

Changes in the softbottom macrobenthic diversity and community structure from the ports of Mumbai, India

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Abstract

Softbottom macrobenthic diversity and community structure were assessed at Mumbai and Jawaharlal Nehru ports during three different periods between 2001 and 2002 (Nov 01 Post- monsoon 1, Apr-May 02 Pre- monsoon, and Oct 02 Post- monsoon 2). A total of 43 macrobenthic invertebrate species belonging to 5 phyla were recorded. Macrofaunal abundance (PM1 186, PreM 106 and PM2 31 ind m⁻²) and species diversity index (PM1 0.87, PreM 0.73 and PM2 0.30) were very low in all the seasons. Polychaetes were the most dominant macrobenthic group (72.09%) followed by decapoda, amphipoda and bivalves (4.56%). Canonical Correspondence Analysis (CCA) showed that sediment texture, temperature and suspended particulate matter (SPM) were the most important environmental variables influencing polychaete species composition. Significant seasonal variations were observed, influenced by dissimilar monsoonal patterns. Macrobenthic population density during Nov 01 was higher than that of Oct 02 post-monsoon season. Pre-monsoon season recorded more carnivorous polychaete species than post-monsoon seasons. The present study showed lower values of polychaete diversity index in all the seasons compared to earlier studies. Out of 31 polychaete species, 19 have been reported for the first time from this area. Polychaete species and *Glycera longipinnis*, *Paraprionospio pinnata* and *Cossura coasta* recorded from 1985-86 were also observed in the present study. Species like *Sigambra constricta*, *Perinereis cavifrons*, *Prionospio polybranchiata* and *Parheteromastus tenuis* were not recorded in the present study, although they were observed during earlier studies in this area.

Keywords: Harbour; Macrobenthos; Polychaete; Species diversity index; Monsoon; India

Introduction

Harbours are considered as the most altered coastal habitat due to heavy traffic and human perturbation (Darbra et al. 2005). Usually, harbours are enclosed areas characterized by low hydrodynamism, depleted oxygen in the water column, high concentrations of pollutants in water and sediment, and low biodiversity (Guerra-Garcia and Garcia-Gomez 2004). Pollution due to various anthropogenic, industrial and maritime discharges renders the harbour environment hostile for native species and opens a window for the proliferation of opportunistic native and exotic species (Galil 2000). As harbour areas have empty niches, they are prone to marine bio-invasion via ballast water discharges (Rilov and Crooks 2009) which is a global concern due to its adverse effect on the ecosystem (Anil et al. 2002). In recent years, substantial attention has been paid to identify the biota present in harbour areas for proper management, from the marine bio-invasion risk perspective; and this strategic move needs to be preceded by a thorough and synergic study of the biological components of that ecosystem. Without having a baseline dataset on native biota, it is virtually impossible to imply management protocol stringently and identify alien species. So, keeping this point in mind, under the Port Biological Baseline Surveys of the Global ballast water management Program (GloBallast), a GEF (Global Environment Facility) /UNDP (United Nations Development Programme) /IMO (International Maritime Organization) (<http://globallast.imo.org/>) initiative, a wide range of biological and chemical sampling was done in Mumbai port (west coast of India) and its adjoining areas.

Among the biological entities, macrobenthos play a significant role in the aquatic community considering its involvement in mineralization, mixing of sediments, flux of oxygen into sediments and cycling of organic matter (Snelgrove 1998). Due to their reduced mobility and short life cycles, benthic communities are often used as indicators in biomonitoring studies, and they perform a crucial role in the foodweb, either as feeder of detritus or at tertiary level, as food for demersal economically important fishes (Gray and Elliot 2010). Given the high level of pollution, macrobenthic fauna within harbours is disturbed and impoverished, and is generally dominated by stress tolerant opportunistic species (Estacio et al. 1997; Ingole et al. 2009). Though harbour areas have great ecological and economical importance (Anil et al. 2002), till date very few studies have focused on the diversity of macrobenthos on a seasonal basis in India. Moreover, previous reports (Govindan et al. 1976; Mathew and Govindan 1995; Sukumaran and Saraladevi 2009) from Mumbai harbour were mainly restricted to group-level or taxocene specific identification and covered a relatively limited area.

The objective of the present study was to examine the benthic community of the harbour and its surrounding areas, along with environmental parameters, during three different sampling periods between 2001 and 2002 and to compare the results with earlier reports. The present documentation could provide baseline data and serve as background information for biodiversity, bio-invasion and management studies.

Materials and Methods

The study area

Mumbai (18°54'N; 72°40'E) and Jawaharlal Nehru ports (18°57'N; 72°57'E) are situated in Mumbai, along the west coast of India (Fig. 1), and fall within tropical southwest monsoon regime. These two ports together form a semi-enclosed basin, which opens in the Arabian Sea along the south-western side. Over the past hundred years, these harbours have grown to a major harbour with intensive shipping activities, dense urbanized area and poor water quality. Extensive urban, industrial, and port development around the harbour have caused substantial changes to the surrounding environment. Due to their prime geographical position, Mumbai and Jawarharlal Nehru ports have been playing a paramount role in developing the county's trade and finance. Mumbai Harbour is one of the busiest ports in India carrying 35.31 million tonnes of imports and 19.22 million tonnes of exports in the year 2009-2010 (<http://mumbaiport.gov.in/newsite/updates/yearly.htm>).

Sampling and analysis

Sampling sites covered wider areas including anchorages, berths, dry docks, piers, spoil grounds and ship breaking areas. All the selected stations had justification for their selections. Stations 5 and 6 had low water circulation (i.e. potential habitat for settlement of planktonic organisms). Station 10 and 24 were potential habitat for introduction of ballast water sediments. Station 15 and 25 selected because those stations had shipping navigation channel/structure in view of deballasting from ships. All the remaining stations were potential sites for deballasting from ships. Macro-benthic samples were collected in triplicate either by scuba diving with plastic cores (25 cm diameter; 20 cm deep), wherever possible, or by a Van Veen grab up to 15-20 cm penetration (0.04 m²) at 25 sites (Fig. 1) during November 2001 (Post-Monsoon 1; PM1), April/May 2002 (Pre-Monsoon; PreM) and October 2002 (Post-Monsoon 2; PM2). The samples were in situ washed separately through 0.5 mm mesh size nylon bags, transferred to plastic bags and preserved in 5% formalin in seawater containing Rose Bengal stain. Fauna samples were transported to the laboratory and identified to species level using a microscope with the help of available taxonomic literature (Satyamurti 1952, 1956; Fauvel 1953; Day 1967; Hartman 1974a, 1974b; Srikrishnadhas et al. 1987; Subba Rao et al. 1991; Lyla et al. 1998). Species numbers were expressed in no. m⁻².

Sediment samples were also collected and analyzed for sediment Total Organic Carbon (TOC) by wet oxidation method using chromic acid digestion followed by back titration with 0.2N ferrous ammonium sulphate solution (El Wakeel and Riley 1957). Percentage composition of grain size was determined following pipette analysis (Buchanan 1984). Near bottom water samples were collected and analyzed for temperature, salinity, pH, dissolved oxygen (DO) and suspended particulate matter (SPM) following standard protocols published elsewhere (e.g., Sawant et al. 2007).

Data analysis

Univariate and multivariate analyses of data were performed using PRIMER version 6 (Plymouth Routines in Multivariate Ecological Research) package (Clarke and Gorley 2006; Clarke et al. 2008). The following indices were determined: Shannon diversity (H'), Margalef's species richness (d) and Pielou's evenness (J'). Non-Multidimensional scaling (NMDS) and Bray-Curtis similarity index were constructed based on macrofaunal abundance after square-root transformation. A similarity profile (SIMPROF) test was conducted to detect the significantly different station groups using the default of 1,000 permutations for the mean similarity profile and 999 permutations for the simulated profile with a significance level of 0.05. Similarity of percentages analysis (SIMPER) was carried out to identify the major species which typified groups and those most responsible for the discrimination between groups. A two-way ANOVA was done to check for the significant spatial and temporal variation.

The spatial variations in the polychaete community in three seasons were illustrated by bubble plot using SURFER 8 program (developed by Golden software Inc., USA). To evaluate the relationship between the polychaete community and environmental variables, CCA (Canonical Correspondence Analysis) was applied using the Multi-Variate Statistical Package (MVSP) program version 3.1 (Kovach 1998). Downweighting of rare species was performed. Only polychaetes were selected because it comprises the bulk of the macrobenthos in terms of percentage. Only those stations, where corresponding three seasons physicochemical data are available were selected for CCA analysis. Polychaete feeding types were assigned according to Fauchald and Jumars (1979).

Results

Environmental features

Average bottom water temperature, salinity, pH and DO values are plotted in Fig. 2a. During PM1 and PM2 water temperature ranged from 26.0-30.0°C and 28.0-30.6°C respectively. Average temperature in PreM was 30.3°C. Salinity varied 34.7-36.0, 35.5-36.6, and 34.8-35.5 during PM1, PreM and PM2 respectively. Average pH ranged from 7.8-8.0 throughout the study period. In the present study, PM1 showed lowest DO value (4.1 mg l⁻¹) compare to other two seasons. Station 9 recorded very low DO value (1.8 mg l⁻¹) during PM1. The sediment texture was silty-clay or clay at all sites with high TOC during all the seasons (Fig. 2b-d). Percentage of silt and clay varied between 18.3 to 74.0 and 24.9 to 81.0 respectively. Average sand percentage ranged from 1.4-1.8 through out three seasons. Over three seasons average sediment TOC varied between 7.1 to 24.6 mg. g⁻¹ dry wt. (15.0±3.5) (Fig. 2b-d). During PM1 station 10 recorded high TOC (24.6 mg. g⁻¹), which is a potential habitat for introduction of ballast water sediment. Station 6 and 9 recorded maximum TOC values during PreM and PM2 respectively. Middle of the harbour or offshore stations recorded comparatively very low TOC values might be

due to regular maintenance dredging activities. In general, the water was euryhaline in nature with low oxygen and high turbidity.

Benthic community

In the present study, a total of 225 sediment samples were analyzed from 25 sites in three different seasons. All the sites had fauna except for 6 sites in each season (sites 9, 12, 15, 19, 20, and 22 during PM1; sites 2, 6, 19, 20, 24, and 25 during PreM; and sites 4, 7, 12, 15, 17, and 23 during PM2) (Table 1). 43 species of macro invertebrates belonging to 5 phyla were recorded, polychaete species being dominant. Among them, polychaetes (31 spp., 72.09%), decapoda (2 spp., 4.56%), amphipoda (2 spp., 4.56%), isopoda (1 sp., 2.32%), cirripedia (1 sp., 2.32%), cumacea (1 sp., 2.32%), bivalves (2 spp., 4.56%), gastropoda (1 sp., 2.32%), ophiroidea (1 sp., 2.32%) and sipuncula (1 sp., 2.32%). Maximum species count (16) was recorded at station 13 during PM1. The maximum number of organisms was 1532 ind m⁻² at station 6 in PM1. Dominant species, in order of abundance, were the polychaete *Timarete dasylophius* (1363 ind m⁻², site 6), the bivalve *Mytilopsis sallei* (350 ind m⁻² and 500 ind m⁻² at sites 4 and 5) and the amphipoda *Melita* sp. (208 ind m⁻², site 16) during PM1, PreM and PM2 respectively. With the exception of molluscs, all phyla showed a declining trend from PM1 to PM2 through PreM (Fig. 3). Average macrofaunal abundance was 31 and 186 ind m⁻² during PM2 and PM1 respectively. PreM showed average abundance 106 ind m⁻². Most of the benthic fauna were deposit-feeders, except the bivalve *M. sallei*, amphipods, shrimps, the barnacle *Balanus amphitrite* and few carnivorous polychaetes belonging to families Glyceridae, Nereididae and Nephtyidae, crabs and Ophiroides. Two-way ANOVA indicated significant variation (ANOVA: $p < 0.01$) between average abundance of macrobenthos and sampling seasons (PM1, PreM and PM2), whereas there were no significant differences between sampling sites (25 stations). The density of *M. sallei*, an introduced bivalve, was relatively higher during pre-monsoon periods. Highest abundance of this fouling species was found at sites 4 and 5 which are enclosed docks. The low water circulation at these stations makes these places suitable for settlement of planktonic organisms (indicated in materials and methods section). During PM2 this species were not observed at those stations but their abundance was relatively higher during PreM than during PM1. Throughout the three seasons suspension - feeder amphipod *Metila* sp. was observed in high densities at station 16. This station is an isolated island and had comparatively low value of TOC. The presence or absence of macrofaunal species during each of the studied season is presented in Table 2.

Cluster analyses of the Bray-Curtis similarity matrix based on macrobenthic species delineated 4 groups and two separate stations (SIMPROF test $p < 0.05$) during PM1 (Fig. 4a). Sites 1 and 11 were segregated because of different species dominance, *Neanthes glandicincta* in site 1; and *Namalycastis indica* and *Malacoceros indicus* at site 11. Group 1 and 2 had *Paraprionospio pinnata* and *M. sallei* as common species respectively. *T. dasylophius* was the dominant species in group 3 stations. SIMPROF analysis showed group 2 was the most significant (86.94% similarity) among other groups during that season. SIMPER analyses indicated *T. dasylophius* (82.05%)

and *Paradiastylis* sp. (24.04%) contributed significantly in group 3 and 4 formation. The average similarities of these two groups were 58.88 and 17.35 respectively. Each cluster represents a number of species, which are similar in habitat or specialized ecotone. Group 4 had the highest number of sites and species, representing the middle and offshore areas of the harbour (except station 2), rich in benthic fauna and were relatively more homogeneous with respect to species composition. The co-existence of these species is mainly attributed to the interaction of numerous biotic and abiotic factors (mainly temperature, salinity and pH). During PreM, there were 2 groups identified in the cluster analyses (Fig. 4b). All stations, except station 11, and 4 and 5 were grouped together to form group 1. SIMPER analysis indicated *P. pinnata* and *Cossura coasta* contributed 27.59% and 24.59% correspondingly in formation of group 1 (group average similarity 15.15). Station 11 was dominated by two carnivorous polychaete species *N. indica* and *N. glandicineta* in high abundance 142 and 242 ind m⁻² respectively during this season. High density of fouling bivalve *M. sallei* made station 4 and 5 to form a group. In other stations they were absent in PreM. Four groups were observed in PM2. Stations 11, 14 and 24 completely separated from the other groups (Fig. 4c). *P. pinnata* contributed 100% in construction of group 3 (SIMPER analysis). *Alpheus malabaricus* (53.39%) and *P. pinnata* (46.61%) were the dominant contributors in group 4. *Cirriformia chrysoderma* and *Goniadopsis longicirrata* were only present at station 14 during PM2. Presence of *Goniada emerita* made station 24 isolated from other stations (Fig. 4c). SIMPROF analysis and NMDS plot based on all three seasons macrobenthic species data showed certain grouping of stations from each season thus indicating some similarity in the benthic faunal community of that season (Fig. 5). SIMPER analysis indicated *P. pinnata* contributed 100% and *Melita* sp. contributed 42.61% in group 4 and 9 formation. Group 4 and 9 had most number of stations belonging to a specific season (PM2 and PM1 respectively). Similar to each seasons cluster plots (4a-c), three seasons combined cluster and NMDS plot (Fig. 5) indicated separation of few stations (station 1 and 11 of PM1, station 11 of PreM and station 24 of PM2). Distinct faunal composition of those stations with respect to that season made them separated from other groups.

Margalef's species richness was high during PM1 (0.59) and low during PM2 (0.15). Shannon diversity index (H') ranged from 0.30 bit·ind⁻¹ (PM2) to 0.87 bit·ind⁻¹ (PM1). Only station 13 had more than 2 bit·ind⁻¹ during PM1. During PreM, most of the stations had Shannon diversity values below 1 bit·ind⁻¹. In PM2 all stations had diversity values below 1 bit·ind⁻¹. Pielou's evenness (J') values were more or less similar (0.80) in all the seasons (Table 1).

Polychaete community

During the present study, polychaetes belonging to 17 families were the dominant macrofauna in all the seasons. Percentages of deposit-feeding polychaetes (surface and sub-surface combined) were dominant during both post-monsoon periods (i.e. PM1 and PM2, 82.64% and 83.47%, respectively), though the density varied considerably (Fig. 6a-c). A total of 23 genera and 31 species of polychaetes have been identified. *C. coasta*, *C. chrysoderma*

and *P. pinnata* were present in all the seasons (Table 2). In PM1, PreM and PM2, Shannon diversity index (H') for polychaetes ranged from 0.50-1.90 bit·ind⁻¹, 0.43-1.65 bit·ind⁻¹, and 0.62-0.69 bit·ind⁻¹ respectively. The highest polychaete abundance varied considerably from 1532 ind m⁻² at stn 6, 384 ind m⁻² at stn 11 and 67 ind m⁻² at stn 9 during PM1, PreM and PM2 respectively (Fig. 7). In PM1, stations 6 and 8 were dominated by surface deposit feeders *T. dasylophius*. *N. glandicincta* was the dominant polychaete species at station number 11 during PreM. In PM2 polychaete species were homogeneously distributed over the sampling area with very low abundance and deposit feeding polychaete *P. pinnata* showed highest abundance at station 25.

NMDS ordination plots for only polychaete species indicated five groups during PM1 (Fig. 8a). Stations 1, 2 and 23 were separated from other stations. These stations were mainly dominated by similar carnivorous and deposit-feeding polychaete species. During PreM, except station 11 all stations clustered together (Fig. 8b). Except 5 stations (1, 9, 14, 18 and 24), all stations grouped together indicating similarity in polychaete faunal compositions during PM2 (Fig. 8c). Specific seasonal clustering was not observed in three seasons combined cluster analysis, SIMPROF and NMDS plot, but some stations from each seasons grouped together indicating similarity in polychaete faunal composition of that season (Fig. 9). In group 3, five PreM stations were clustered together. SIMPER analysis showed *Magelona rosea* contributed 81.97% in that group. *C. coasta* was the common species (56.65% contribution) in group 4 (average similarity 15.49). Similar to PM2 polychaete community NMDS plot (Fig. 8c) majority of the stations during that season grouped together in all seasons combined NMDS plot (group 2) (Fig. 9). *P. pinnata* was the common recorded species at those stations.

In CCA biplot for polychaete species the five axes explained 90.07% of the relationship between species and environmental variables. Sediment texture, temperature and SPM were the important environmental variables influencing polychaete species composition (Fig. 10a). Polychaete species showed specific preference towards certain environmental parameters. For example, deposit-feeding polychaete species *P. pinnata*, *C. coasta*, *Heteromastus similis* showed preference towards silty sediment texture. Majority of these species dominated the post-monsoon season characterized by the above mentioned environmental condition (i.e. silty sediment texture). Stations with high silt content showed high density of these species. The carnivorous polychaete *Glycera alba* and the deposit-feeder *Pista typha* preferred sandy substratum. *Nephtys oligobranchia* was associated with elevated temperature and salinity. Deposit-feeding polychaete species *T. dasylophius* and filter-feeder *Protula tubularia* profited by high value of TOC and clayey substratum. *C. chrysoderma*, *Dendronereides heteropoda*, *Nephtys polybranchia*, *Kinbergonuphis investigatoris* favoured elevated pH. Surface deposit-feeder *M. rosea* preferred high DO. Sub-surface deposit-feeder *Euclymene annandalei*, *Maldane sarsi* and carnivorous species *Nereis falcaria*, *G. longicirrata*, *Lumbrineris japonica* were not influenced by any of the environmental parameters. Seasonal patterns were also observed in the station biplot. In PreM season, stations 1, 13 and 21 clustered together associated with the elevated condition of temperature, salinity, SPM, pH and DO (Fig. 10b). During PM1, station

7 was associated with high OC content. In PM2, stations were not associated with any particular environmental parameter. In PM1 and PreM, stations 16, 21 and 7, 12 respectively were fairly separated from environmental variables (Fig. 9b). *C. coasta*, *E. annandalei*, *G. longicirrata*, *M. sarsi*, *N. falcaria* and *L. japonica*, *M. rosea* were only present in PM1 and PreM season at those stations respectively.

Discussion

Average macrobenthic abundance declined considerably in the study area from 620 ind m⁻² (Mathew and Govindan 1995) to 107 ind m⁻² (present study). These changes might be due to environmental conditions deteriorated in the harbour area over the years. During the last three decades growing population and industries at Mumbai increased the sewage discharge at alarming manner (Sawant et al. 2007). Coastal waters of Mumbai receives industrial discharges up to 230 million litres per day (MLD) and domestic wastes of around 2,200 MLD of which, 1800 MLD are untreated or partially treated (Zingde and Govindan 2000). They reported 35 mg l⁻¹ of total nitrogen in the waste water of Mumbai. The nutrient level especially the nitrate concentration has increased gradually over the years with a simultaneous decrease in dissolved oxygen, indicating increase in biological activity (Sawant et al. 2007). Based on Assessment of Estuarine Trophic Status (ASSETS) model, the harbour environment is poor and gradually degrading (Sawant et al. 2007). It has direct impact on biotic community including macrobenthos. It is universally accepted that areas with lower diversity and richness indicate a polluted or stressed condition (Magurran 1988). According to Wilhm and Dorris (1966), species diversity index (H') value >3.00 bit·ind⁻¹ indicates unpolluted conditions, 1.00 to 3.00 bit·ind⁻¹ indicates moderately polluted and <1.00 bit·ind⁻¹ indicates heavily polluted condition of aquatic medium. The average macrobenthic diversity value in the study area during different seasons ranged from 0.30 to 0.87 bit·ind⁻¹, which clearly shows that the study area is polluted and the macrobenthic community is under stress due to natural and/ or anthropogenic factors. During PM1, only station 13 had diversity value >2 bit·ind⁻¹, other 8 stations (2, 8, 14, 16, 17, 23, 24, 25) had values >1 bit·ind⁻¹ and the rest, <1 bit·ind⁻¹. Generally, harbour areas are stressed and have lower benthic diversity index. The present results are in agreement with this view. In all the seasons, deposit-feeders were dominant, indicating the stressed condition of the harbour area. Surface or sub-surface deposit feeding polychaete species *C. coasta*, *C. chrysoderma* and *P. pinnata* were recorded throughout the study period and they are considered as pollution indicator species (Grassle and Grassle 1974; Pearson and Rosenberg 1978). Dominance of environmental stress tolerant opportunistic polychaete species were also reported in the study area by earlier reports (Mathew and Govindan 1995; Sukumaran and Saraladevi 2009). In the last two decades, Mumbai harbour has experienced a substantial change in the context of polychaete diversity index values. Mathew and Govindan (1995) and Sukumaran and Saraladevi (2009) reported moderate diversity values (0.87-1.84 bit·ind⁻¹) and (0.06-2.56 bit·ind⁻¹) during 1985-86 and 1996 respectively (note for former one only three stations in harbour area and for latter only inside the harbour areas stations were taken into consideration). The present study showed further lower

values of polychaete diversity index in all the seasons (0.14-0.70 bit·ind⁻¹) indicating change in environmental condition. In the harbour area, Mathew and Govindan (1995) noticed reduction in population count during monsoon than pre and post monsoon seasons. Though we did not have monsoon data but impact of low salinity on benthic fauna was evident on PM2 samples.

Comparison of the present dataset with earlier reported literature from this area showed some changes in the polychaete faunal composition (Table 3). Only polychaete species were observed to keep homogeneity in the selected published reports (note Sukumaran and Saraladevi (2009) only concentrated on polychaete taxocene). Some polychaete species were previously reported but not recorded in the present study or vice-versa (Table 3). Mathew and Govindan (1995) reported 43 macrobenthic species and 8 other groups (cladocerans, cumecean, ostracoda, copepoda, mysid, amphipods, isopoda and lobster larvae) from the harbour area (only 3 stations were taken into consideration) during August 1985 to October 1986. Among 43 macrobenthic species, 18 were polychaetes. From November-December 1996 sampling, Sukumaran and Saraladevi (2009) reported 45 species of polychaetes from the subtidal and harbour stations (intertidal stations were not included in the comparison). In the present study, only 31 polychaete species were identified. From the above two earlier reports it can be deduced that the present macrobenthic species abundance and diversity (mostly polychaete) declined considerably in the study area. Jaccard's similarity coefficient (1908) was calculated using different years polychaete species presence/absence data matrix (Table 3) in MVSP version 3.1 (Kovach, 1999). These coefficients were used to construct a dendrogram by the unweighted pair group method of arithmetic average (UPGMA). According to the similarity index (supplementary Table 1) and the cluster analysis (supplementary Fig. 1), the lowest similarity was found between 1996 and present study, with a value of 0.103. On the other hand 1985-86 and present study gave the highest similarity ratio, 0.140. In the dendrogram, 1985-86 and present data of polychaete species formed a group. From these results, it may be inferred that the polychaete species similarities between different years were not high. Compared to 1996 polychaete fauna (Sukumaran and Saraladevi 2009), only seven common polychaete species have been observed in the present study. These were *Glycera longipinnis*, *Goniada emerita*, *P. pinnata*, *C. coasta*, *H. similis*, *M. sarsi* and *P. tubularia*. Spionid polychaete species *P. pinnata* and *Dipolydora giardi* were dominant during 1996 but, in the present study, these species have been replaced by *T. dasylophius* in PM1, *M. rosea* in PreM and *P. pinnata* in PM2. Polychaete species like *Sigambra constricta*, *Perinereis cavifrons*, *Prionospio polybranchiata* and *Parheteromastus tenuis* were not recorded in the present study but those species were present during two earlier conducted macrobenthic surveys in the harbour area. Only *G. longipinnis*, *P. pinnata* and *C. coasta* reported in the study area from 1985-86 were also observed in this study (Table 3). However, considering the intertidal transects of Sukumaran and Saraladevi (2009) few more common species were also recorded in different years (marked in Table 3). Over the years, polychaete species composition is changing largely due to change in the water and sediment quality in the harbour area which can be attributed to

the growth of harbour activities. As there was no seasonal macrobenthic species composition data available from the study area, seasonal comparison over different years is not possible at this point of time.

A clear difference in the abundance of zooplankton (Gaonkar et al. 2010a), dinoflagellate species (D'Costa et al. 2008) and hard bottom fouling community (Gaonkar et al. 2010b) have also been observed in the study area during the identical sampling period. Gaonkar et al. (2010b) found a marked difference in the number of hard-bottom community species between the two post-monsoon seasons in both intertidal and subtidal samples. Similarly, macrobenthic species number recorded during PM2 (13 species) was lower than in PM1 (34 species) season (Table 2). During PreM there was a decrease in nutrient concentration along with an increase in temperature, salinity and SPM, which directly affected the dinoflagellate, zooplankton and hard-bottom communities (D'Costa et al. 2008; Gaonkar et al. 2010a; Gaonkar et al. 2010b). In PreM, purely herbivorous copepods like *Nannocalanus minor*, *Paracalanus* sp. and *Temora discaudata* decrease in abundance whereas carnivorous forms like *Centropages furcatus*, *Oithona* sp. and *Corycaeus* sp. were comparatively more abundant (Gaonkar et al. 2010a). Identical to this, carnivorous polychaetes were more dominant in PreM season than in the other two seasons (Fig. 6b). The water column was respiration dominated during post monsoon periods and production dominated during pre- monsoon (D'Costa et al. 2008) and presumably provided more food supply to the macrobenthic carnivorous polychaete species.

CCA analysis clearly indicated the effect of environmental variables on the polychaete community (Fig. 10a). The length of environmental variables arrows and their orientation on the CCA plot showed their relative importance on each axis. The direction of each arrows increases in the direction of its mean values. All water quality environmental parameters clustered together (salinity, temperature, SPM, pH and DO). Majority of the polychaete species strongly correlated with those parameters (right half of CCA species biplot, Fig. 10a). Except *T. dasylophius* and *P. tubularia* all other polychaete species were negatively correlated with OC and clay. Sediment texture, organic carbon, temperature salinity and DO are considered determining factors in structuring benthic community (Gray 1974; Alongi 1990; Harkantra and Parulekar 1991; Jayaraj et al. 2007). In the present study deposit-feeding polychaete species *P. pinnata*, *C. coasta*, *H. similis* were associated with silt. Preferences for finer sediments (silty-clay/clayey) by those species were also reported by Ganesh and Raman (2007). Carnivorous polychaete species *G. alba* were associated with sandy substratum and low organic carbon. Harkantra and Parulekar (1985) found similar preference by this species at Siridao beach, Goa, west coast of India. In general, the CCA plot showed a distinct pattern where all carnivorous polychaetes were correlated (except species *C. chrysotherma* and *M. rosea*) (Fig. 10a). Occurrences of those species during PreM season were clearly evident in CCA station plot (Fig. 10b).

Species composition of macrobenthos showed numerical dominance of polychaetes (72.09%), followed by crustaceans and molluscs (except PreM). Mathew and Govindan (1995) also observed the same pattern during

their survey of harbour area. Highest abundance of surface deposit-feeding polychaete species *T. dasylophius* (1363 ind m⁻²) was recorded at station 6 during PM1. The probable cause of such high abundance of this species was high organic carbon and low water circulation at that station (mentioned in materials and methods section). In general, macrofaunal abundance was comparatively lower during PM2 than PM1. This could be due to the variation in rainfall during the two years sampled. The study area is a tropical mesotrophic environment highly influenced by southwest monsoon (D'Costa and Anil 2010). The sampling years experienced different pattern of monsoon in terms of length and intensity (Fig. 11). Such difference in rainfall might have affected the population abundance during PM2. Salinity is an influencing factor in determining the abundance and distribution of macrobenthic fauna (Sanders et al. 1965; Parulekar et al. 1980). Hence, variation in salinity due to heavy rain may increase physiological stress, which can result in the reduction of species number due to mortality of adult and larval population or to migration (Alongi 1990). In 2002, monsoon was bimodal and ended early; species once settled might have faced severe mortality or migrated during the second phase of rainfall due to lower salinity and heavy run-off. Moreover, rainfall is generally associated with high waterflow, which brings terrigenous sediments and create anoxic condition to the benthic fauna (Norkko et al. 2002) and lead to the death of smothered macrobenthic fauna. Average percentage of clay during PM2 was higher than in the other two seasons (Fig. 2d). The source might be Thane creek which is positioned at the northern side of the study area. Deposit-feeding opportunist species thrive well in flooding condition (Salen-Picard et al. 2003), but suspension-feeders are mostly affected due to clogging of their feeding apparatus (Norkko et al. 2002). During PM2, there was no record of filter feeding polychaete species in the present study, which might be due to above mentioned reason. Results from the study clearly indicated an inter-sampling variation for other macrobenthic groups. High densities of bivalves were observed in stable marine salinities but abundance reduced considerably with lower salinity (Pillay and Perissinotto 2008). Molluscan population showed comparatively high abundance in PreM, but lower abundance in PM2 season probably due to salinity drop during the second phase of rainfall in 2002 (Fig. 3). Considerable decline in shallow water macrobenthos was recognized due to lower salinity during southwest monsoon (Seshappa 1953). In a normal monsoon-influenced tropical environment, considerable increase in faunal abundance is generally predicted after monsoon declines, mainly due to high rate of species succession in a stabilized estuarine environment (Pannikar 1969; Parulekar et al. 1980; Harkantra and Rodrigues 2003). In the case of disturbance caused by abnormal meteorological events (bimodal rainfall) as in 2002, macrobenthic communities could be severely affected and the population would not be able to stabilize.

Serpulid polychaete species *P. tubularia* was categorized as non indigenous species in the study area and its probable introduction route was discussed by Gaonkar et al. (2010c). They reported this species might have been introduced from Sri Lanka via ballast water discharge. This species was recorded at station number 7 and 8 during PM1, but absent in the other two seasons. These stations are a potential habitat in view of deballasting from ship. Apart from this polychaete species, *M. sallei*, a fouling bivalve, was also recorded throughout the study period.

The native range of this species is tropical and sub-tropical Atlantic water. This species is also reported as invasive species in Indian waters (Karande and Menon 1975; Gaonkar et al. 2010c). They were predominantly recorded from the station 2, dock, and berth areas. In the present study, out of total 31 polychaete species, 19 are reported for the first time from this area. High number of newly reported species from the harbour area might be due to extensive sampling carried out in this study (GloBallast) programme. Since Mumbai harbour is one of the busiest ports in India in terms of maritime traffic, the possibility of invasive species arrival and colonization can be expected over the years and continued monitoring is desirable.

Conclusion

The present study provided information on macrobenthic diversity and community structure in the Mumbai and Jawaharlal ports and showed the changes in abundance and community structure over the years due to changing environment. Macrobenthic species density declined considerably in the last two decades and low benthic diversity index in all the seasons indicates that the study area is under stress. The temporal variations of benthic fauna exhibited highest abundance during PM1 and lowest during PM2. Such variations might be due to difference in the monsoonal pattern in 2002 which adversely affected the colonization of benthic fauna after monsoon. The study area also showed seasonal changes in terms of relative abundance of species and taxonomic groups, from polychaete species *Timarete dasylophius* in PM1 to amphipod *Melita* sp. in PM2 through bivalve *Mytilopsis sallei* in PreM period. Polychaete species *Glycera longipinnis*, *Paraprionospio pinnata* and *Cossura coasta* reported in the study area from 1985-86 were also observed in this study. Since, the present study provides a complete database on the softbottom macrobenthic fauna from this area, it can serve as a baseline for future studies.

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Legends to the figures:

Fig. 1 Locations of sampling stations at Mumbai and Jawaharlal Nehru ports, India.

Fig. 2 a Seasonal variation in temperature, salinity, pH and DO in the study area. Spatial variations in the sediment texture (percentage) and organic carbon (mg g^{-1}) b PM1 (post-monsoon 1), c PreM (pre-monsoon), d PM2 (post-monsoon 2).

Fig. 3 Seasonal variation of macrofaunal group in the study area. Error bars: standard deviation values.

Fig. 4 Cluster plot based on Bray-Curtis similarity coefficient of macrobenthic species during three different sampling periods a PM1, b PreM, c PM2. In the cluster plot the main groups of stations (after SIMPROF Test) can be identified by dark black lines.

Fig. 5 Cluster and NMDS (Non-metric multidimensional scaling) ordination plot of macrobenthic community for all three seasons together. In the cluster plot the main groups of stations (after SIMPROF Test) can be identified by dark black lines.

Fig. 6 Polychaete community composition depending on feeding habit (SDF- surface deposit feeders; SSDF- sub-surface deposit feeders; C- carnivores; FF- filter feeders) during three sampling periods a PM1 (post-monsoon 1), b PreM (pre-monsoon), c PM2 (post-monsoon 2).

Fig. 7 Station-wise variation in the abundance of polychaete community during three different sampling periods. PM1 (post-monsoon 1), PreM (pre-monsoon) and PM2 (post-monsoon 2). Data were scaled using the square-root function. The maximum symbol diameter corresponds to 1532 nm^{-2}

Fig. 8 NMDS (Non-metric multidimensional scaling) ordination plot based on Bray-Curtis similarity coefficient of polychaete species during three different sampling periods a PM1 (post-monsoon 1), b PreM (pre-monsoon), c PM2 (post-monsoon 2)

Fig. 9 Cluster and NMDS (Non-metric multidimensional scaling) ordination plot of polychaete community for all three seasons together. In the cluster plot the main groups of stations (after SIMPROF Test) can be identified by dark black lines.

Fig. 10 Ordination diagrams for species and stations based on Canonical Corresponding Analysis (CCA) of polychaete community. The environmental variables (temperature, salinity, SPM, pH, DO, sand, silt, clay, organic carbon) are indicated by arrows. Station codes and species codes are given in Figure 1 and table 2 respectively.

Fig. 11 South West monsoon pattern in Mumbai and Jawaharlal Nehru ports. Arrows indicate sampling periods. PM1, post monsoon 1; PreM, pre-monsoon; PM2, post monsoon 2.

Legends to the figures (supplementary):

Fig. 1 Dendrogram (UPGMA) showing the polychaete species relationships among different years at the study area.

Table 1 Seasonal variation in benthic community indices for all stations

	Stations	S	N	d	J'	H'	1 - λ'	
PM1	1	1	37	0.00	0.00	0.00	0.00	
	2	5	95	0.88	1.00	1.61	0.81	
	3	2	74	0.23	1.00	0.69	0.51	
	4	2	197	0.19	0.35	0.24	0.12	
	5	1	92	0.00	0.00	0.00	0.00	
	6	6	1532	0.68	0.28	0.50	0.21	
	7	2	57	0.25	0.92	0.64	0.45	
	8	7	237	1.10	0.56	1.08	0.48	
	10	1	19	0.00	0.00	0.00	0.00	
	11	2	38	0.27	1.00	0.69	0.51	
	13	16	734	2.27	0.79	2.18	0.82	
	14	9	294	1.41	0.75	1.65	0.70	
	16	7	821	0.89	0.61	1.18	0.54	
	17	6	71	1.17	0.98	1.75	0.83	
	18	1	10	0.00	0.00	0.00	0.00	
	21	2	38	0.27	1.00	0.69	0.51	
	23	4	95	0.66	0.96	1.33	0.73	
	24	4	112	0.64	0.96	1.33	0.73	
	25	3	93	0.44	0.96	1.06	0.65	
	PreM	1	2	25	0.31	0.90	0.63	0.45
		3	2	56	0.25	0.92	0.64	0.46
		4	1	350	0.00	0.00	0.00	0.00
		5	1	500	0.00	0.00	0.00	0.00
		7	1	42	0.00	0.00	0.00	0.00
		8	5	174	0.78	0.66	1.06	0.55
9		2	109	0.21	0.62	0.43	0.27	
10		4	41	0.81	0.95	1.32	0.73	
11		2	384	0.17	0.95	0.66	0.47	
12		3	58	0.49	0.91	1.00	0.62	
13		6	191	0.95	0.78	1.39	0.67	
14		2	50	0.26	0.63	0.44	0.27	
15		1	8	0.00	0.00	0.00	0.00	
16		6	191	0.95	0.60	1.08	0.50	
17		3	24	0.63	1.00	1.10	0.70	
18		1	8	0.00	0.00	0.00	0.00	
21		8	148	1.40	0.87	1.82	0.81	
22		4	100	0.65	0.70	0.97	0.51	
23		6	191	0.95	0.81	1.45	0.73	
PM2		1	3	58	0.49	0.71	0.78	0.45
		2	2	50	0.26	0.63	0.44	0.27
		3	2	21	0.33	0.96	0.66	0.50
		5	1	25	0.00	0.00	0.00	0.00
	6	1	17	0.00	0.00	0.00	0.00	
	8	1	17	0.00	0.00	0.00	0.00	
	9	2	84	0.23	0.73	0.50	0.33	

10	2	16	0.36	1.00	0.69	0.53
11	2	25	0.31	0.90	0.63	0.45
13	1	8	0.00	0.00	0.00	0.00
14	2	16	0.36	1.00	0.69	0.53
16	2	216	0.19	0.23	0.16	0.07
18	2	75	0.23	0.99	0.69	0.50
19	1	8	0.00	0.00	0.00	0.00
20	1	8	0.00	0.00	0.00	0.00
21	2	50	0.26	0.92	0.64	0.46
22	1	8	0.00	0.00	0.00	0.00
24	1	8	0.00	0.00	0.00	0.00
25	1	56	0.00	0.00	0.00	0.00

S, Total number of species; N , Total population density nm^{-2} ; d , Species richness (Margalef), J' , Pielou's evenness; H' , Shannon index, $1 - \lambda'$, Simpson index.

Table 1 (supplementary) Similarity index (Jaccard's coefficient) of different years polychaete species.

Years	1985-86	1996	2001-02
1985-86	1.000		
1996	0.127	1.000	
2001-02	0.140	0.103	1.000

Table 2 Seasonal variation of macrobenthic species in the study area, 2001-2002. PM1- post-monsoon 1, PreM- Pre-monsoon, PM2- post-monsoon 2. CCA codes for polychaete species are also tabulated. + present, - absent

Species	CCA codes	PM1	PreM	PM2
<i>Cossura coasta</i>	1	+	+	+
<i>Timarete dasylophius</i>	2	+	+	-
<i>Cirriiformia chrysoderma</i>	3	+	+	+
<i>Euclymene annandalei</i>	4	+	-	+
<i>Dendronereides heteropoda</i>	5	-	+	-
<i>Glycera alba</i>	6	+	-	+
<i>Glycera longipinnis</i>	7	+	-	-
<i>Glycera unicornis</i>	8	-	+	-
<i>Goniada emerita</i>	9	+	-	+
<i>Goniadopsis longicirrata</i>	10	+	-	+
<i>Protula tubularia</i>	11	+	-	-
<i>Heteromastus similis</i>	12	+	-	-
<i>Hesion e pantherina</i>	13	-	+	-
<i>Lumbrineris japonica</i>	14	-	+	-
<i>Namalycastis indica</i>	15	+	+	-
<i>Maldane sarsi</i>	16	+	+	-
<i>Magelona rosea</i>	17	-	+	-
<i>Neanthes glandicincta</i>	18	+	+	-
<i>Neanthes cricognatha</i>	19	+	-	-
<i>Nereis falcaria</i>	20	+	+	-
<i>Nerine cirratulus</i>	21	+	-	-
<i>Nephtys polybranchia</i>	22	-	+	-
<i>Nephtys oligobranchia</i>	23	+	+	-
<i>Kinbergonuphis investigatoris</i>	24	-	+	-
<i>Onuphis holobranchiata</i>	25	+	-	+
<i>Lagis abranchiata</i>	26	+	-	-
<i>Paraprionospio pinnata</i>	27	+	+	+
<i>Petaloproctus terricola</i>	28	+	-	-
<i>Pista typha</i>	29	-	-	+
<i>Malacoceros indicus</i>	30	+	-	-
<i>Sabellastarte spectabilis</i>	31	+	-	-
<i>Peronia verruculata</i>		+	-	-
<i>Alpheus malabaricus</i>		+	+	+
<i>Balanus amphitrite</i>		-	+	-
<i>Mactra cuneata</i>		+	-	-
<i>Mytilopsis sallei</i>		+	+	+
<i>Melita sp.</i>		+	+	+
<i>Caprella sp.</i>		+	-	-
<i>Cyathura sp.</i>		+	+	-
<i>Parasesarma plicatum</i>		+	-	-
<i>Ophiothrix sp.</i>		+	-	-
<i>Paradiastylis sp.</i>		+	+	-
<i>Themiste sp.</i>		+	+	+

Table 3 Occurrence of different polychaete species since 1985-86 from the area

Macrobenthic species	1985-86	1996	2001-02
<i>Sthenelais boa</i>		√	
<i>Aphrodita alta</i>		√	
<i>Amphinome</i> sp.		√	
<i>Sigambra constricta</i>	√	√	
<i>Hesione pantherina</i>			√
Hesionidae		√	
<i>Haplosyllis spongicola</i>		√	
<i>Neanthes cricognatha</i>			√
<i>Nereis falcaria</i>			√
<i>Neanthes glandicincta</i>			√
<i>Neanthes unifasciata</i>	√		
<i>Platynereis</i> sp.		√	
<i>Dendronereides heteropoda</i>			√
<i>Namalycastis indica</i>			√
<i>Perinereis cavifrons</i>	√	√	
<i>Nephtys oligobranchia</i>	√		√
<i>Nephtys polybranchia</i>			√
<i>Nephtys dibranchis</i>		√	
<i>Nephtys sphaerocirrata</i>		√	
<i>Glycera longipinnis</i>	√	√	√
<i>Glycera alba</i>	√	*	√
<i>Glycera unicornis</i>			√
<i>Glycera incerta</i>		√	
<i>Goniadopsis longicirrata</i>			√
<i>Goniada emerita</i>		√	√
<i>Diopatra neapolitana</i>	√	*	
<i>Diopatra cuprea cuprea</i>		√	
<i>Onuphis holobranchiata</i>			√
<i>Kinbergonuphis investigatoris</i>			√
<i>Marphysa</i> sp.		√	
<i>Lumbrineris japonica</i>	√		√
<i>Lumbrineris simplex</i>		√	
<i>Prionospio polybranchiata</i>	√	√	
<i>Paraprionospio pinnata</i>	√	√	√
<i>Minuspio cirrifera</i>		√	
<i>Spiophanes bombyx</i>		√	
<i>Dipolydora giardi</i>		√	
<i>Nerine cirratulus</i>			√
<i>Malacoceros indicus</i>			√
<i>Magelona rosea</i>			√
Magelonidae		√	
<i>Orbinia angrapequensis</i>		√	

Ctenodrilidae		√	
<i>Cirriformia chrysoderma</i>		*	√
<i>Timarete dasylophius</i>			√
<i>Cirratulus cirratus</i>		√	
<i>Cirratulus concinnus</i>		√	
<i>Cirriformia afer</i>		√	
<i>Tharyx filibranchia</i>		√	
<i>Petaloproctus terricola</i>			√
<i>Scyphoproctus djiboutiensis</i>		√	
<i>Cossura coasta</i>	√	√	√
<i>Cossura longocirrata</i>		√	
<i>Parheteromastus tenuis</i>	√	√	
<i>Heteromastus similis</i>		√	√
<i>Heteromastides bifidus</i>		√	
<i>Notomastus aberans</i>		√	
<i>Notomastus fauveli</i>		√	
<i>Capitella capitata</i>		√	
<i>Pulliella armata</i>	√	*	
<i>Clymene grossa</i>	√		
<i>Euclymene annandalei</i>		*	√
<i>Maldane</i> sp.	√		
<i>Maldane sarsi</i>		√	√
<i>Owenia fusiformis</i>		√	
<i>Owenia</i> sp.	√		
<i>Sternaspis scutata</i>		√	
<i>Pista indica</i>		√	
<i>Pista typha</i>			√
<i>Pista pachybranchiata</i>		√	
<i>Ampharete capensis</i>		√	
<i>Neosabellaria cementarium</i>	√		
<i>Lagis abbranchiata</i>			√
<i>Terebellides</i> sp.	√		
<i>Sabellastarte spectabilis</i>			√
Sabellidae		√	
<i>Protula tubularia</i>		√	√

1985-86 (Mathew and Govindan 1995), 1996 (Sukumaran and Saraladevi 2009), 2001-02 (present study)

* reported from intertidal transects

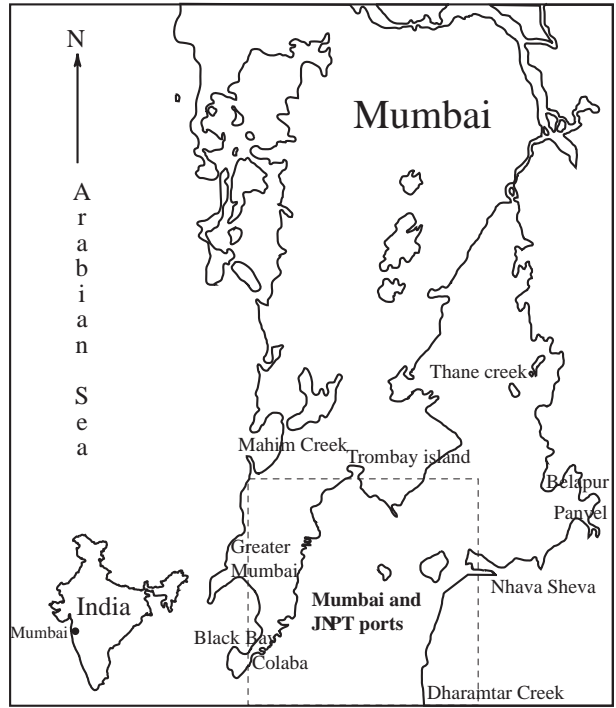


Figure 1

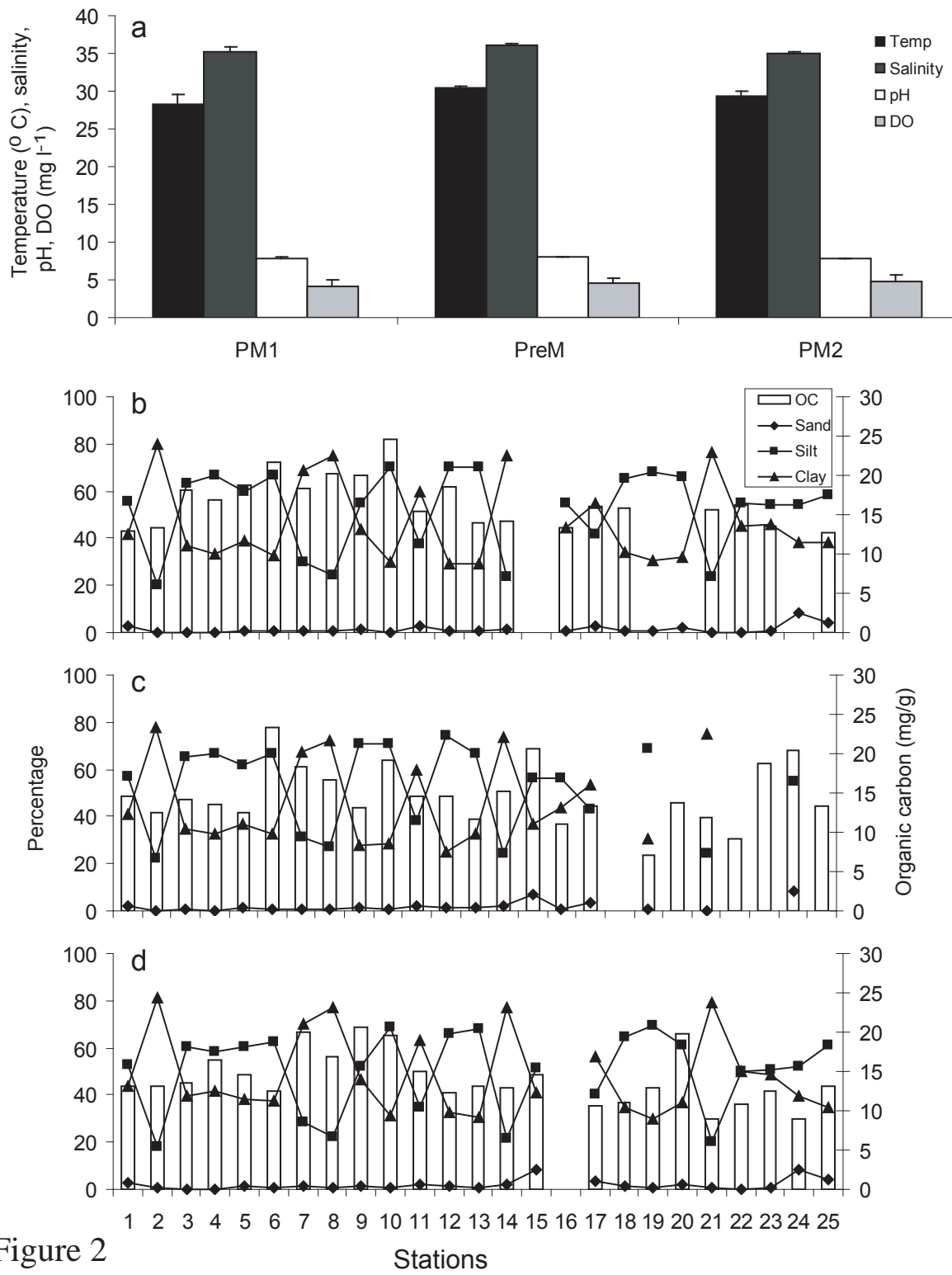


Figure 2

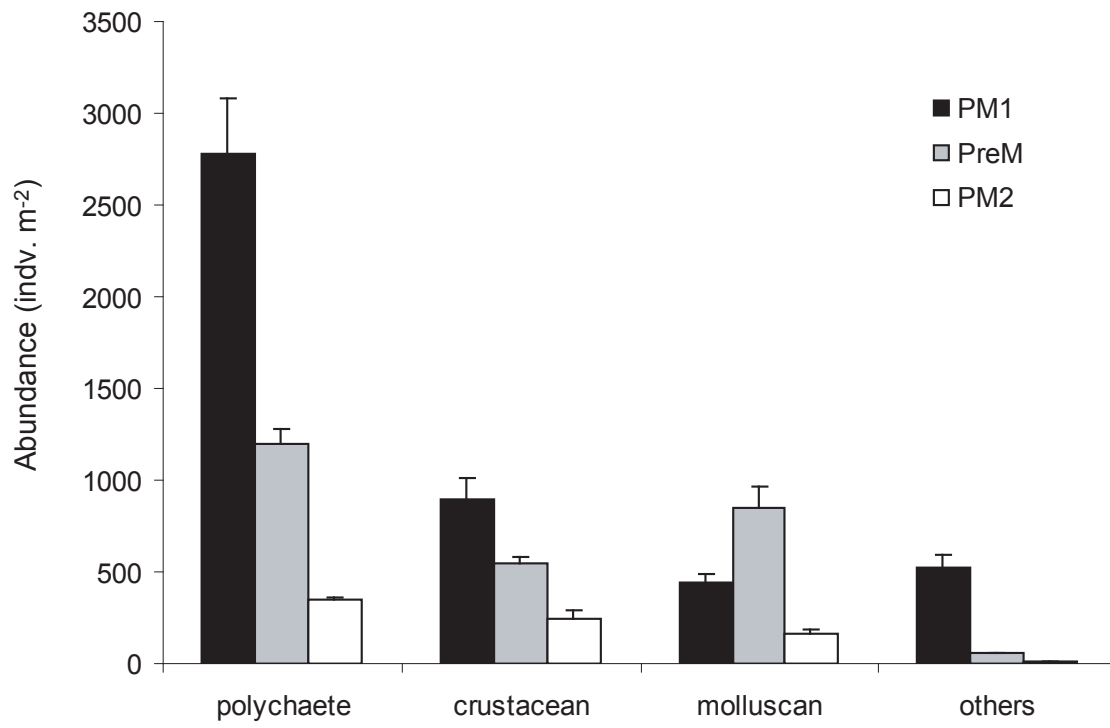


Figure -3

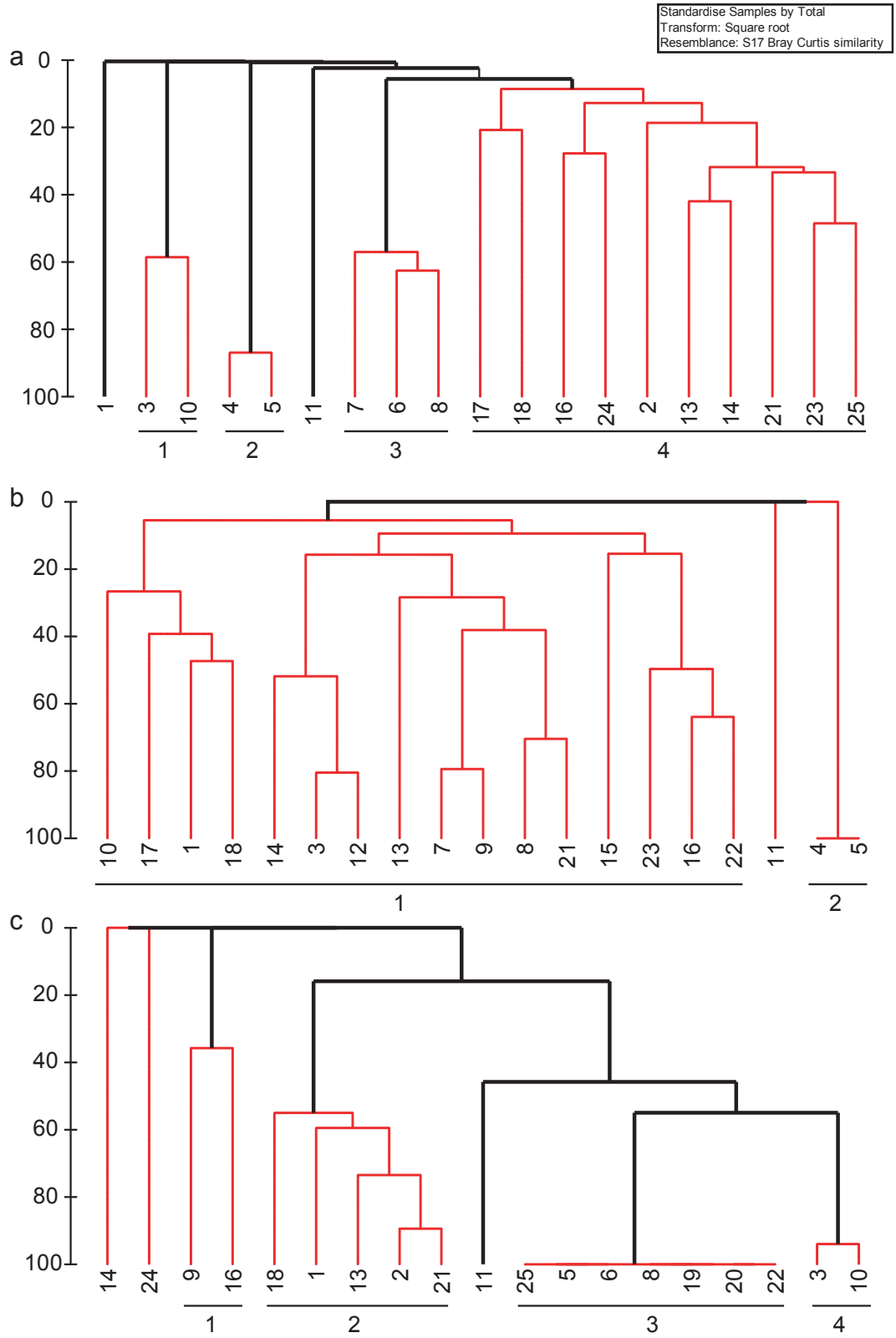


Figure 4

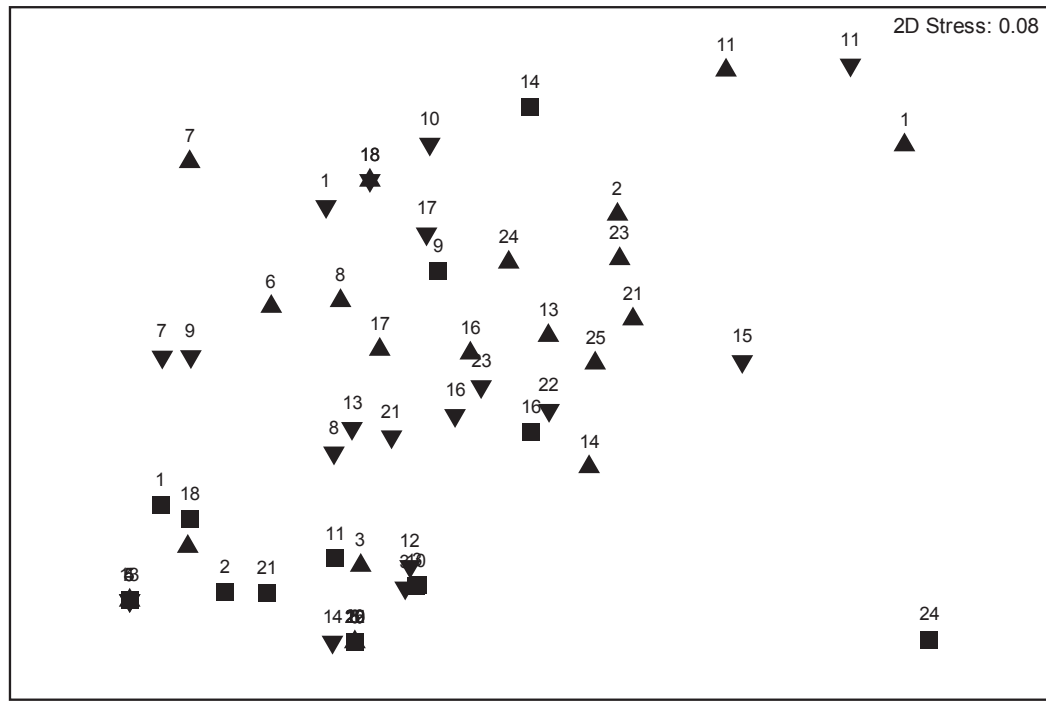
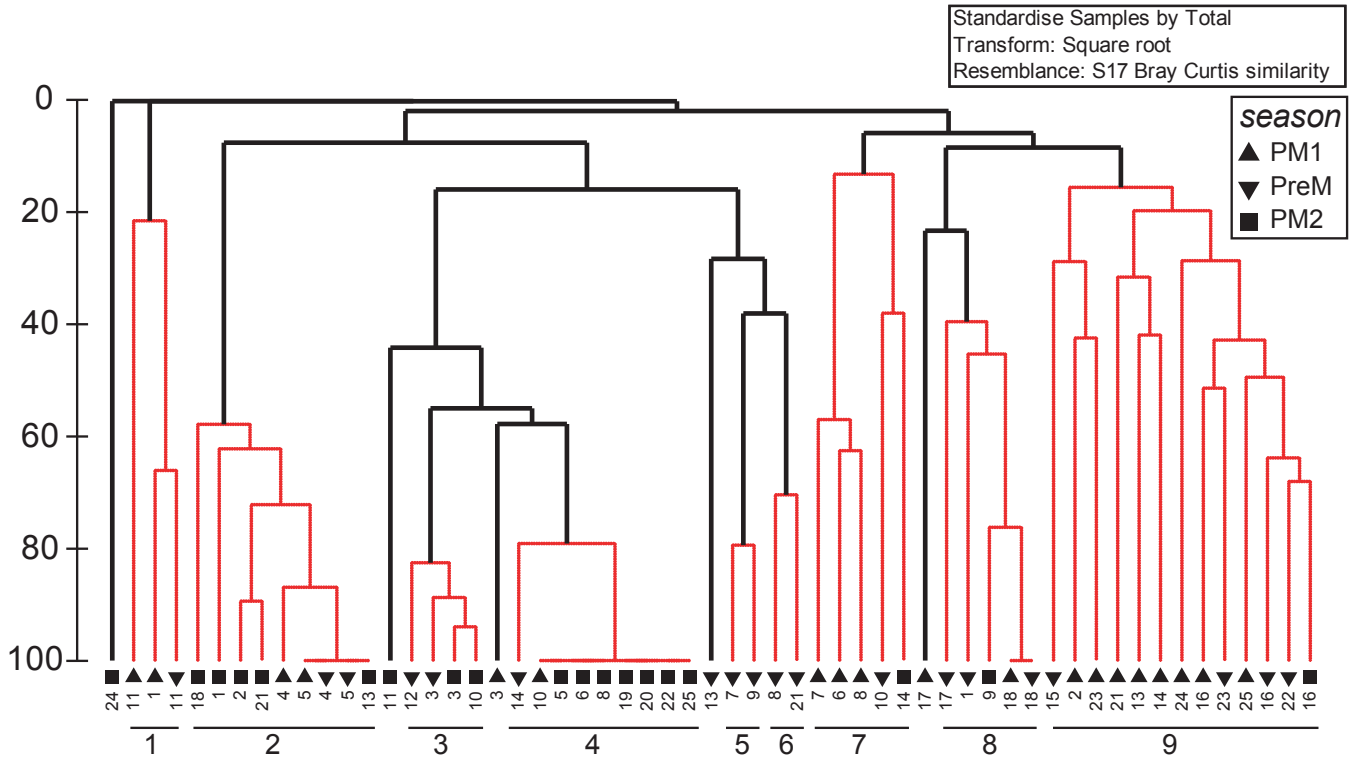


Figure 5

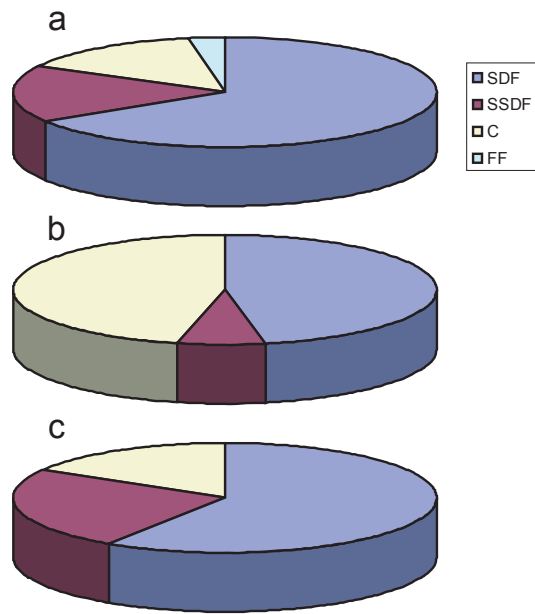


Figure 6

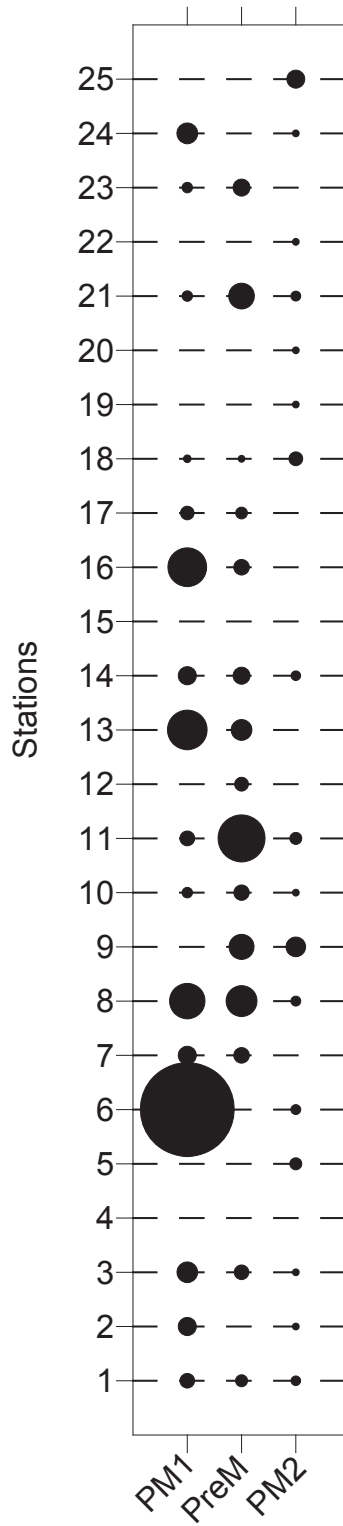


Figure 7

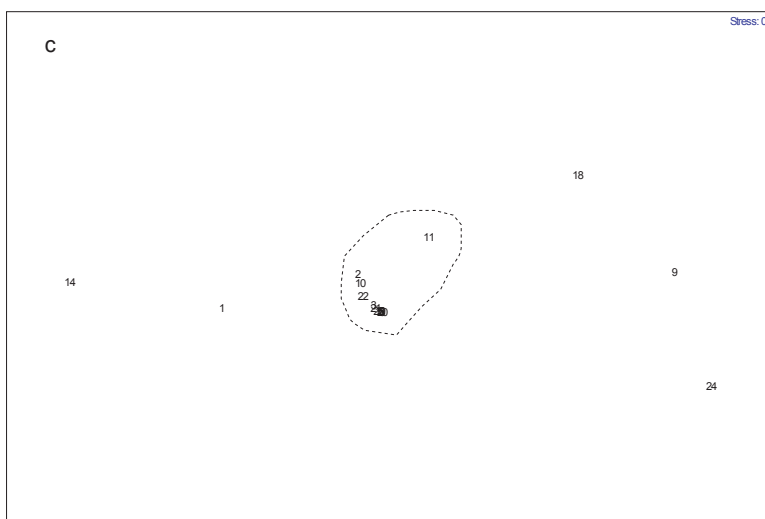
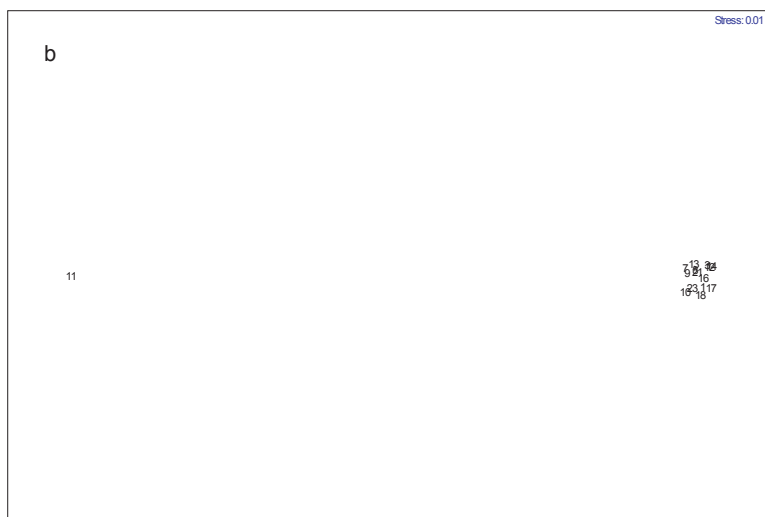
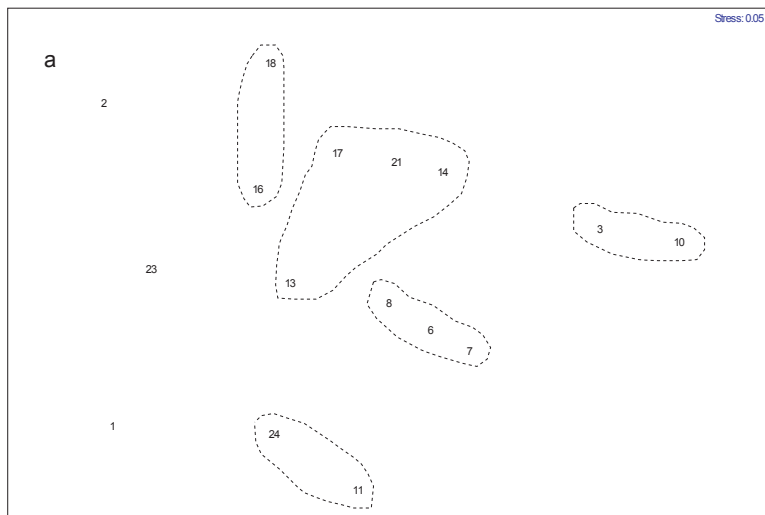


Figure 8

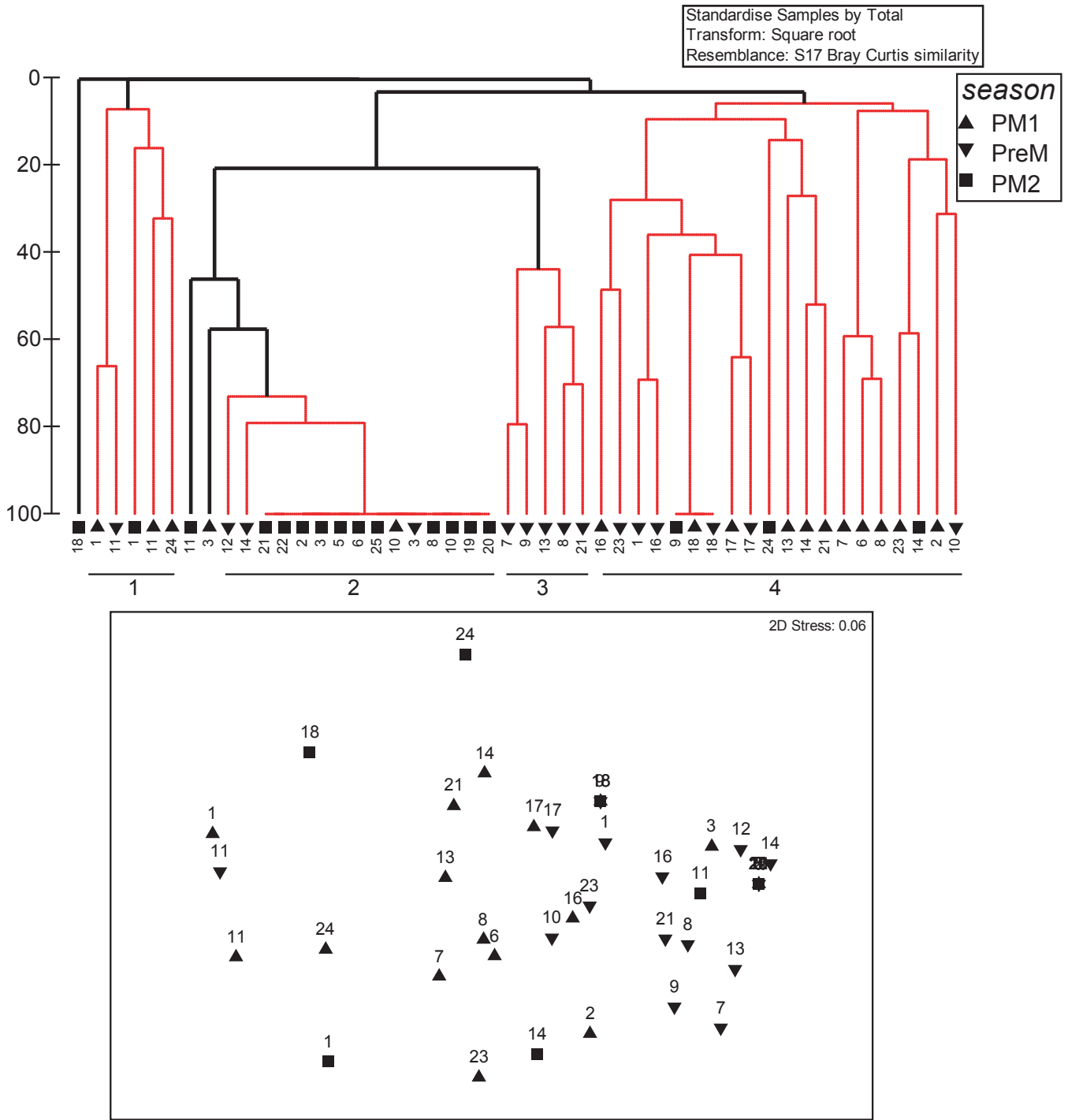
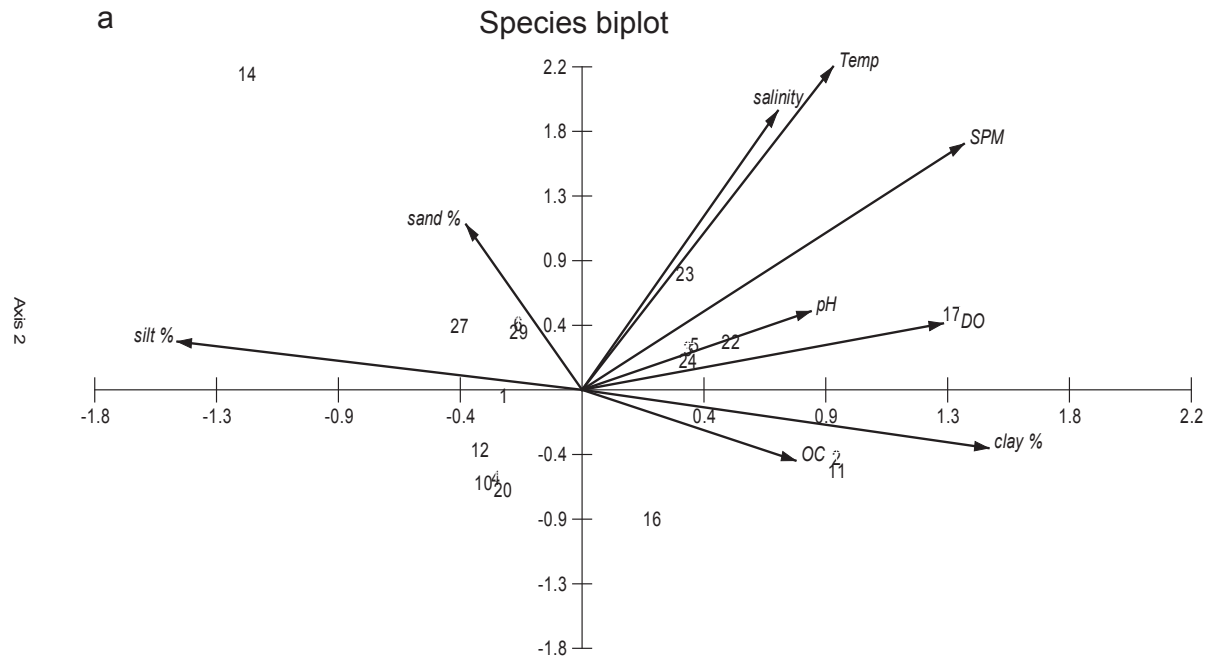
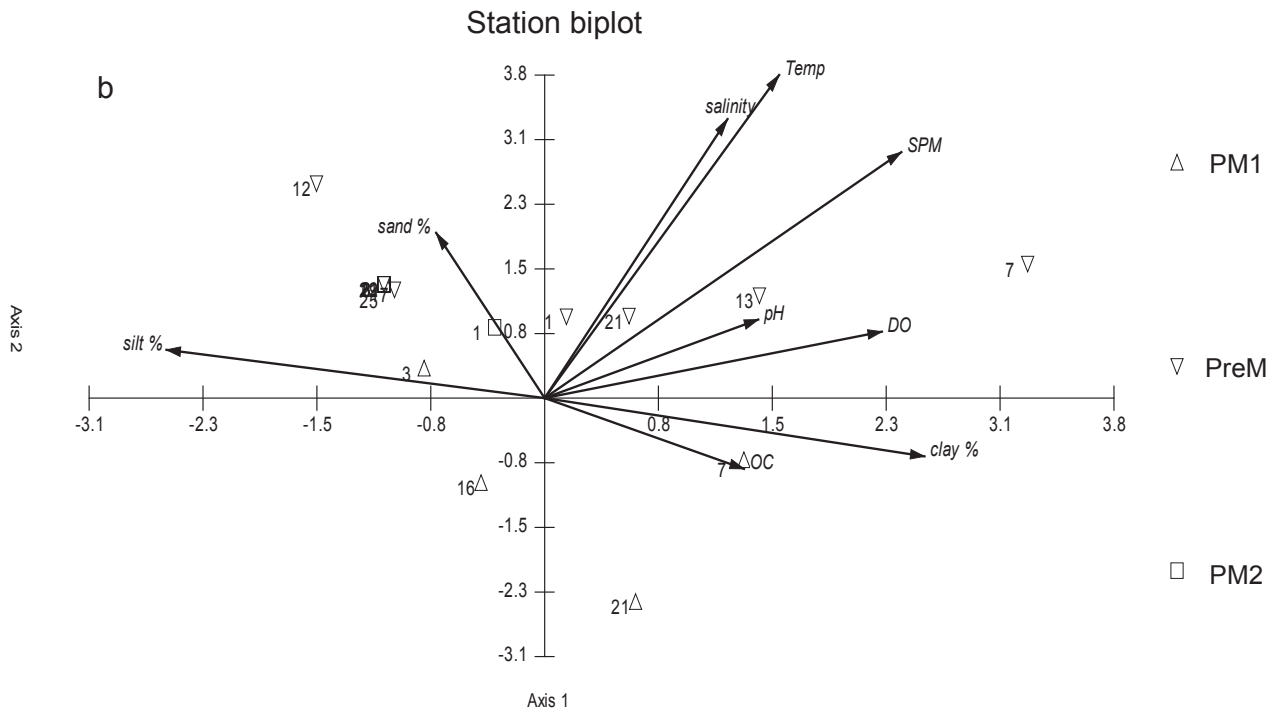


Figure 9



Vector scaling: 2.82



Vector scaling: 4.84

Figure 10

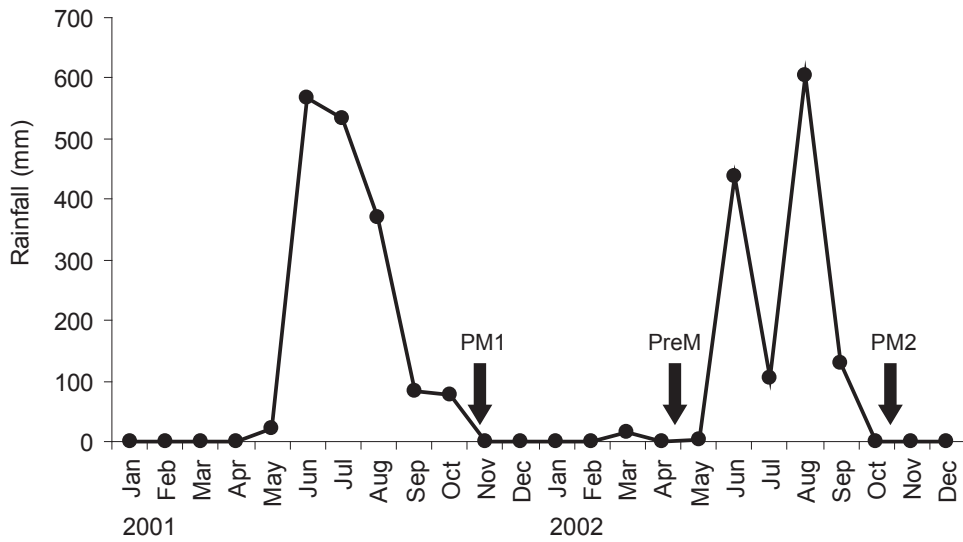


Figure 11

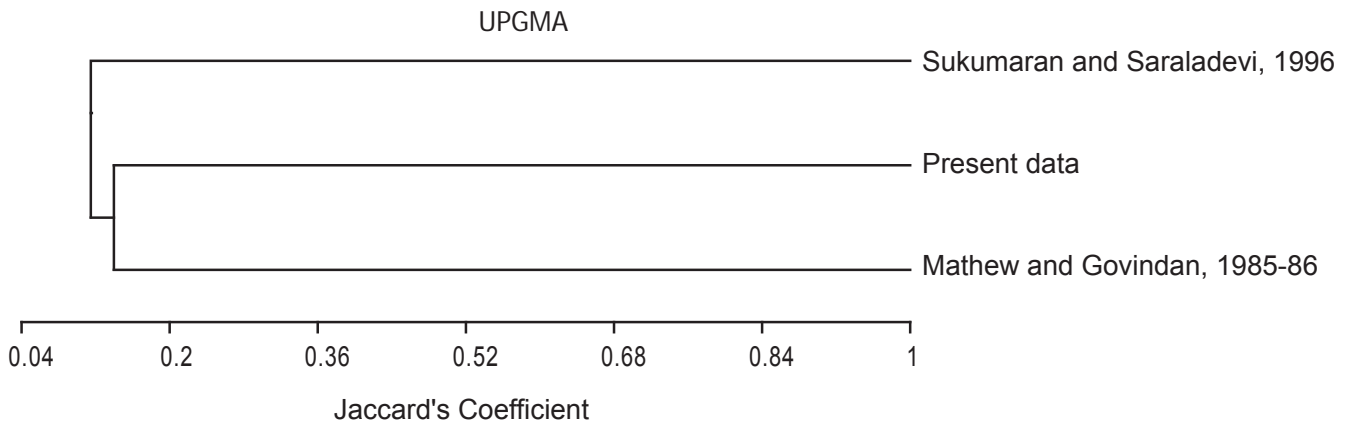


Figure 1 (Supplementary)