

## **Spatio-temporal variation in the macrobenthos of Paradip port, east coast of India**

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### **Abstract**

The spatio-temporal variation in the abundance and community structure of macrobenthic invertebrates, which are useful ecological indicators was assessed along with associated environmental settings and sediment characteristics in Paradip port, Odisha state along the east coast of India. The Paradip port is a coastal port directly connected to the Bay of Bengal and is influenced by the tropical monsoons. The maximum diversity and abundance of macroinvertebrates was reported during monsoon seasons while it was minimum during post-monsoon and pre-monsoon and attributed to higher organic carbon in the sediment. The sediment characteristics (sediment composition and total organic carbon) were the major factors influencing the abundance and community composition of benthic organisms. Silty-sand was dominant throughout the port environment. The polychaetes were the dominant macrobenthos organisms followed by Pantopoda and Crustaceans. Organically rich and sandy-silt sediment lead to the dominance of pollution indicator taxa such as *Tharyx* sp., *Prionospio* sp., *Cossura* sp., *Magelona* sp. and *Mediomastus* sp. The multivariate index of trophic state (TRIX) indicated good water quality in near bottom water however, high organic carbon load in the sediment could have resulted in stressed environment. This study will serve as a baseline for the future studies on the diversity of macrobenthic invertebrates and benthic ecology of the monsoon influenced coastal habitats especially in a busy port subjected to rigorous physical and anthropogenic stress.

**Keywords:** Macrobenthos, Paradip port, Polychaetes, Spatio-temporal, Species diversity.

## **Introduction**

The benthic fauna are an important link in the food web and are useful ecologically and economically. Benthic organisms play a major role in the marine community with their involvement in mineralization, sediment mixing, oxygen flux, nutrient cycling and in the recovery of organic matter<sup>1</sup>. They are used as bio-indicators for pollution monitoring studies owing to their short life cycles and limited mobility, tertiary level feeders and food for several bottom dwelling higher invertebrates and fishes<sup>2</sup>. Polychaetes are the most abundant and dominant groups in the benthic community which contribute to 80 % of total macrobenthic population and they are being used for biomonitoring organic pollution and to check the quality of marine environment<sup>3</sup>.

Ports are considered as the lifeline of a country's economic development and the port areas one of the highly altered coastal habitats due to heavy traffic owing to shipping and also human activities<sup>4</sup>. Since they are often located in the coastal environments, are subjected to various forms of anthropogenic stressors such as untreated sewage or municipal runoff, terrestrial runoff during the monsoon, and port related activities such as dredging, oil spill, petroleum effluents, out-fall of variety of cargo handled by the port etc<sup>5</sup>. Port waters are often characterized by low dissolved oxygen and presence of pollutants in the sediment and water<sup>5,6,7,8</sup>. As harbour areas have empty niches, they are prone to marine bio-invasion especially due to discharge of ship's ballast water<sup>9, 10</sup>, as the empty niches are formed due to instability of the equilibrium between the origination and extinction of the benthic community<sup>11</sup>. Bioinvasion is of global concern due to its adverse effect on the biodiversity and on the ecosystem functioning<sup>12</sup>.

The distribution and community of macrobenthic organisms depend on the interaction between the physical, chemical and biological variables in both water column and sediment. So to study the diversity and abundance of macrobenthic organisms it is important to assess the factors affecting benthic community sediment characteristics such as texture, organic content and the food availability.

The present study was carried out to describe the spatio-temporal variation in the macrobenthic diversity and abundance and to examine the impact of sediment characteristics and environmental parameters on macrobenthos in a dynamic port environment, situated along the east coast of India.

## **Material and Methods**

### **Sampling and analysis**

#### **Study area**

Sampling in Paradip port was carried out during August 2014 (Monsoon I – M I), December 2014 (Post monsoon – PM), May 2015 (Pre-monsoon – Pre-M) and August 2015 (Monsoon II – M II) representing different seasons. Paradip port is a major port along the north east coast of India in the state of Odisha (20° 15' N, 86° 40' E) (Figure 1). The port is influenced by south-west monsoon (June-September) and received 75-80 % of rain during these months and remaining during the northeast monsoon (October-December). On the east coast, Paradip Port is located in the state of Odisha, India, and this port manages a large trade on the eastern coast of the country. Even though this port is a natural deep water port, artificial bunds (Breakwaters) were built to reduce the severe wave intensity in the port, thus it resembles an artificial lagoon type. The breakwaters are 1). South breakwater with a length of 1217 m and 2). North breakwater with a length of 538 m. It is a major port that handles various cargo such as crude oil, POL (petroleum, oil and lubricants), iron ore, thermal coal, chrome ore, coking coal, manganese, and other ores, fertilizer raw materials and containers etc. The samples were collected from 22 stations in accordance to berths, and their details have been provided in Table 1.

#### **Sampling and Analysis**

The near-bottom seawater samples were collected (in triplicate) for the analysis Chlorophyll *a*, salinity, dissolved oxygen (DO), temperature and nutrients using Niskin water sampler and analysed using standard protocols<sup>13</sup>. Analysis of different nutrients such as nitrate (NO<sub>3</sub>), phosphate (PO<sub>4</sub>), nitrite (NO<sub>2</sub>), ammonium (NH<sub>4</sub>) and silicate (SiO<sub>4</sub>) was carried out using SKALAR SAN<sup>plus</sup> analyzer. Sediment samples were collected in triplicate from an average depth of 13-16 m using a van Veen grab (0.04 m<sup>2</sup>). The sediment samples were washed separately through a 500 µm nylon mesh at the field and then preserved in 10% formaldehyde in seawater containing rose Bengal stain before transferring them in a plastic container. Laboratory analysis involved in the sorting of macrobenthic organisms from the sediment samples that are sieved through a 500 µm metal sieve. The macrobenthic fauna collected were preserved in plastic vials containing 10% formaldehyde solution for further microscopic analysis. Polychaetes (Phylum – Annelida) were identified to the highest taxonomic level (genus or species), with the help of available identification keys<sup>14, 15, 16</sup> and other macrobenthos were identified up to group, family or genus levels. Numerical abundance of each species was expressed as number per square metre (no. m<sup>-2</sup>). Biomass was determined using wet

weight method and expressed as milligram per metre square ( $\text{mg. m}^{-2}$ )<sup>17</sup>. The Total carbon (OC), inorganic carbon (IC) and percentage composition of sediment (sand, silt and clay) that are expressed by the percentage of sediment dry weight were determined by using CHNS Analyser (Vario MICRO Select, Germany) and pipette analysis respectively<sup>18,19</sup>. The total organic carbon (TOC) content was obtained by the difference between TC and IC ( $\text{TOC} = \text{TC} - \text{IC}$ )<sup>20</sup>.

Number of individual or specimens (N), number of species (S), total abundance (A), Margalef species richness (d), Pielou's evenness (J') and Shannon index (H') using  $\log_2$  scale are used to determine the environmental and ecological assessment of macrobenthic organisms in each stations. PRIMER-v5<sup>21</sup> is used to determine the similarity of species diversity in macrobenthic polychaetes by Bay-Curtis. Canonical correspondence analysis (CCA) and redundancy analysis was performed to evaluate the relationship between environmental variables and different group of macrobenthos. The multivariate index of trophic state (TRIX) method was used to evaluate the trophic status of Paradip port<sup>22</sup>, this allows us to determine the water quality and also the relationship between trophic status of near bottom water and sediment. TRIX was calculated,  $\text{TRIX} = (\log_{10} (\text{chl}a \times \text{a}\%O_2 \times \text{DIN} \times \text{DIP} + k)/m$ . Where DO saturation ( $\text{abs } |100 - \%O_2| = \text{a}\%O_2$ ), Chlorophyll *a* is in  $\text{mg. m}^{-3}$ , DIP = dissolved inorganic  $\text{PO}_4$  in  $\text{mg m}^{-3}$ , DIN = dissolved inorganic nitrogen including  $\text{NO}_3$ ,  $\text{NO}_2$ ,  $\text{NH}_4$  in  $\text{mg m}^{-3}$  and *m* - Transparency: [Secchi depth: *m*].

## Results

### Environmental Parameters

The variations in the near-bottom environmental parameters such as temperature, salinity and dissolved oxygen, are presented in Table 2 and Figure 2. The near-bottom seawater temperature during different seasons ranged between  $26.2 \pm 0.6$  °C to  $29.7 \pm 0.45$  °C (Table 2; Figure 2a to d). The salinity of near bottom water varied with seasons and it was low ( $26.5 \pm 0.7$  and  $30.2 \pm 1.4$  during M I and M II respectively) during monsoons compared to non-monsoon seasons ( $32.1 \pm 0.5$  and  $33.9 \pm 0.04$  during PM and Pre-M respectively) (Table 2; Figure 2a to d). The near bottom DO ranged from  $3.9 \pm 0.3$   $\text{mg. l}^{-1}$  to  $4.5 \pm 0.9$   $\text{mg. l}^{-1}$  respectively during the study (Table 2; Figure 2a to d). The concentration of bottom water nutrients varied with the seasons and stations (Supplementary Figure 9). The tidal range at Paradip port is from 0.2 to 3.5 m and the maximum wave height is 5.3 m. The multivariate index of trophic state (TRIX) analysed for the bottom water during the study was  $1.8 \pm 0.8$  indicating high state of water quality with low eutrophication. TRIX scores ranged from 0.07 to 3.39 during all the seasons indicating healthy bottom water conditions.

The sediment texture composed of sand, silt and clay and it varied spatio-temporally within the port (Figure 3a-d). In general silt was the dominant component  $59.0\pm 26.8\%$  followed by sand,  $37.3\pm 26.3\%$  and Clay,  $2.8\pm 9.5\%$  during all the seasons in most of the stations. The sand content was comparatively higher during Pre-M season. The silt content showed a wide fluctuation and it ranged from 5.3% to 94.6% (Figure 3b). The percentage of clay was minimum when compared to sand and silt and it ranged from 0.3 to 3.8% (Figure 3 a to d). Overall, the sediment texture at Paradip port is dominated by silt, followed by silty-sand and sandy-silt and few stations were dominated by sand (Figure 3e). The total organic carbon in the sediment ranged from 0.5% at S06 to 31.6% at S04. During MI (Figure 4a to d) the average TOC was maximum ( $5.6\pm 7.4\%$ ) and it was minimum ( $1.8\pm 1.8\%$ ) during M II. During PM and Pre-M the TOC content was  $4.1\pm 5.6\%$  and  $3.7\pm 2.3\%$  respectively (Figure 4a to d).

The sediment chlorophyll *a* during M I, PM, Pre-M and M II was  $0.22\pm 0.1$  mg.  $m^{-2}$ ,  $2.9\pm 1.2$  mg.  $m^{-2}$ ,  $1.6\pm 0.7$  mg.  $m^{-2}$  and  $1.4\pm 0.8$  mg.  $m^{-2}$  respectively (Figure 4a to d). The sediment chlorophyll *a* was maximum during PM followed by Pre-M indicating that the chlorophyll *a* content was higher during non-monsoon season (Figure 4a to d).

### **Seasonal variation in the abundance of macrobenthic organisms**

The macrobenthic organisms in Paradip port comprised of Annelida (polychaeta and Oligochaeta), Arthropoda (Pantopoda, Amphipoda, and Isopoda), Mollusca (bivalvia) and Echinodermata (Sea anemones and brittle stars). The polychaetes were the most common and abundant organisms during all the seasons. Among the 30 macrobenthic forms, 20 were polychaetes contributing more than 70% to the total macrobenthic abundance. Polychaetes belonging to genus *Mediomastus* and *Cossura* were observed during all the seasons. The maximum abundance of macrobenthos was during M I ( $1893$  no.  $m^{-2}$ ) (Table 3a), followed by M II ( $1444$  no.  $m^{-2}$ ) (Table 3d), PM ( $922$  no.  $m^{-2}$ ) (Table 3b) and Pre-M ( $767$  no.  $m^{-2}$ ) (Table 3c) seasons. During M I, maximum abundance of macrobenthos was at station, S06- $323$  no.  $m^{-2}$  and S11- $446$  no.  $m^{-2}$ ; during PM at station S04  $122$  no.  $m^{-2}$ ; during Pre-M at S18-  $216$  no.  $m^{-2}$  and during M II at S12- $324$  no.  $m^{-2}$  respectively (Table 3 a to d). The biomass was maximum during M I -  $12313$  mg.  $m^{-2}$  (Table 3a), followed by M II  $9528$  mg.  $m^{-2}$  (Table 3d), PM - $3596$  mg.  $m^{-2}$  (Table 3b), and it was minimum during pre-monsoon season  $3050$  mg.  $m^{-2}$  (Table 3d). The maximum biomass during M II was  $5085$  mg.  $m^{-2}$  at S11 and minimum was  $10.7$  mg.  $m^{-2}$  at S15 (Table 3d). During PM and Pre-M seasons the biomass was higher at S04 ( $980$  mg.  $m^{-2}$ ) and S18 ( $1562$  mg.  $m^{-2}$ ), and low at S15 ( $47$  mg.  $m^{-2}$ ) and S07 ( $25$  mg.  $m^{-2}$ ) respectively (Table 3c&3b).

During MI, the maximum abundance of polychaete was contributed by the Cirratulidae, *Tharyx* sp. (447 no. m<sup>-2</sup>), followed by *Mediomastus* sp. (292 no. m<sup>-2</sup>) and *Cossura* sp. (232 no. m<sup>-2</sup>) along with organisms belonging to order Pantopoda (185 no. m<sup>-2</sup>) (Figure 5a). The abundance of *Prionospio* sp. during this season was 155 no. m<sup>-2</sup> (Figure 5a). *Tharyx* sp. contributed 21% to total macrobenthic abundance followed 14.1% by *Mediomastus* sp., and 11.2% by *Cossura* sp. (Figure 5a). Among the non-polychaete taxa, Pantopoda contributed 9% followed by *Nototropis* sp. and Iospilidae (2.9 % and 2.2% respectively) to the total macrobenthos abundance (Figure 5a). Stations S11, S06 and S08 showed higher abundance of macrobenthos, and Pantopoda was observed only at S11. At stations S02, S12, S18, S21 and S22 macrobenthos were not reported. Compared to M I, during PM the abundance of macrobenthos was less and the community was dominated by *Tharyx* sp. (at stations - S01, S04, S12, S17 and S22) and *Cossura* sp. (at stations – S04, S09, S12 and S14) with an abundance of 200 no. m<sup>-2</sup> and 184 no. m<sup>-2</sup> respectively (Figure 5b; Table 3b). The polychaetes, *Cossura longocirrata*, *Magelonasp.* and *Mediomastus* sp. contributed considerably to the total abundance of macrobenthos (Table 5b). The abundance and diversity of macrobenthos was minimum during Pre-M compared to other seasons. The most abundant group was Cirolanidae (215 no. m<sup>-2</sup>) at S18. Among the polychaetes, *Nephtys* sp. was dominant (169 no. m<sup>-2</sup>) followed by *Cossura* sp. (38 no. m<sup>-2</sup>) (Figure 5c; Table 3c). The other polychaetes found were *Kirkegaardiasp.*, *Tharyx* sp., *Magelonasp.*, *Diopatrasp.* and *Prionospio* sp. (Table 3c; Figure 5c). Monsoon seasons were more productive in terms of occurrence of macrobenthos as compared to non-monsoon seasons in Paradip port. *Tharyx* sp. was the most abundant during M II with a total abundance of 339 no. m<sup>-2</sup> and found in S10, S11, S12, S15, S16 and S17, followed by *Mediomastus* sp. (168 no. m<sup>-2</sup>) and *Maldane* sp. 169 no. m<sup>-2</sup> (Figure 5d and 6). The other common Polychaetes were *Cossura longicerrata* 123 no. m<sup>-2</sup>, *Lumbrineris* sp. 123 no. m<sup>-2</sup>, *Prionospio* sp. 61 no. m<sup>-2</sup>, *Melinna* sp. 46 no. m<sup>-2</sup>, *Megalona* sp. 77 no. m<sup>-2</sup>, *Glycera* sp. 61 no. m<sup>-2</sup> and *Paraonis* sp., 61 no. m<sup>-2</sup> respectively (Figure 5d and 6).

### **Variation and Species diversity in macrobenthos**

Margalef species richness (d), Shannon-Weiner index (H') and evenness (J') is used to calculate the species diversity index at the stations. The maximum number of species were encountered during M I, and the correspondence values of the Shannon-Weiner index (H') during M I and M II are 1.9 and 1.5 followed by Pre-M (1.3) and PM (1.3) season respectively. Post monsoon showed low species diversity and abundance compared to other three seasons (Table 3b; Figure 5 and 6). Bray-Curtis similarity index at 50% similarity level, M I and M II showed two and three groups, and the diversity and abundance was higher during the monsoon seasons compared to other seasons (Table 4). Monsoon season's showed maximum diversity and biomass of macrobenthos with high

temperature and low salinity in near bottom water compared to other seasons (Table 2& 3 a to d, Figure 2). During M I, high diversity and least similarity among stations (Table 4) was observed. The group I stations were dominated by *Prionospio* sp. (contribution to abundance – 7.5 %) and in group II, *Tharyx* sp. was abundant with 21.7% contribution to the total abundance and the other abundant species were *Mediomastus* sp. and *Cossura* sp. contributing 14.1% and 11.2% respectively (Figure 7a). During PM season the similarity of organisms and their average abundance in group I, II, III and IV was dominated by *Tharyx* sp. (20%), *Cossura* sp. (18.4%), *Mediomastus* sp. (7.6%), *Nephtys* sp. (4.6%), and *Magelonasp.* (7.7%) (Figure 7b). In the case of Pre-M season, average similarity among group I, II and III was 36.6%, 61.5% and 50% respectively (Figure 7c). During M II, three groups were observed, with group I (stations S09, S11, S15 and S17), group II (stations S03 and S13) and group III (stations S01 and S08) with similarity of 66.6, 66.6 and 54.9% respectively (Figure 7d).

CCA and Redundancy analysis (Figure 8 a-d) of the study indicated sediment characteristics and total organic carbon to play an important role in influencing the community structure of benthic organisms during different seasons at different stations. Length of gradient value  $>2$  was obtained during MI and MII seasons and during PM and Pre-M season it was  $<2$ . The correlation percentage between macrobenthic abundance and the environmental variables during M I and MII was 81.4% and 96.7%, and during PM and Pre M it was 92.6% and 82.8% respectively. The canonical correspondence analysis indicated that during MI (Figure 8a) sand, near bottom water temperature and total organic carbon influenced the abundance of the organisms such as *Prionospio* sp., *Lumbrineris* sp., *Kirkegaardia* sp., silt, organic nitrogen and D.O. positively influenced *Goniada* sp., *Magelonasp.*, *Cossura* sp., *Streblospio* sp. The polychaetes, *Mediomastus* sp. and *Eteone* sp. were not influenced by the environment variables. During PM season, *Tharyx* sp., Penaeidae and *Aricidea* sp. were positively influenced by Silt, DO, and salinity. It seems that *Mediomastus* sp., *Magelonasp.*, *Glycera* sp. and Pantopoda survive well in clayey sediment and in low DO, salinity and silt content (Figure 8b; Table 3b). The redundancy analyses (Figure 6c; Table 3c) during Pre-M showed that sand and bottom water temperature positively influenced *Tharyx* sp., *Prionospio* sp., *Nephtys* sp., and they were negatively influenced by total organic carbon, organic nitrogen, silt and chlorophyll *a*. The polychaetes, *Magelonasp.* and *Cossura* sp. thrived well in high organic carbon and nitrogen rich silty or sandy sediments. The CCA plot during M II showed that silt, chlorophyll *a*, organic nitrogen and silicate contributed to higher abundance of *Tharyx* sp., *Maldane* sp., *Paraonis* sp., Longosomatidae and Acantharia, while, Errantiate polychaetes, *Glycera* sp., *Lumbrineris* sp., and *Melinna* sp. could adapt to sandy sediment with high temperature and DO (Figure 8d; Table 3d).

## Discussion

The studies on the biodiversity of the benthic organisms from the tropical regions are limited when compared to higher altitudes<sup>23</sup> and same is true for Paradip port situated on the east coast of India, off the coast of Paradip, Odisha state<sup>24</sup>. The study of macrobenthic organisms is important to understand and establish a database for region to improve our understanding on distribution, abundance, diversity and other characters of macrobenthic organisms in marine environment<sup>25</sup> as they play an important role in the food web dynamics and ecological functioning of the benthic ecosystems. The changes occurring in these parameters can lead to the disturbance in the benthic faunal diversity and abundance. In the present study macrobenthic community structure and their abundance varied with the seasons, associated with changes in salinity (lower in monsoon and higher in non-monsoon seasons), temperature, DO, and sediment characteristics. The sediment quality is the most important parameter for seasonal and spatial distribution and diversity of benthic organisms, various properties related to sediment quality are permeability, penetrability that are controlled by erosion, resuspension and water content in the sediment<sup>26</sup>. The sediment quality in Paradip port indicated that there are limited changes in the spatio-temporal variation in the texture of sediment which was mostly dominated by silt followed by sand with minimum contribution of clay. The TRIX analysis for bottom water showed that the near bottom water quality was also good and rich in organic matter indicating healthy bottom water conditions<sup>27</sup>. There is wide range in salinity variation (25-34) during the non-monsoon and monsoon seasons, resulting in the euryhaline species such as Cossuridae and Cirratulidae to adapt and survive during monsoon and stenohaline organisms such as isopods and crustaceans (Penaeidae) dominated during the non-monsoon seasons.<sup>28</sup> Observed that the near bottom seawater nutrients were higher during pre-monsoon (summer) than in other seasons due to gradual increase in temperature. The present study area also showed increased nutrient levels during pre-monsoon compared to monsoon and post-monsoon seasons.

The organic carbon enrichment was high in Paradip port especially during M I and PM and it was low during Pre-M and MII and such an increase in the organic carbon in the sediment leads to hypoxic conditions, leading to decrease in the abundance and diversity of benthic organisms<sup>29</sup>. The stations with high organic content in the study area were either dominated by the indicator species or had lower abundance of macrobenthos. The distribution of organic carbon also varied in the surface sediments with stations along with changes in the sand-silt content, as organic carbon content was high in silt dominated areas. The finer silt particles accumulated higher organic carbon content, due to the lack of disturbance in the sediment. There was a dominance of sub-surface dwelling polychaetes, which are biological indicators of high organic matter in the sediments. This high



organic matter content may be due to plant material and faeces that settle down, and such organic matter is removed from the water column and at the sediment water interface by the benthic fauna. The deposited organic material either becomes part of particulate organic matter, which is taken in by benthic fauna or directly ingested by deposit feeders<sup>30</sup>. The temporal changes such as salinity, sediment size gradient and other environmental stresses associated with organic carbon enrichment leads to the succession of different species<sup>31</sup>. The present study also showed changes in the diversity pattern of macrobenthos due to seasonal variation along with increased organic carbon input.

The most common organisms reported were *Tharyx* sp., *Prionospio* sp., *Cossura* sp., and *Magelona* sp. in Paradip port and these species are termed as opportunistic species and are well known pollution indicators<sup>32</sup>. These organisms are mostly found in stations with high organic carbon in the sediment indicating they may be surface or subsurface deposit feeders<sup>33</sup>. Earlier study indicated higher abundance of *Prionospio* sp. in semi-polluted (moderate organic carbon) region of the Visakhapatnam harbour<sup>5</sup>. It has been reported that *Prionospio* sp. and few other species burrow in sand and are capable of constructing tubes in which they hide and also protect them from predators indicating their sub-surface deposit feeding habit<sup>34</sup>. With regard to properties of sediment dynamics, it has been suggested that high silt-clay fraction in the sediment contains more food particles which are commonly composed of decomposable organic constituent and sustain deposit feeding benthic organisms<sup>5,27,35,36</sup>. Organisms belonging to *Cossura* sp. are mostly burrowers in the soft-sediment dominated by high silt. Higher abundance of deposit feeders belonging to genus *Cossura* were reported in high silt area at Visakhapatnam port<sup>5</sup>. *Prionospio* sp. has been reported as an indicator of organic enrichment in subtidal areas which is an inhabitant of sub-surface region of the sediment<sup>7</sup>. Previous study has reported that sub-surface deposit feeding polychaetes such as *Mediomastus* sp., *Tharyx* sp. and *Cossura* sp. are capable of feeding on freshly settled organic carbon and are capable of feeding on aged organic matter in the sediment<sup>37</sup>. The *Magelona* sp. is a subsurface deposit feeder and their feeding activity usually occur below the surface<sup>38</sup>.

Spatial variation in benthic community is observed mostly in the estuaries and bays, under extreme or abnormal circumstances of organic matter overloading in the coastal water leading to disturbance in the faunal community<sup>39</sup>. They are also mostly deposit feeders and are present in sandy-silt sediment with high total organic carbon as observed in *Mediomastus* sp.<sup>38</sup> Similar conditions were observed in the Paradip port and *Mediomastus* sp. which is one of the most abundant sedentary polychaete was present in the fine grain sandy habitats dominated by silt with high organic matter. The individuals of *Mediomastus* sp. were present during all the seasons, and these are non-selective feeders as they engulf food directly from the sediment<sup>40</sup> and this may be related to less

disturbance in the sediment as they are observed during all the seasons. The polychaete, *Cossura* sp., a stress tolerant macrobenthic polychaete which is a suspension feeder and prefer sandy and fine silty sediment, and is a burrower preferred soft sediment with high silt as reported earlier<sup>41</sup>. The other dominant polychaete, *Nephtys* sp. found during all the seasons is an active predator that prefers fine sandy sediments, and studies have reported higher abundance of these organisms in fine sandy sediment<sup>40, 41</sup>. The hypoxia and pollution tolerant polychaetes, *Tharyx* sp. and *Prionospio* sp. the deposit feeders were observed during all the seasons, thus indicating the health of the ecosystem. Even though *Tharyx* sp. is a selective feeder which inhabit the mud coloured tubes, they are found in highly polluted areas<sup>16</sup>. During monsoon season the observed high organic carbon content can be attributed to collapse and sinking of phytoplankton from the surface waters<sup>42</sup>. The presence of Spionidae, *Prionospio* sp. and Cossuridae, *Cossura* sp. in the sediment shows sediment instability and disturbed environment and both these species are deposit feeders and feed on fresh surface organic matter<sup>43,44</sup>. The diversity of macrobenthos is limited in Paradip port, as high organic matter content promotes the abundance of tolerant species and reduce the abundance of sensitive species<sup>29</sup>, and this leads to reduction in their diversity and abundance. There is also another possibility of macrobenthic assemblages in high organic carbon sediments, where black carbon contributes more to organic carbon content present in the sediments<sup>45</sup>. The presence of indicator species of pollution belonging to genera *Prionospio* sp., *Streblospio* sp., *Mediomastus* sp. and *Tharyx* sp., in the present study indicate further that these species thrive in low oxygen and high organic load<sup>46</sup>.

*Lumbrineris* sp. are carnivores or carrion feeders and they prey on other polychaetes, Nemertea, Crustacea and bivalvia<sup>16</sup>. It is possible that the disturbance in the surface sediments during monsoon season may lead to the exposure of burrowing organisms and this may be the reason for reporting *Lumbrineris* sp. during monsoon seasons. The *Magelona* sp. is another organisms found during all the seasons, and the studies on *Magelona* indicate that they are non-selective surface deposit feeders and are also alternate their feeding mode to suspension feeding<sup>16</sup>. In respect to their non-selective feeding behaviour and the presence of sufficient organic matter in the study area lead to the distribution of genera *Magelona* sp. to be found in all the seasons despite variations in their abundance. There is a difference in species abundance and diversity in accordance to the seasonal changes in Paradip port with higher abundance during monsoon season.<sup>23</sup> The life cycle of a tropical macrobenthic organisms integrate with the monsoon and this results in seasonal differences in occurrence and abundance of macrobenthic organisms. The previous studies on Indian ports shows reduction in the macrobenthic species composition, density and biomass due to dredging and anthropogenic activities as observed in Cochin port<sup>47</sup>. In Visakhapatnam port, a coastal ecosystem

the macrobenthic community composition varied in the port due to various levels of pollutant accumulation in the sediment spatially showing the difference in benthic community in the port ecosystem<sup>5</sup>. The loss in the macrobenthic communities and their rapid recovery in these stations are due to the migration of these fauna from the nearby sediment patches that are not leading to reclamation of macrobenthos in suitable conditions as observed in Cleveland Bay<sup>48</sup>. The previous studies shows that due to variations in the sediments, the macrobenthic populations increased or decreased in the small port ecosystem as observed in the present study. The presence of higher organic carbon in sediment also causes a depletion in the species diversity, abundance and biomass<sup>49</sup>, resulting in proliferation of opportunistic species. Present study shows higher organic carbon in the study area leading to the depletion in diversity and also survival of pollution tolerant species albeit their count. The present study shows that the Paradip port environment is influenced by the seasonal variation mostly brought in by the monsoons and the anthropogenic activities, however, healthy bottom water quality and high amount of organic load accumulated in the sediment leads to the survival and proliferation of indicator macrobenthos species.

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## Captions for Figures

**Figure 1.** Map showing the sampling stations in Paradip port. S01- Boat Basin, S02- Slip Way, S03- Deep Sea Trawler Berth, S04- Area Adjacent to Fertilizer Berths, S05- Fertilizer Berth-I, S06- Fertilizer Berth-II, S07- Multipurpose Berth, S08- North Quay-II, S09- Central Quay-III, S10- Central Quay-II, S11- Central Quay-I, S12- Turning Circle, S13- South Quay, S14- East Quay-I, S15- East Quay-II, S16- East Quay-III, S17- North Quay-I, S18- Coal Berth-I, S19- Coal Berth-II, S20- Iron Ore Berth, S21- Stone Pitching Side and S22- Oil Berth.

**Figure 2.** Seasonal variations in the bottom water parameters, Temperature ( $^{\circ}\text{C}$ ), Salinity and Dissolved oxygen  $\text{mg.m}^3$  at Paradip port.

**Figure 3.** Variations in the sediment characteristics during different seasons (a). Monsoon, (b). Post monsoon, (c). Pre-monsoon and (d). Monsoon II, (e). Ternary plot at Paradip port.

**Figure 4.** Seasonal variations in the Total organic carbon (%) and sediment Chlorophyll a ( $\text{mg. m}^{-2}$ ) at Paradip port during different seasons.

**Figure 5.** Figure 5. Seasonal variation in the abundance ( $\text{no. m}^{-2}$ ) of dominant macrobenthic taxa at Paradip port.

**Figure 6.** Figure 6. Box-plots depicting the abundance ( $\text{no. m}^{-2}$ ) of dominant macrobenthos at Paradip port.

**Figure 7.** Dendrogram for hierarchical clustering of macrobenthic polychaetes with Bray–Curtis similarity indices during different seasons (a) Monsoon I (b) Post-monsoon (c) Pre-monsoon (d) Monsoon II.

**Figure 8.** CCA and RDA plots illustrating the correlation between environmental parameters and sediment characteristics and macrobenthos species during different seasons (a) Monsoon I, (b) Post monsoon, (c) Pre-monsoon (d) Monsoon II at Paradip port. (Abbreviation for macrobenthos: ANC - Ancistrosyllis sp., ARI - Aricidea sp., COS - Cossura sp., C.LON - Cossura longocirrata, ETE- Eteone sp., EUN - Eunice sp., EPI - Diopatra sp., GLY - Glycera sp., GON - Goniada sp., HES - Hesione sp., LUM - Lumbrineris sp., MAL - Maldane sp., MED - Mediomastus sp., MEG - Magelona sp., MEL - Melinna sp., MON - Kirkegaardia sp., NEP - Nephtys sp., NOT - Nototropis sp., PAR - Paraonis sp., PRI - Prionospio sp., STR - Streblospio sp., THA - Tharyx sp., ACA - Acantharia, CIR - Cirolanidae, HET - Longosomatidae, ISO - Iospilidae, ISOP - Isopoda, PAN - Pantopoda, PEN - Penaeidae and SIP – Sipuncula), (ON-Organic Nitrogen (%), OSI- Organic sediment index (%), DO - Dissolved oxygen ( $\text{mg.m}^{-3}$ ), TOC - Total organic Carbon (%)).

**Supplementary Figure:Figure 9.** Near bottom water nutrients at Paradip port during different seasons.

## Captions for Tables

**Table 1:** - Paradip port stations and their locations.

**Table 2:** Variations in Temperature, salinity and Dissolved oxygen in near bottom water at Paradip port at different stations during different seasons (M I - Monsoon I, Pre-M – Pre-monsoon, PM – Post-monsoon, M II – Monsoon II).

**Table 3.** Variation in the abundance ( $\text{no.m}^{-2}$ ) of macrobenthos in Paradip port during different seasons. Table 3a. Abundance ( $\text{no.m}^{-2}$ ) of macrobenthic organisms in Paradip port during Monsoon I, Table 3b. Abundance ( $\text{no.m}^{-2}$ ) of macrobenthic organisms in Paradip port during Post-monsoon, Table 3c. Abundance ( $\text{no.m}^{-2}$ ) of macrobenthic organisms in Paradip port during Pre-monsoon, Table 3d. Abundance ( $\text{no.m}^{-2}$ ) of macrobenthic organisms in Paradip port during Monsoon II.

**Table 4.** Number of species (S), Number of specimens (N), Margalef species richness (d), Pielou's evenness (J'), Shannon index (H), of macrobenthic organisms during different seasons at Paradip port.

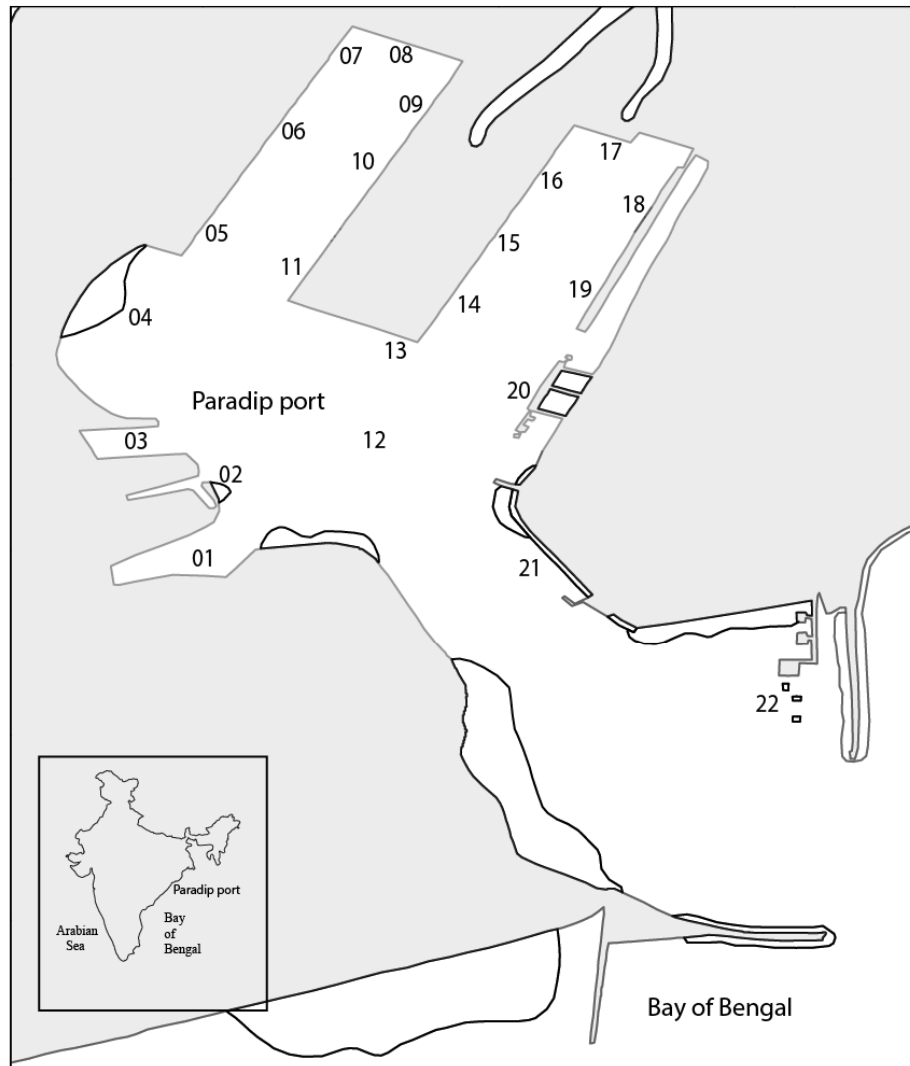


Figure 1. Map showing the sampling stations of various berths in Paradip port. S01- Boat Basin, S02- Slip Way, S03- Deep Sea Trawler Berth, S04- Area Adjacent to Fertilizer Berths, S05- Fertilizer Berth-I, S06- Fertilizer Berth-II, S07- Multipurpose Berth, S08- North Quay-II, S09- Central Quay-III, S10- Central Quay-II, S11- Central Quay-I, S12- Turning Circle, S13- South Quay, S14- East Quay-I, S15- East Quay-II, S16- East Quay-III, S17- North Quay-I, S18- Coal Berth-I, S19- Coal Berth-II, S20- Iron Ore Berth, S21- Stone Pitching Side and S22- Oil Berth.



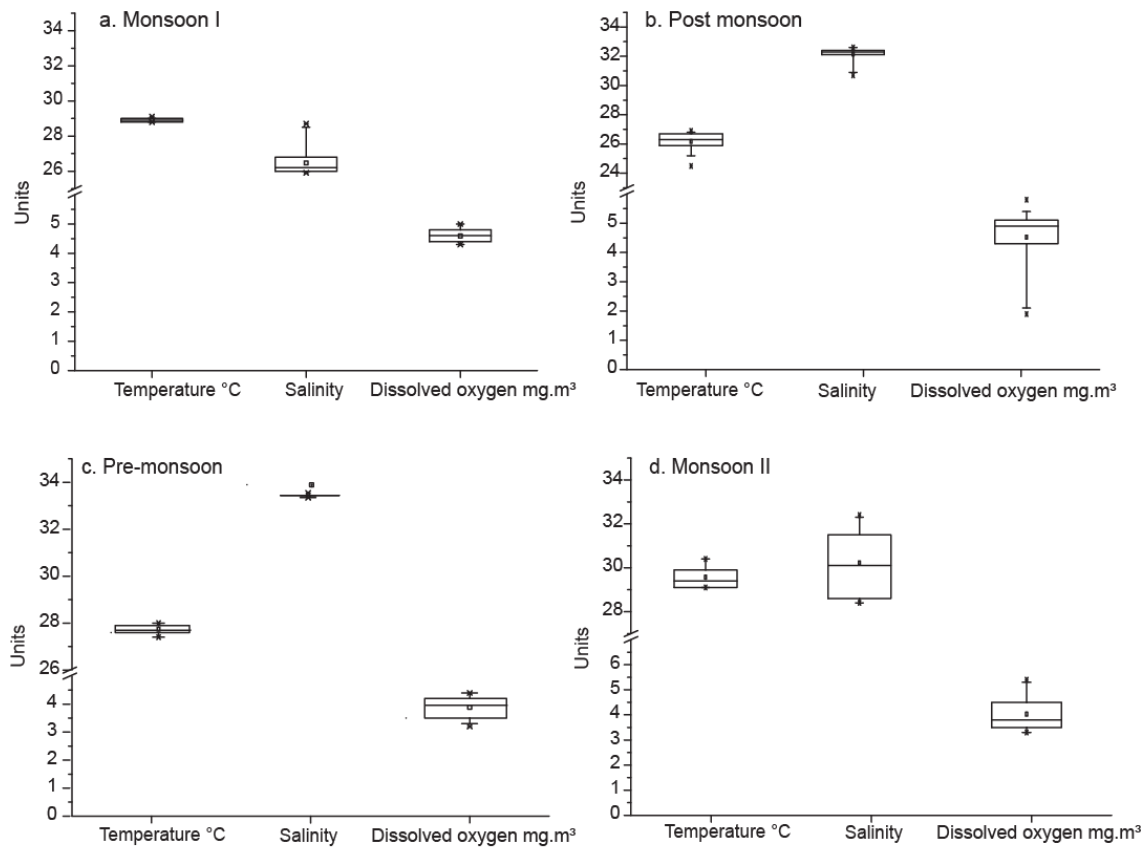


Figure 2. Seasonal variations in the bottom water parameters, Temperature (°C), Salinity and Dissolved oxygen mg.m<sup>3</sup> at Paradip port.

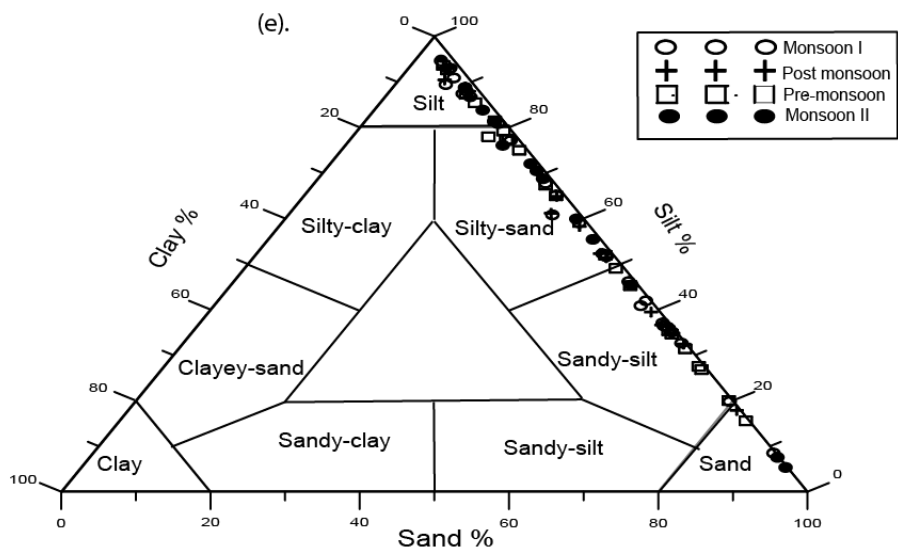
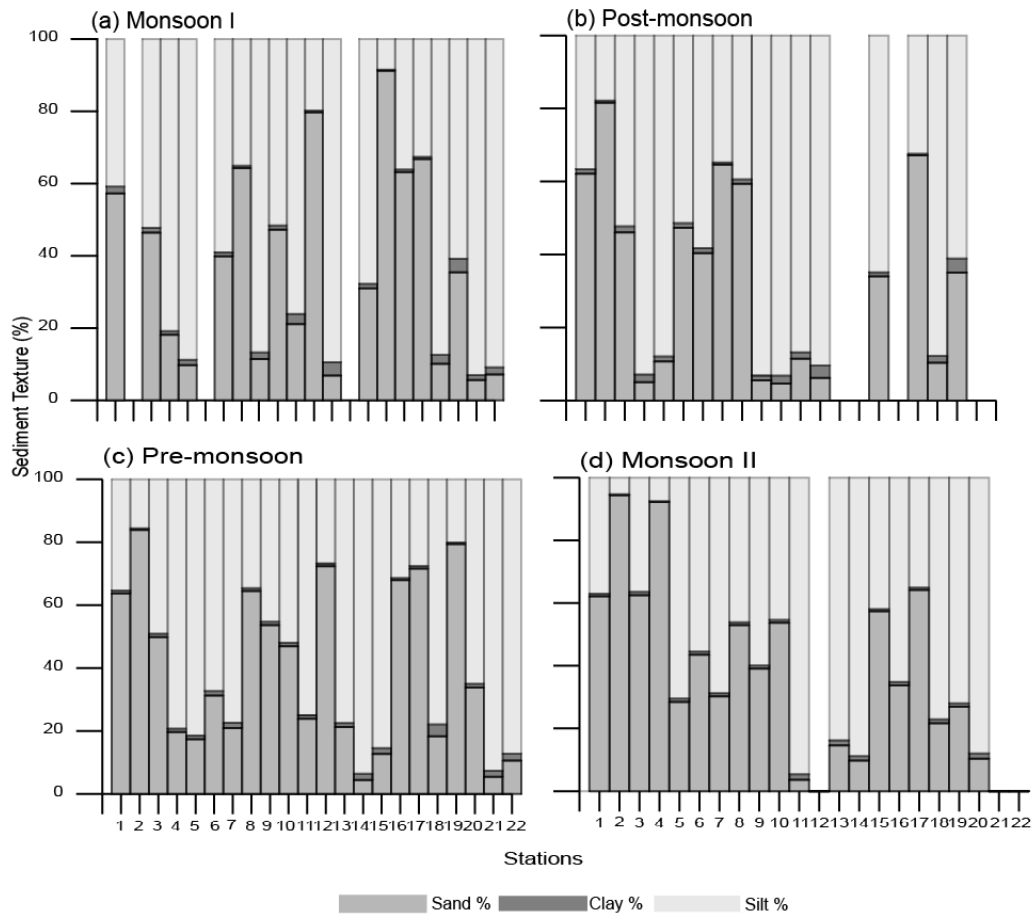


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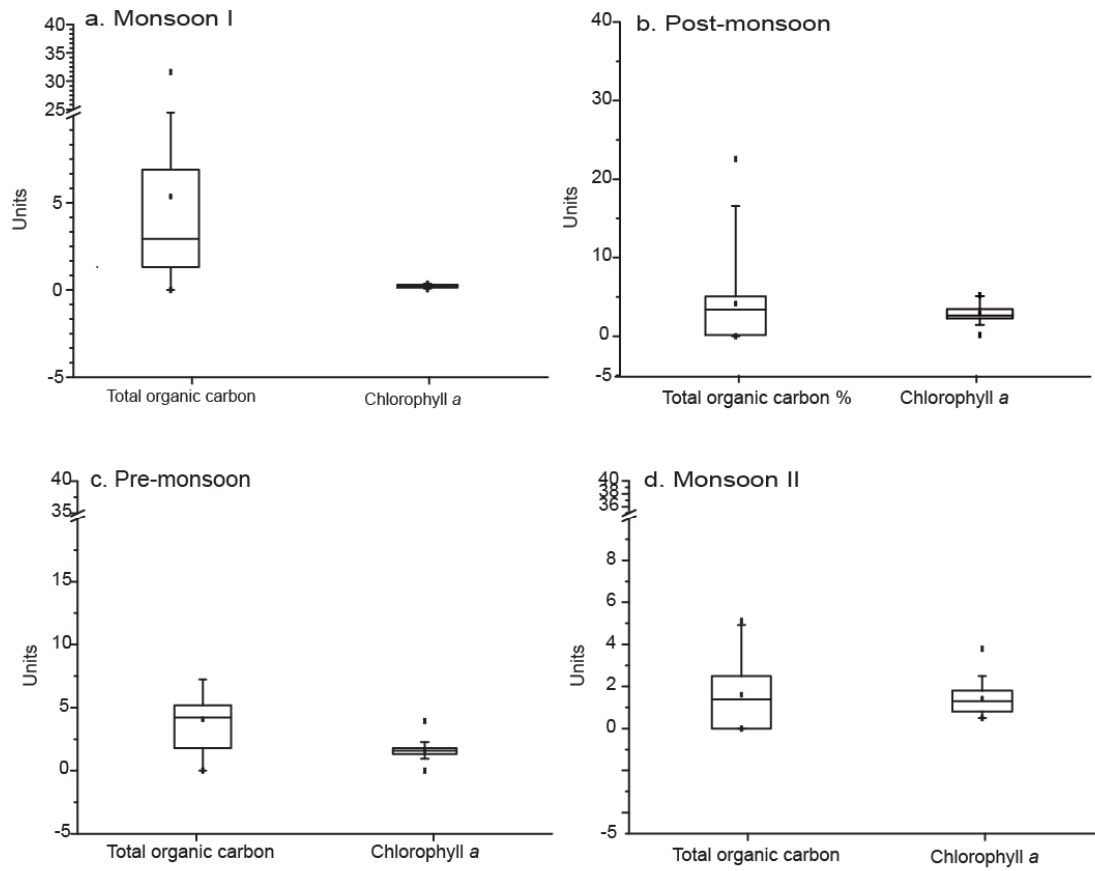


Figure 4. Seasonal variations in the Total organic carbon (%) and sediment Chlorophyll a ( $\text{mg. m}^{-2}$ ) at Paradip port during different seasons.

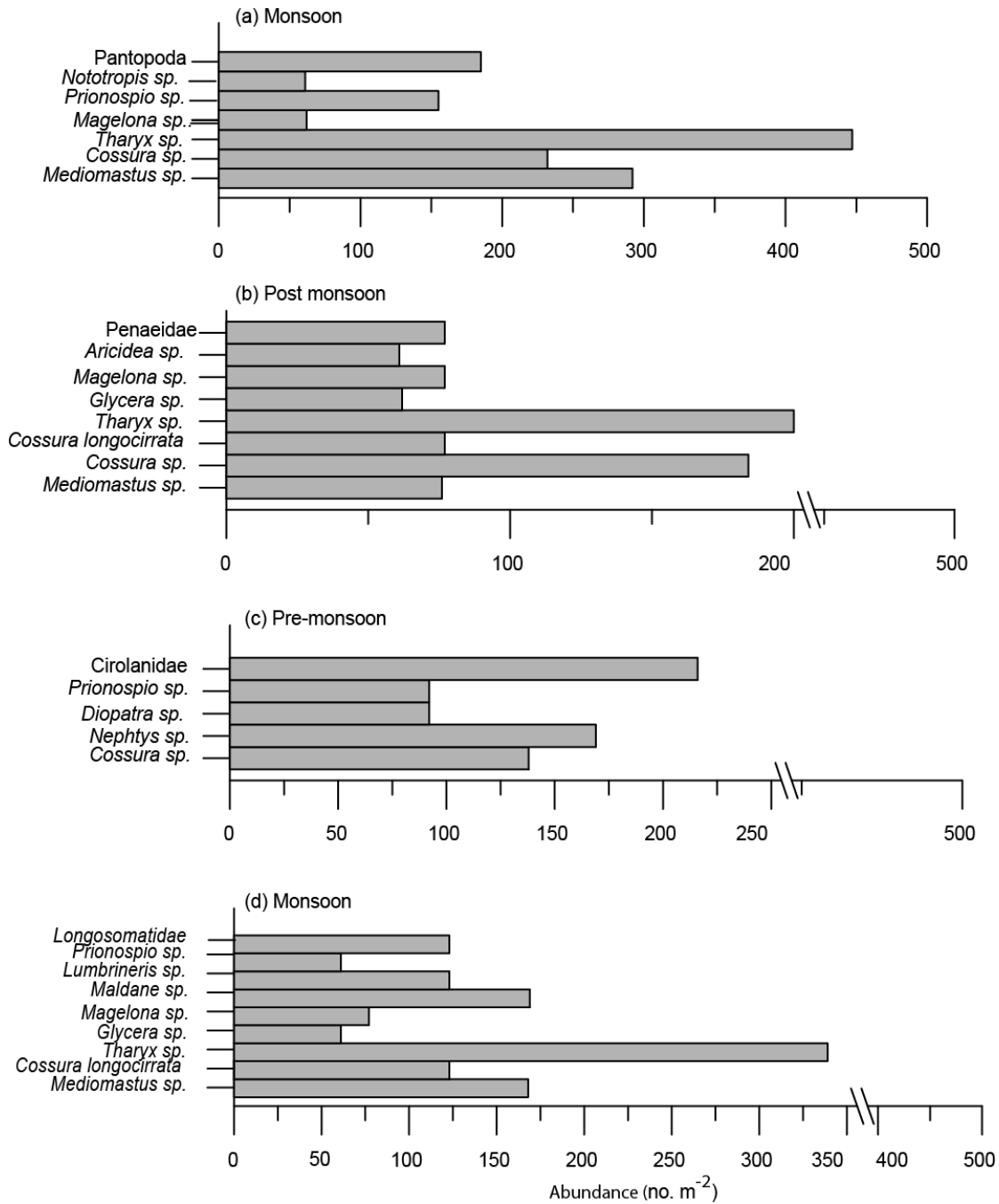


Figure 5. Seasonal variation in the abundance (no. m<sup>-2</sup>) of dominant macrobenthic taxa at Paradip port.

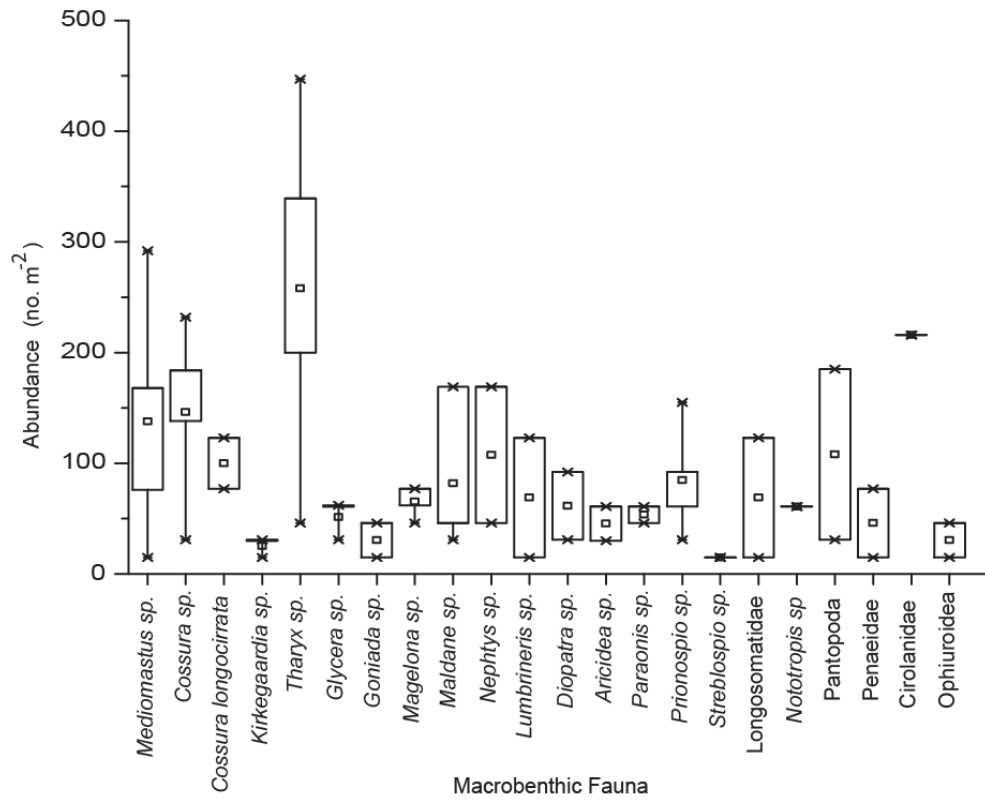


Figure 6. Box-plots depicting the abundance (no. m<sup>-2</sup>) of dominant macrobenthos at Paradip port.

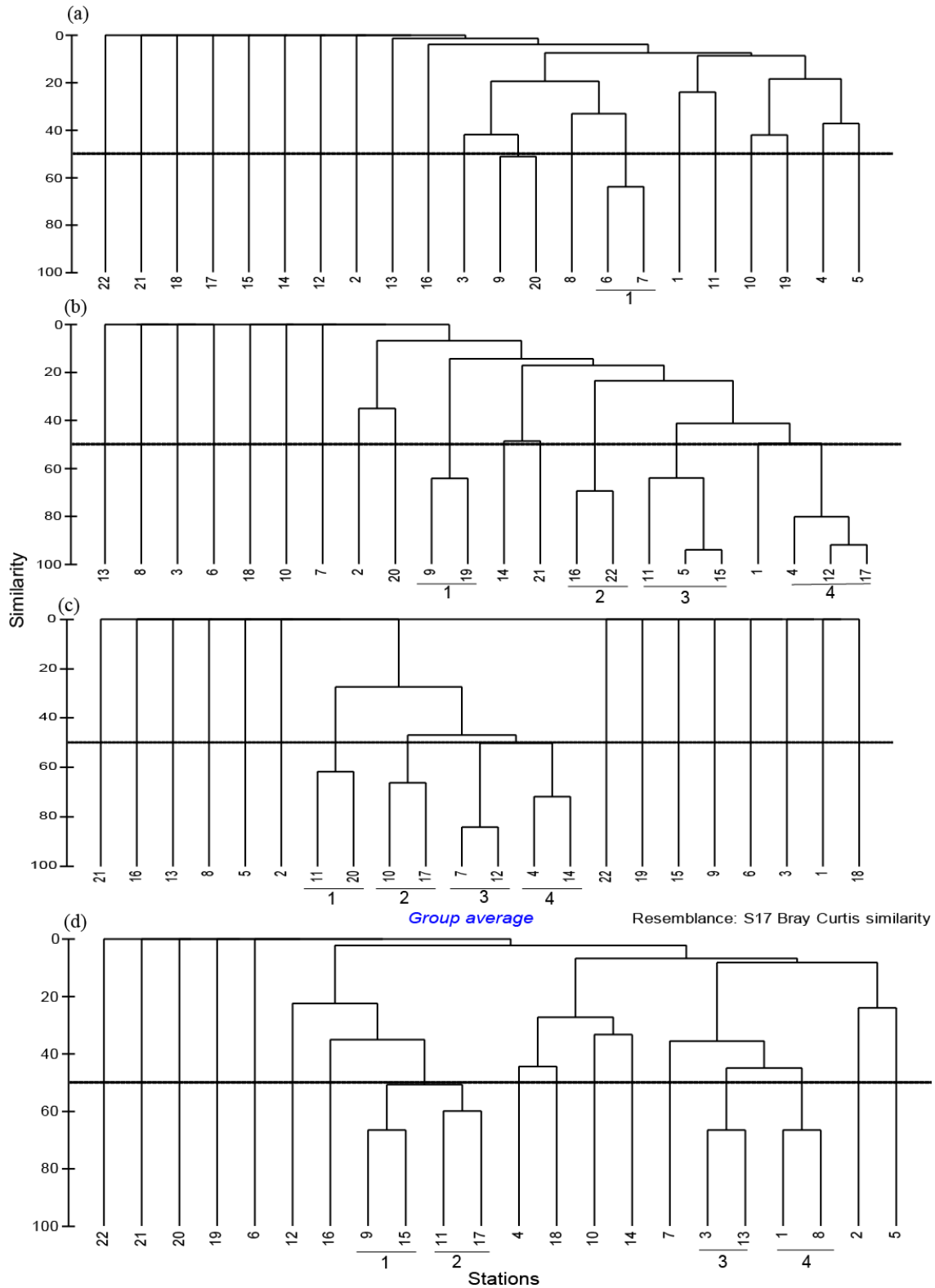


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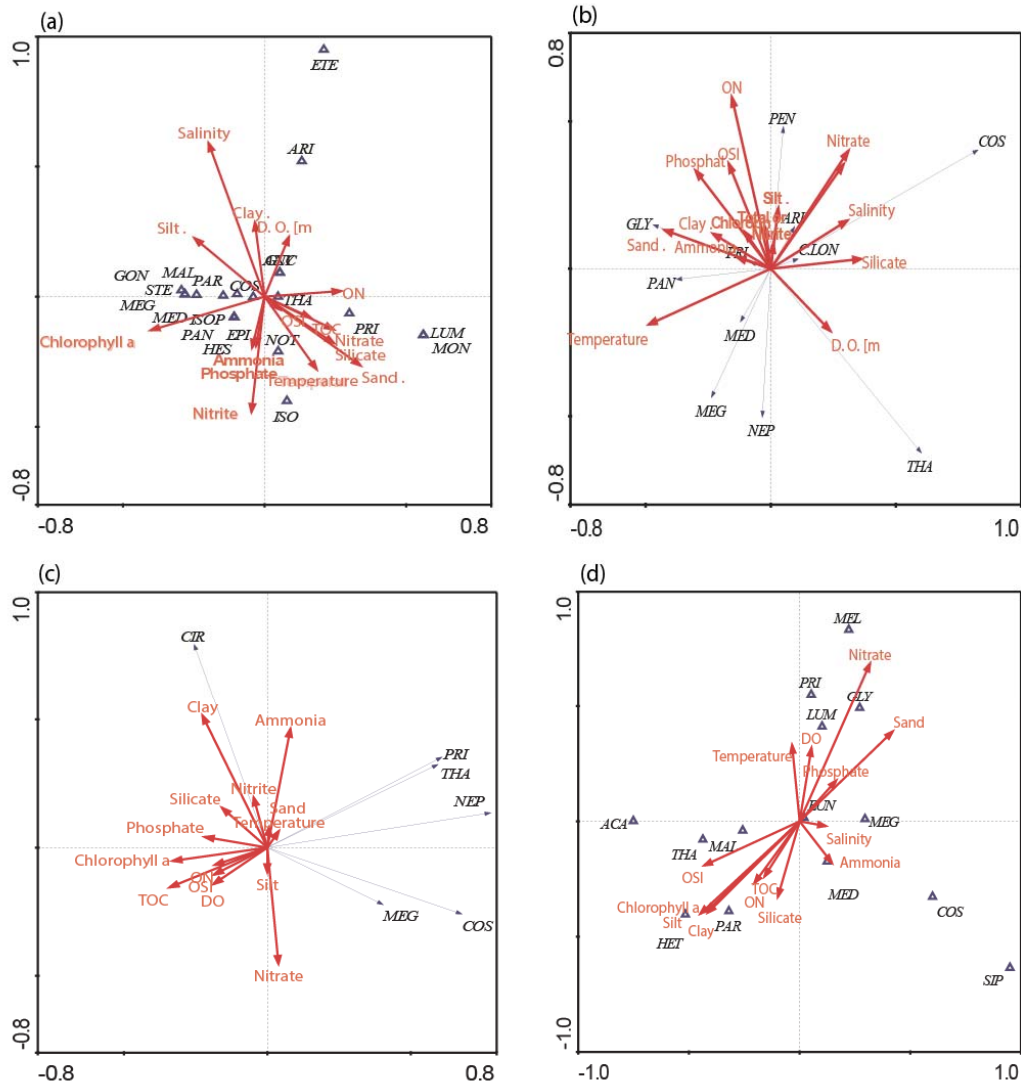


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**Table 1:** - Paradip port stations and their locations.

<b>Stn. No.</b>	<b>Stn. Name</b>	<b>Latitude</b>	<b>Longitude</b>
1	Boat Basin	N 20°16'07.6"	E 86°40'03.1"
2	Slip Way	N 20°16'12.1"	E 86°40'07.4"
3	Deep Sea Trawler Berth	N 20°16'18.3"	E 86°40'02.4"
4	Area Adjacent to Fertilizer Berths	N 20°16'27.8"	E 86°40'02.9"
5	Fertilizer Berth-I	N 20°16'38.1"	E 86°40'06.2"
6	Fertilizer Berth-II	N 20°16'45.3"	E 86°40'11.2"
7	Multipurpose Berth	N 20°16'52.7"	E 86°40'14.8"
8	North Quay-II	N 20°16'54.0"	E 86°40'19.4"
9	Central Quay-III	N 20°16'50.2"	E 86°40'19.1"
10	Central Quay-II	N 20°16'43.2"	E 86°40'15.5"
11	Central Quay-I	N 20°16'35.3"	E 86°40'11.6"
12	Turning Circle	N 20°16'15.2"	E 86°40'15.5"
13	South Quay	N 20°16'27.3"	E 86°40'14.2"
14	East Quay-I	N 20°16'30.5"	E 86°40'22.5"
15	East Quay-II	N 20°16'37.9"	E 86°40'26.3"
16	East Quay-III	N 20°16'46.7"	E 86°40'29.7"
17	North Quay-I	N 20°16'46.1"	E 86°40'35.6"
18	Coal Berth-I	N 20°16'38.7"	E 86°40'34.9"
19	Coal Berth-II	N 20°16'30.3"	E 86°40'29.0"
20	Iron Ore Berth	N 20°16'23.4"	E 86°40'25.5"
21	Stone Pitching Side	N 20°16'08.8"	E 86°40'30.0"
22	Oil Berth	N 20°15'52.6"	E 86°40'43.1"



**Table 2:** Variations in Temperature, salinity and Dissolved oxygen in near bottom water at Paradip port at different stations during different seasons (M I - Monsoon I, Pre-M – Pre-monsoon, PM – Post-monsoon, M II – Monsoon II).

Station	Temperature [°C]				Salinity [PSU]				D.O. [mg.m <sup>-3</sup> ]			
	M I	PM	Pre-M	M II	M I	PM	Pre-M	M II	M I	PM	Pre-M	M II
1	28.9	26.0	27.9	30.4	25.9	30.7	33.8	28.4	5.0	5.0	4.4	5.2
2	28.9	26.1	27.7	30.4	26.0	30.9	33.8	28.6	5.0	3.7	4.4	5.3
3	28.9	26.1	27.8	30.2	26.0	31.2	33.8	28.4	4.8	4.3	4.4	5.4
4	28.9	25.2	27.4	29.2	26.9	32.4	33.9	29.8	4.6	4.6	4.2	4.0
5	28.9	24.5	27.6	29.1	26.8	32.4	33.9	30.1	4.4	4.0	3.5	3.8
6	29.0	26.4	27.8	29.1	26.0	32.5	33.9	30.6	4.3	1.9	4.2	3.6
7	28.8	26.4	27.8	29.4	26.1	32.3	33.9	30.1	4.4	5.2	4.2	3.6
8	28.9	26.1	27.9	29.4	26.0	32.1	34.0	29.3	4.6	5.3	4.3	3.7
9	28.9	26.2	27.9	29.4	26.0	32.3	33.9	29.7	4.4	5.1	4.2	3.9
10	28.8	26.6	27.7	29.1	26.0	32.4	33.9	32.4	4.4	2.1	3.5	3.3
11	28.8	25.9	27.6	29.1	26.8	32.4	33.9	32.1	4.7	4.4	3.4	3.4
12	29.0	25.4	27.6	29.6	28.7	32.6	33.9	28.4	4.9	5.8	4.0	4.3
13	28.8	25.8	27.4	29.1	28.5	32.6	33.9	32.3	4.8	3.4	4.2	3.8
14	28.8	25.5	27.9	29.1	26.9	32.2	33.9	32.2	4.6	4.4	3.9	3.3
15	29.0	26.7	28.0	29.4	26.4	32.5	33.8	31.4	4.3	4.8	3.9	3.4
16	29.0	26.8	27.7	29.6	26.3	32.3	33.9	31.6	4.4	4.9	3.2	3.3
17	29.1	26.7	28.0	29.4	26.4	32.3	33.9	31.5	4.5	4.8	3.6	3.5
18	28.8	26.7	27.7	29.6	26.1	32.1	33.9	31.4	4.6	5.1	3.8	3.5
19	28.8	26.9	27.6	30.3	26.0	32.6	33.9	29.9	4.9	5.1	3.8	4.8
20	28.8	26.7	27.9	29.9	26.0	31.9	33.9	28.6	4.3	5.4	3.4	4.2
21	28.9	26.6	27.7	29.9	26.3	32.1	33.9	29.7	4.6	5.1	3.6	4.5
22	29.0	26.3	27.6	29.9	26.2	32.4	33.9	28.4	4.5	5.0	3.3	4.8
<b>Min</b>	28.8	24.5	27.4	29.1	25.9	30.7	33.8	28.4	4.3	1.9	3.2	3.3
<b>Max</b>	29.1	26.9	28.0	30.4	28.7	32.6	34.0	32.4	5.0	5.8	4.4	5.4
<b>Mean</b>	28.9	26.2	27.7	29.6	26.5	32.1	33.9	30.2	4.6	4.5	3.9	4.0
<b>SD</b>	0.09	0.60	0.17	0.44	0.76	0.52	0.04	1.43	0.22	0.99	0.39	0.68

**Table 3.** Variation in the abundance of macrobenthos in Paradip port at different stations during different seasons.  
**Table 3a.** Abundance (no.m<sup>-2</sup>) of macrobenthic organisms in Paradip port during Monsoon I.

Monsoon I																							
Organisms/Stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total
<i>Hesione</i> sp.											31												31
<i>Mediomastus</i> sp.				31	77	92		15			46								31				292
<i>Cossura</i> sp.	139							31			62												232
<i>Kirkegaardia</i> sp.			31																				31
<i>Tharyx</i> sp.						231	108	62	46														447
<i>Glycera</i> sp.								31															31
<i>Goniada</i> sp.				46																			46
<i>Magelona</i> sp.					62																		62
<i>Maldane</i> sp.										31										15			46
<i>Lumbrineris</i> sp.			15																				15
<i>Diopatra</i> sp.											31												31
<i>Aricidea</i> sp.								15					15										30
<i>Paraonis</i> sp.								15			15									31			61
<i>Eteone</i> sp.													15										15
<i>Ancistrosyllis</i> sp.								15															15
<i>Prionospio</i> sp.			62					31	31												31		155
<i>Streblospio</i> sp.					15																		15
Iospilidae																46							46
<i>Nototropis</i> sp.									15		15					31							61
Pantopoda											185												185
Isopoda											46												46
Total	139	0	108	77	154	323	108	215	92	31	431	0	30	0	0	77	0	0	77	31	0	0	1893
Biomass (mg/m <sup>2</sup> )	964	0	416	243	512	2640	677	837	231	52	5086	0	104	0	11	279	54	0	132	85	0	0	

**Table 3b.** Abundance (no.m<sup>-2</sup>) of macrobenthic organisms in Paradip port during Post monsoon.

Post monsoon																								
<b>Organisms/Stations</b>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total	
<i>Mediomastus</i> sp.	15				15										31					15			76	
<i>Cossura</i> sp.				31	15				31		15	31		31	15		15							184
<i>Cossura longocirrata</i>														46							31			77
<i>Tharyx</i> sp.	31			46								31				15	46					31	200	
<i>Glycera</i> sp.		31																			31		62	
<i>Magelona</i> sp.																				15	31	31	77	
<i>Nephtys</i> sp.																15						31	46	
<i>Aricidea</i> sp.		46		15																			61	
<i>Prionospio</i> sp.			31																				31	
Pantopoda																					31		31	
Penaeidae									46												31		77	
Total	46	77	31	92	30	0	0	0	77	0	15	62	0	77	46	30	61	0	31	92	62	93	922	
Biomass (mg/m <sup>2</sup> )	178	259	84	980	185	0	0	70	218	0	48	260	0	315	47	182	216	0	59	450	184	271		

**Table 3c.** Abundance (no.m<sup>-2</sup>) of macrobenthic organisms in Paradip port during Pre-monsoon.

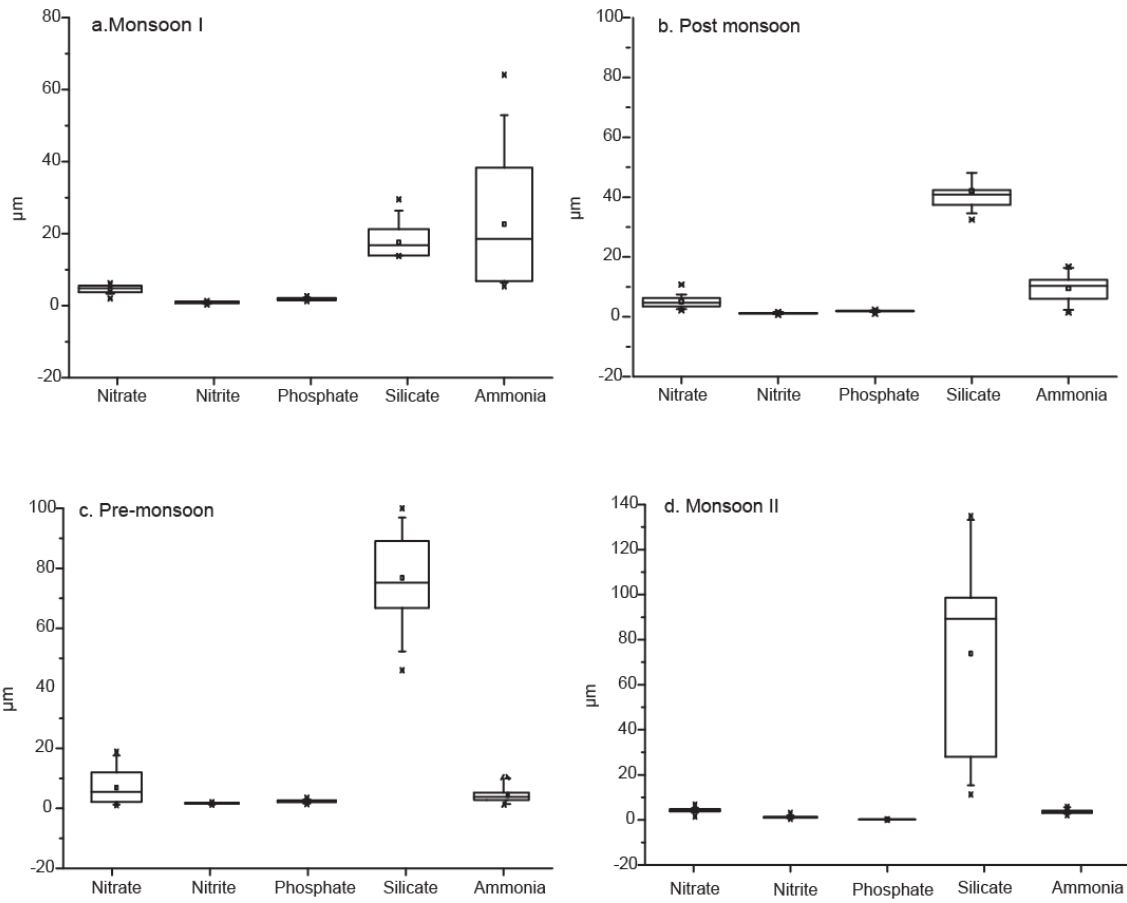
Pre-monsoon																							
<b>Organisms/Stations</b>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total
<i>Cossura</i> sp.				31						15			46			15				31			138
<i>Tharyx</i> sp.																46							46
<i>Magelona</i> sp.				46																			46
<i>Nephtys</i> sp.				31			15			31		46		15			31						169
<i>Diopatra</i> sp.	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	0	92
<i>Prionospio</i> sp.										15	15						31						61
Cirolanidae																		215					215
Total	0	0	0	108	15	0	15	0	0	46	30	46	0	61	0	0	123	215	0	31	77	0	767
Biomass (mg/m <sup>2</sup> )	0	0	0	196	19	0	25	94	0	132	29	58	0	120	0	0	515	1562	0	70	238	0	

**Table 3d.** Abundance (no.m<sup>-2</sup>) of macrobenthic organisms in Paradip port during Monsoon II.

Monsoon II																							
Organisms/Stat ions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total
Sipuncula				31																			31
<i>Melinna</i> sp.		46																					46
<i>Mediomastus</i> sp.	31		15		15		31	46					15					15					168
<i>Cossura longocirrata</i>				31						15				15					62				123
<i>Tharyx</i> sp.									31		46	139				15	77						339
<i>Glycera</i> sp.		46											15										61
<i>Magelona</i> sp.					31									46									77
<i>Maldane</i> sp.					108		15					31				15							169
<i>Lumbrineris</i> sp.		31			62					15					15	0							123
<i>Eunice</i> sp.							46																46
<i>Paraonis</i> sp.	15											31											46
<i>Prionospio</i> sp.		31			15										15								61
Longosomatidae												123											123
Acantharia											31												31
Total	46	154	15	62	231	0	92	46	31	30	77	324	30	61	61	30	77	77	0	0	0	0	1444
Biomass (mg/m <sup>2</sup> )	114	1167	90	139	1498	0	251	122	61	48	1524	2879	52	124	171	116	760	422	0	0	0	0	

**Table 4.** Number of species (S), Number of specimens (N), Margalef species richness (d), Pielou's evenness (J'), Shannon index (H), of macrobenthic organisms during different seasons at Paradip port.

a.Monsoon I						b. Post- Monsoon						c.Pre-monsoon						d. Monsoon II					
Stations	S	N	d	J'	H'(loge)	Stations	S	N	d	J'	H'(loge)	Stations	S	N	d	J'	H'(loge)	Stations	S	N	d	J'	H'(loge)
1	1	139	0	****	0	1	2	46	0.2612	0.9109	0.6314	1	0	0	****	****	0	1	2	6	0.5454	0.9919	0.6875
2	0	0	****	****	0	2	2	77	0.2302	0.9724	0.6741	2	0	0	****	****	0	2	4	15	1.118	0.9989	1.385
3	3	108	0.4272	0.8657	0.9511	3	1	31	0	****	0	3	0	0	****	****	0	3	1	3	0	****	0
4	2	77	0.2302	0.9724	0.6741	4	3	92	0.4423	0.9183	1.009	4	3	108	0.4273	0.9821	1.079	4	2	7	0.517	1	0.6931
5	3	154	0.3971	0.8554	0.9397	5	2	30	0.294	1	0.6931	5	0	0	****	****	0	5	5	18	1.387	0.9866	1.588
6	2	323	0.1731	0.8619	0.5975	6	0	0	****	****	0	6	0	0	****	****	0	6	0	0	****	****	0
7	1	108	0	****	0	7	0	0	****	****	0	7	1	15	0	****	0	7	3	10	0.8644	0.9922	1.09
8	8	215	1.303	0.9326	1.939	8	0	0	****	****	0	8	0	0	****	****	0	8	1	4	0	****	0
9	3	92	0.4423	0.9183	1.009	9	2	77	0.2302	0.9724	0.6741	9	0	0	****	****	0	9	1	3	0	****	0
10	1	31	0	****	0	10	0	0	****	****	0	10	2	77	0.2302	0.971	0.673	10	2	6	0.5808	1	0.6931
11	8	431	1.154	0.8329	1.732	11	1	15	0	****	0	11	2	31	0.2918	1	0.6931	11	2	7	0.5026	0.9979	0.6917
12	0	0	****	****	0	12	2	62	0.2423	1	0.6931	12	1	46	0	****	0	12	4	17	1.066	0.9894	1.372
13	2	30	0.294	1	0.6931	13	0	0	****	****	0	13	0	0	****	****	0	13	2	6	0.5808	1	0.6931
14	0	0	****	****	0	14	2	77	0.2302	0.9724	0.6741	14	2	62	0.2427	0.8113	0.5623	14	2	7	0.5277	0.9817	0.6805
15	0	0	****	****	0	15	2	46	0.2612	0.9109	0.6314	15	0	0	****	****	0	15	3	9	0.9078	0.9952	1.093
16	2	77	0.2302	0.9724	0.6741	16	2	30	0.294	1	0.6931	16	0	0	****	****	0	16	2	6	0.5808	1	0.6931
17	0	0	****	****	0	17	2	61	0.2433	0.8047	0.5578	17	4	123	0.6232	0.9528	1.321	17	1	4	0	****	0
18	0	0	****	****	0	18	0	0	****	****	0	18	1	216	0	****	0	18	2	7	0.5164	0.9729	0.6744
19	3	77	0.4604	0.9569	1.051	19	1	31	0	****	0	19	0	0	****	****	0	19	0	0	****	****	0
20	1	31	0	****	0	20	4	92	0.6635	0.9554	1.325	20	1	31	0	****	0	20	0	0	****	****	0
21	0	0	****	****	0	21	2	62	0.2423	1	0.6931	21	0	0	****	****	0	21	0	0	****	****	0
22	0	0	****	****	0	22	3	93	0.4412	1	1.099	22	0	0	****	****	0	22	0	0	****	****	0



Supplementary Figure 9. Seasonal variation of bottom water nutrients at Paradip port.