 0.23 %. Coelenterats were represented by Hydrozoans, 0.08% and Anthozoans, 0.13 %. Molluscans consisted of Amphineurans, 2.32 %, Gastropods, 0.25 % and Pelecypods, 0.17 % (Table-2).

The diversity indices for macrobenthos and polychaetes have been given in Figure-2. The Shannon–Wiener diversity index (H') was observed maximum at Varor for macrobenthos (2.07) and polychaete (2.89). Minimum diversity was noted at Uchheli (0.74) for macrobenthos and at Nandgoan (1.67) for polychaete. The Margalef's index (*d*') for the macrofauna was in the range of 1.0 (Nandgoan) - 1.9 (Varor) and polychaete 0.74 (Nandgoan) - 1.6 (Varor). Pielou's evenness index (*J'*) was evidenced with a similar trend for macrofauna as well as polychaete, the minimum was observed at Uchheli, 0.21 and 0.54 and maximum at Chinchani, 0.54 and 0.83 for macrobenthos and polychaetes respectively. This does not show significant variation among impacted and controlled stations. K-dominance plot for all locations plotted for macrobenthos and polychaete giving low lying line of Varor which got maximum diversity (Figure-2). Dendrogramme plotted for macrobenthos abundance from the result of Bray-curties similarity, indicated two distinct groups as Light house and Nandgaon and TAPS 1 and 2 and TAPS 3 and 4 with 68.9 % and 73.2 % similarity respectively. Bray–Curtis similarity matrix was constructed with these data and then subjected to MDS ordination to visualize and determine the extent of any similarity or difference in the species compositions of the benthic macroinvertebrates around the study area. Cluster analysis indicated four clusters, each of macrofauna and polychaete. In both the cases, Uchheli was separated out from other locations. The clusters of macrobenthos are as follows; Cluster I - TAPS 1 and 2 and TAPS 3 and 4; Cluster II - Nandgoan, light house; Cluster III – Uchheli and Cluster IV - Varor and Chinchani. For polychaetes, the four clusters are, Cluster I - TAPS 3and4 and Varor; Cluster II - Uchheli; Cluster III - Chinchani, Nandgoan; Cluster IV - TAPS 1 and 2 and Light house (Figure-4 and Figure-5).

Discussion: Macrobenthos are more sensitive towards any alteration occurring in their habitation whether natural or anthropogenic[36]. For example, alteration in water temperature, dissolved oxygen, water flow and sediment content impart significant effects on composition and abundance of macrobenthos[37]. Further modification in population densities on seasonal scales has been characteristic of variable patterns in reproduction, larval settlement and growth which are directly related to variations in temperature[38-39]. Although these changes may be minor for the most of the places, yet the alteration in the distribution of macrofaunal grouping was relatively clear representing that the assessment of benthic macrofauna is an influential tool to distinguish even slight variation in environmental parameters[40-41]. In India, there are few studies on coastal aquatic system related to heated effluent from atomic power stations and most of them are on the study of the gradient change of diversity along discharge. Poornima *et al.*[42-43], studied the impact of thermal discharge from Madras Atomic Power Station (MAPS), Kalpakkam, on primary productivity and phytoplankton with an interpretation that treatment driven chlorine concentration was a major cause of impact rather than heated effluent and thermal stress which was relatively localized with negligible effect at the mixing point. Panampunnayil and Desai[2], showed no difference of the faunal composition of zooplankton at intake and discharge points of the Tarapur Atomic Power Station. Results obtained by Satpathi and Nair[44], from five year monitoring (1982-86) around MAPS revealed that there was no warming up of near shore water due to heated effluent. In contrast, Satpathi and Nair[45], observed the death of flora and fauna around MAPS. Kailasam and Sivakami[46] also found a negative correlation between rise in temperature and benthic cover at Tuticorin coast.

There are few studies which proved either very little or no impact of heated effluent on surrounding environment[20,47,48]. In view of this, detail macrofauna perceived around TAPS coastal site. It consisted of 24 major groups of 8 different phyla and 17 polychaete families, as stated by Soares-Gomes *et al.*[49], who found that family level data are sufficient for cost effective monitoring. Polychaetes families were divided into five groups on the basis of feeding guild as deposit feeders (45.4%), omnivores (38.8%), carnivores and herbivores (7.7%), carnivores (6.2%) and carnivores and deteretivores (2%) (Table-3). Nereidae family was dominant among polychaetes (38.75 %), followed by Spionidae (19.5 %) and Capitellidae (18.2 %). Even though there was a maximum number of polychaete families observed at Varor and Uchheli, variation in feeding habit expressed a significant indication. The families such as Nereidae, Spionidae, Aphroditae, Eunicidae, Capitellidae, Syllidae and Glyceridae with diverse feeding nature were observed at Varor whereas only deposit feeder dominated at Uchheli, this was coupled with high organic carbon. Rodrigo *et al.*[50], stated the presence of particular community structure dominated by polychaetes and amphipods that can be partially explained by the influence of current intensity flow coming from turbines and thus responsible for sediment composition and ultimately the community structure. The dominance of polychaetes over amphipods at discharge points and light house which are the nearest locations to discharge canal of TAPS 1 and 2 thus in turn indicated that amphipods are less tolerant to thermal stress than polychaetes. There was no significant correlation between water temperature and any biological values indicating that coastal water around TAPS was not much impacted by heated effluent, a similar result was noticed[51].

Generally salinity gradient plays structuring effect on macrobenthic communities and acts as a physiological barrier on euryhaline marine species[52]. However, at Chesapeake Bay Boesch[53], noticed that the sediment composition was responsible for species distribution and diversity, rather than salinity. It was noticed that high similarity (68.9%) of macrobenthos community between light house and Nandgaon due to similar sediment texture indicating community structure of macrobenthos is sediment texture oriented, which is one of the major determinants of community composition in soft bottoms[54,55] rather than heated effluent impact.

Decrease in species number (S) for polychaetes at Chinchani (S=6) was mainly due to anthropogenic activities, whereas Nandgaon with the lowest number of species of macrobenthos and polychaetes (S=8 and S=5, respectively) was mainly due to high fishing activity. The occurrence of opportunistic polychaetes belonged to family Nereidae, Spionidae and Capitellidae got dominated near the discharge point indicating their tolerance to thermal stress. Mahadevan[56], also reported high abundance of Capitellidae near discharge point of Thampa Bay, Florida.

Conclusion

Macrobenthos showed spatial variation which was supported by polychaete observations. Maximum diversity was observed at Varor, TAPS 1 and 2, TAPS 3 and 4 and Light House which have rocky intertidal area and providing shelter to macrobenthic organisms. Minimum diversity was observed at Uchheli and Nandgoan, as these stations get disturbed by anthropogenic activities. Although Tarapur Atomic Power Station has been running for more than four decades yet the impact on surrounding coastal area is minimum as evidenced by rich biodiversity.

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Table 1
Hydro-sedimentological parameters around Tarapur Atomic Power Station

Hydro-sedimentological parameter	Minimum		Maximum		(Mean ± SD)
	Result	location	Result	location	
Water Temperature (^{0}C)	22	Varor	30.1	TAPS 3 and 4	25.04 ± 3.1
pH	7.5	TAPS 3 and 4	8.2	Chinchani	8.0 ± 0.3
Dissolved oxygen (mg/l)	4.1	Uchheli	7.5	TAPS 1 and 2	6.2 ± 1.1
Salinity ($\%_0$)	35	TAPS 1 and 2, Nandgoan, Uchheli	37	Light house	35.7 ± 0.8
PO_4 (μmoll^{-1})	0.62	Varor	0.94	TAPS 1 and 2	0.8 ± 0.1
NH_4^+-N (μmoll^{-1})	0.02	TAPS 3 and 4	1.3	Varor	0.5 ± 0.3
NO_2-N(μmoll^{-1})	0.02	TAPS 3 and 4	0.24	Chinchni	0.1 ± 0.08
NO_3-N(μmoll^{-1})	1	TAPS 3 and 4	3.21	Uchheli	1.6 ± 0.7
Sand (%)	79.26	Light house	92.16	Chinchni	84.6 ± 4.6
Silt (%)	3.18	TAPS 3 and 4	13.24	TAPS 1 and 2	8.5 ± 3.8
Clay (%)	4.41	Chinchni	7.52	TAPS 3 and 4, Varor	6.9 ± 1.2
Organic carbon (%)	0.28	Chinchni	1.62	Uchheli	0.5 ± 0.4

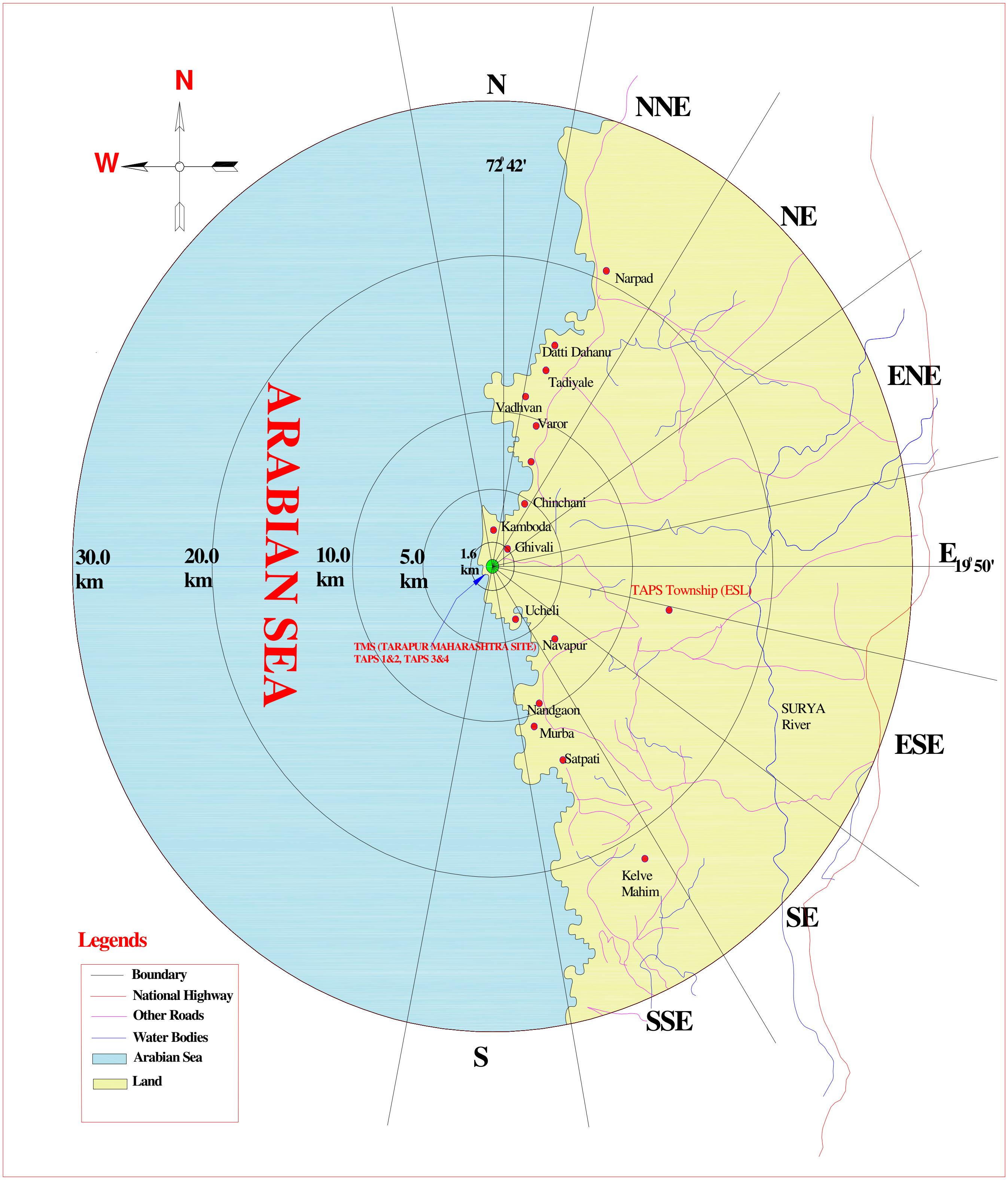


Figure-1
Detailed topographical map of coastal area around Tarapur Atomic Power Station

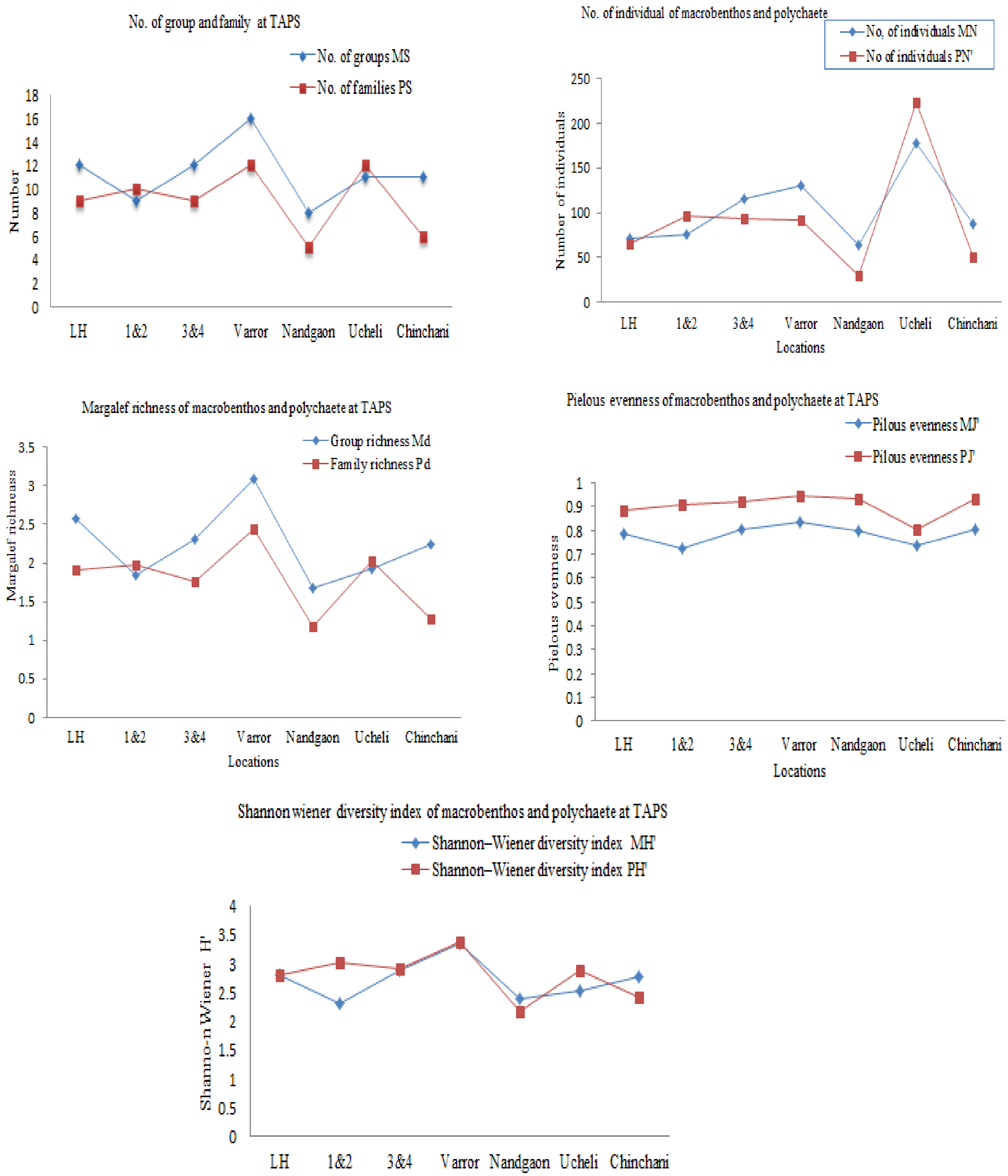
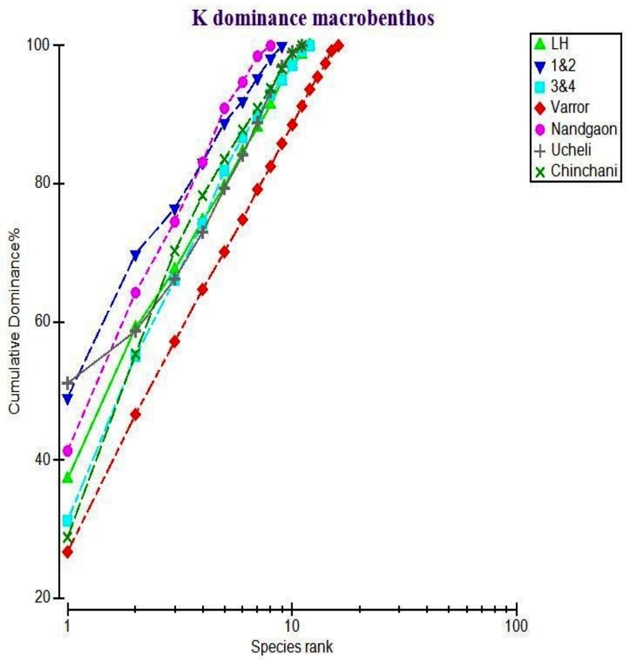


Figure-2
Diversity indices of macrobenthos and polychaete around Tarapur Atomic Power Station



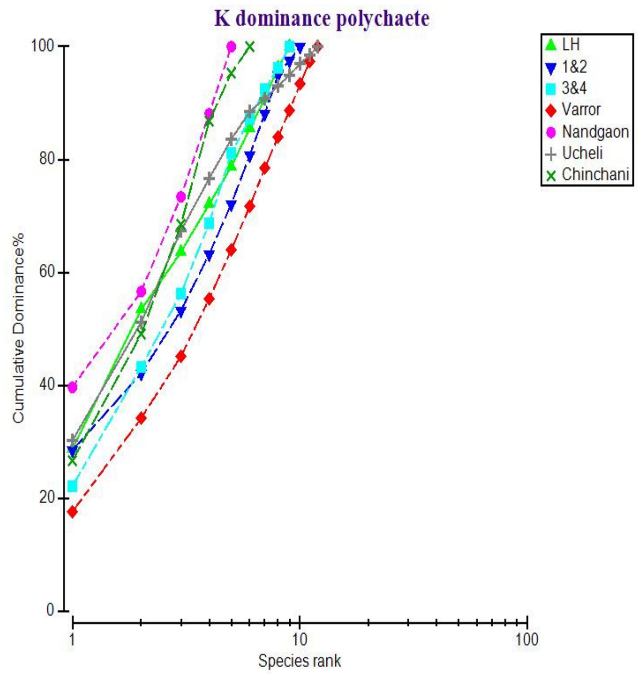
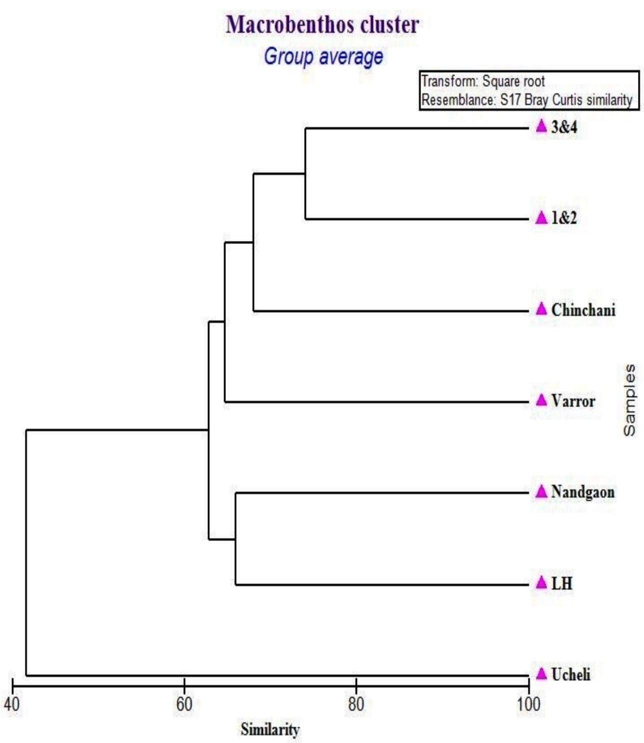


Figure-3
K - dominance of macrobenthos and polychaete around coastal sites of TAPS



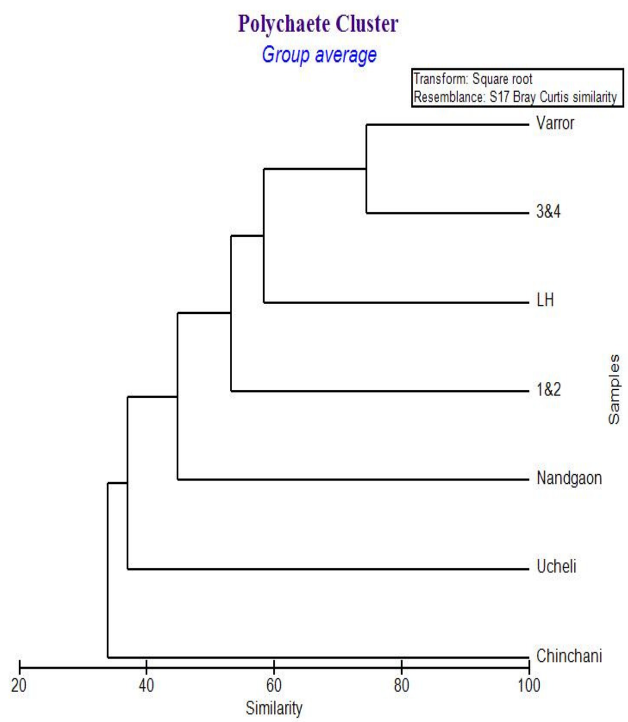


Figure-4
Dendrogram for hierarchical agglomerative clustering of square-root transformed macrobenthos and polychaete data using group average linking of Bray–Curtis similarities at coastal sites of TAPS

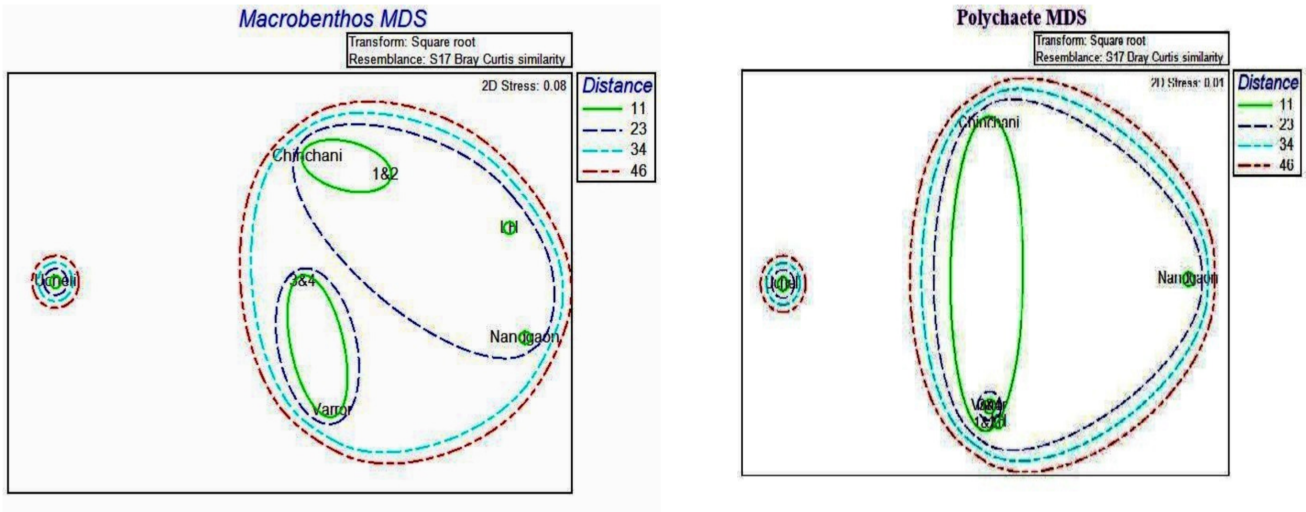


Figure-5
Non-metric multidimensional scaling of square transformed macrobenthos and polychaerate data using similarities at coastal sites of TAPS

Table-2
Percent composition of Macrobenthos around Tarapur Atomic Power Station

Faunal group	LH	1 and 2	3 and 4	Varror	Nandgaon	Ucheli	Chinchani	Average
Hydrozoans	0	0	0	0	0.57	0	0	0.08
Anthozoans	0	0	0.24	0.55	0	0.14	0	0.13
Amphineurans	2.32	1.10	1.25	7.94	2.97	0.69	0	2.32
Gastropods	0.09	0.29	0.49	0.76	0	0.03	0.07	0.25
Pelecypods	0.09	0	0.04	0.04	0	0.75	0.28	0.17
Turbellarian	0	0	0	0.25	0	0	0	0.04
Nemertine worm	0	0	0	0	0	1.36	0	0.19
Sipunculan worm	0	0	0	0.55	0	0	0.90	0.21
Oligochaetes	0	1.45	0.53	0.25	0	0	3.47	0.81
Polychaetes	66.91	80.42	52.79	28.26	20.96	90.25	36.88	53.78
Copepods	0	0	0	0	0	0	0.42	0.06
Barnacles	0	0	0	0	0	0.82	0	0.12
Cumaceans	3.53	0.35	0	3.97	2.39	0	0.42	1.52
Anomurans	0	0	0	0	0	0	0.56	0.08
Brachyurans	0.28	0.12	3.19	0.38	0.10	1.96	1.46	1.07
Amphipods	22.68	14.48	30.84	50.95	68.23	0.48	43.82	33.07
Isopods	1.21	0.35	3.56	1.31	4.21	1.63	0	1.75
Penaeids	0.56	0.00	0.24	0.80	0	0	0	0.23
Tanaids	0	1.45	6.59	2.11	0.57	1.90	11.74	3.48
Lucifer	0	0	0.24	0	0	0	0	0.03
Stomatopods	0.56	0	0	0	0	0	0	0.08
Brachyuran larvae	0	0	0	1.61	0	0	0	0.23
Decapod larvae	0.56	0	0	0	0	0	0	0.08
Fish larvae	1.21	0	0	0.25	0	0	0	0.21

Table-3
Percent composition of macrobenthos around Tarapur Atomic Power Station

Polychaete family	LH	1 and 2	3 and 4	Varor	Nandgaon	Ucheli	Chinchani	Average	Feeding guild
Aphroditae	4.13	3.15	0	11.02	0	0.21	0	2.64	C
Nereidae	2.48	4.95	29.67	28.24	62.86	51.01	1.18	25.77	OM
Syllidae	2.48	8.11	10.05	5.51	11.43	0	0	5.37	C
Eunicidae	46.28	0.45	32.54	9.64	5.71	1.32	16.47	16.06	C and H
Phyllodocidae	0	6.76	0	0	0	0.21	0	1.00	C
Glyceridae	0	0	2.39	4.19	0	0.32	35.29	6.03	Cand DV
Nephtydae	0	12.61	0.96	1.38	0	0.28	0	2.18	C
Magelonidae	0	0	0.96	0.69	0	0.14	0	0.26	SDF
Spionidae	34.71	54.50	10.53	25.54	8.57	14.73	3.53	21.73	SDF
Cirratulidae	1.65	5.41	1.91	2.76	0	2.73	0	2.07	SDF
Orbinidae	0	0	0	0	0	0	24.71	3.53	NSDF
Cossuridae	5.79	0	0	0	0	0	0	0.83	SDF
ophelidae	0	0.45	0	0	0	0	0	0.06	NSDF
Capitellidae	1.65	3.60	11.00	6.89	11.43	24.18	18.82	11.08	MDF
Sabellidae	0	0	0	2.07	0	4.74	0	0.97	SDF
Pectinaridae	0.83	0	0	0	0	0	0	0.12	SDF
Terebellidae	0	0	0	2.07	0	0.14	0	0.32	SDF

H- Herbivore, C-Carnivore, OM-Omnivore, DF- Deposit feeder, SDF- Surface deposit feeder, MDF- Motile deposit feeder, NSDF- non selective deposit feeder, DV- Deteretivores.

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