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Ecology and distribution of tanaids in a large tropical estuary along the Southwest Coast of India

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ABSTRACT

The crustacean order Tanaidacea consists of macrobenthic invertebrates, which constitute a major food source for higher trophic levels in estuarine and marine environments. Based on seasonal sampling in the Kochi Backwaters (KBW), the largest monsoonal estuary along the west coast of India, we present here the distribution of tanaids in relation to the major environmental variables. The results showed that tanaids form one of the most dominant macro-benthic communities in the KBW, regardless of the seasons. Altogether five species of tanaids were recorded from this seasonal sampling in the KBW including two recently described species, *Pagurapseudopsis kochindica* and *Ctenapseudes indiana*. Salinity and sediment texture were found to significantly influence the abundance and distribution of tanaids in the KBW. Multivariate methods showed that tanaids most abundantly occur in mesohaline conditions (5–15 salinity) and clayey silt bottom sediment.

1. Introduction

Benthic organisms live on or in the bottom of a water body, playing a significant intermediary role in transitional ecosystems in linking phytoplankton and/or detritus with higher trophic levels (Popchenko, 1971). Benthic monitoring is considered as an effective and reliable technique to track early indicators of environmental changes. Macrobenthos (>1 mm) have a wide distribution (Moretti and Callisto, 2005; Würdig et al., 2007), mostly linked to the water temperature, salinity and sediment types (Haiming et al., 1996; Bemvenuti and Rosa-Filho, 2000). Estuaries vary considerably in geomorphology, hydrology and bottom sediments. Undoubtedly, salinity is an important environmental factor impacting organism distribution in estuarine systems (Perkings, 1974; Diaz and Schaffner, 1990; Telesh and Khlebovich, 2010). They are characterised by a significant gradient in salinity from the inlet/barmouth to the upstream region, which is primarily governed by a balance between the tidal incursion at the lower end and the riverine discharge on the other end (Rejean and Julian, 1993). Tropical estuaries are important and characterised by complex habitats that play a critical role in global coastal ocean processes (Smith et al., 2003). The relationship between benthic fauna and sediment is an essential criterion for understanding the structure and dynamics of benthic associations. Several past studies report that benthic invertebrates are closely related to the bottom sediments (Forbes and Lopez, 1990; Snelgrove and Butman, 1994). Sediment texture greatly affects benthic community composition, and habitats with high silt-clay content usually have reduced macrobenthic abundance and biomass (Boesch, 1973, 1977; Ricciardi and Bourget, 1999; Seitz et al., 2006).

Tanaidacea is an order of benthic Crustacea predominantly marine, with very few freshwater species (Kudinova-Pasternak, 1972; Jaume and Boxshall, 2008; Kakui et al., 2010; Blazewicz-Paszkowycz et al., 2012. Tanaids are understudied deposit feeders and their abundance varies mainly with hydrographical changes (Bemvenuti, 1987; Leite, 1995; Leite et al., 2003; Bamber, 2008). They are also sensitive to pollutants and have been considered as indicators of pollution in water quality monitoring studies (García and Gomez, 2004; Ambrosio et al., 2014). In Indian waters most of the earlier works on tanaids were focused mainly on the taxonomy of the group (Chilton, 1924, 1926; Barnard, 1935; Pandiyarajan et al., 2017; Priya et al., 2014; Balasubrahmanyan, 1962), but relatively little is known about their ecology in this region, as occurs in other parts of the world (Blazewicz-Paszkowycz et al., 2012).

Tanaids do not undergo a true planktonic stage; their early developmental period is spent within the marsupium of the mother. Consequently, post-larvae, as mancas, they emerge as epibenthic forms; some species are hermaphroditic. Relevant work detailing the larval development and reproduction of tanaids include Bückle-Ramírez (1965); Johnson et al. (2001) and Haxners et al. (2000). It was noticed that variations in environmental conditions will affect the life history strategies of tanaids, causing marked changes in their population dynamics (Pennafirme and Soares-Gomes, 2009). Due to the heterogeneous nature of estuarine waters, benthos species are exposed to a wide range of

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environmental changes (Reish, 1965). An important and challenging aspect of benthic ecology is to understand the mechanisms that regulate the relationships between physicochemical parameters and the organisms (Rhoads, 1974; Snelgrove and Butman, 1994; Gray, 1974). Synchronous with the seasons, hydrographical changes occur in estuaries, which cause changes in the distribution of biota present in the system (Beadle, 1972; Odiete, 1999).

The Kochi Backwaters (KBW), one of the largest tropical monsoonal estuaries, receives the highest seasonal rainfall during the Southwest Monsoon (June to September) followed by the Northeast Monsoon (November–February) and the Pre-monsoon (March–May). During the Northeast and Pre-monsoon, KBW behaves like a true estuarine system with noticeable salinity gradients from the downstream to the upstream regions. Even though macrobenthic communities in the KBW, such as polychaetes, crustaceans, and nematodes, were studied in the past (Ansari, 1977; Devi et al., 1991; Martin et al., 2011), no concerted studies are available on the ecology of tanaids from the KBW. Therefore, in this study, an attempt has been made to investigate tanaids in the KBW to understand (a) influence of major environmental parameters on the distribution of tanaids and (b) the most suitable environmental conditions supporting the abundance of tanaids in the KBW.

2. Study area and methods

2.1. Study area

KBW is located along the southwest coast of India and extends from 9°40′ to 10°12′ N and 76°10′ to 76°30′ E. It is connected to the Arabian Sea through two channels of about 450 m wide at Kochi and another smaller one at Azhikode (Fig. 1). KBW is a typical monsoonal estuary, receiving huge volume of freshwater inflow from seven rivers mainly during the Southwest Monsoon (Vijith et al., 2009). As the rivers bring in enormous volumes of freshwater during the Southwest Monsoon (July–August), KBW behaves like a freshwater lake except near the inlet region (Jyothibabu et al., 2006). Conversely, during the non-monsoon seasons, low freshwater influx of rivers allows active salinity incursion through the inlet and as a result, the downstream of the KBW behaves like an extension of the adjacent Arabian Sea (Madhupratap, 1987; Qasim, 2003; Jyothibabu et al., 2006).

2.2. Sampling and methods

Benthic sediment samples in duplicates were collected from 27 stations along the salinity gradients in the KBW during three seasons (Pre-Monsoon, Southwest Monsoon and Northeast Monsoon) using a van Veen Grab Sampler, with an area of 0.04 m^2 and bottom sediment penetration of 10 cm. The water depth, turbidity and salinity at each sampling location were measured using a Conductivity Temperature Depth (CTD) Profiler (SEA-BIRD). Sediment samples were rinsed over a standard sieve (0.5 mm mesh), and the macrofauna present was separated and preserved in a 5% rose bengal-formaldehyde solution. Subsamples of sediments were collected and placed in plastic bags for sediment texture analysis, using Laser Diffraction Particle Size Analyser (McCave and Syvitski, 1991). Sediment chlorophyll *a* was extracted from surficial sediment in 10 ml 90% acetone under cold and dark conditions, and the supernatant was estimated using a Turner fluorometer (Trilogy, Turner designs, USA) as per standard procedure (UNESCO, 1994). Benthic organisms in the sediment samples were sorted into several groups, tanaids were identified using standard taxonomic keys (Lang, 1949; Anderson, 2012). The taxonomic status of the genera recorded was also verified and updated with WoRMS (World Register of Marine Species) website.

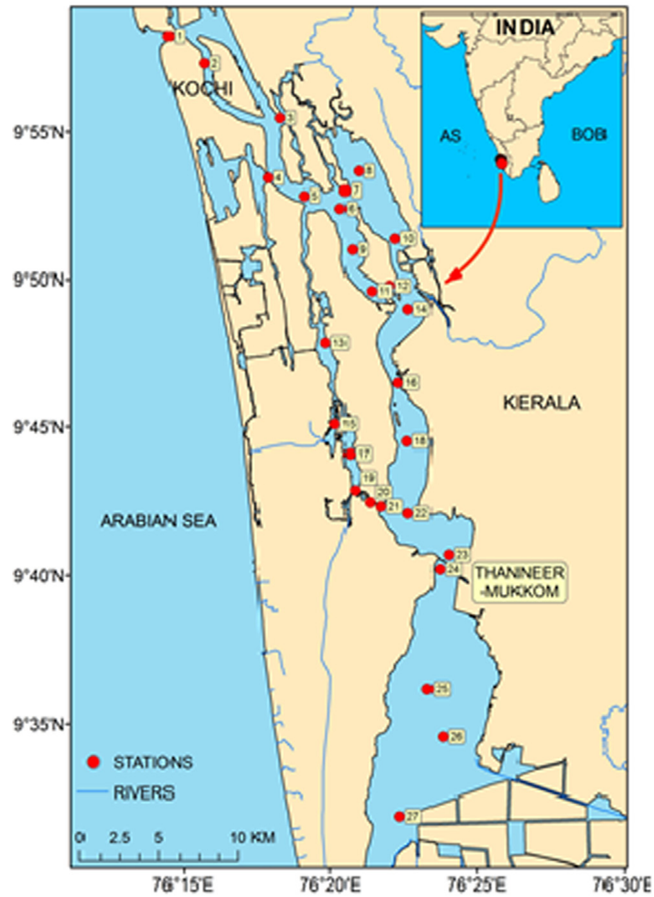

Fig. 1. Study area and 27 locations sampled during the three seasons.

2.3. Data analysis

Spatial and seasonal variations in environmental and biological data collected were tested for their normality (Shapiro–Wilk test) in distribution. Parametric ANOVA was carried out on normally distributed data, whereas non-parametric ANOVA (Kruskal–Wallis ANOVA) was used for data with irregular distribution (Zar, 1999). The tests of normality, parametric and non-parametric ANOVA were carried out in the XL stat pro-software package.

2.4. Non-metric multidimensional scaling (nMDS)

Cluster/Non-metric multidimensional scaling (nMDS) plots were used to group the locations with similar properties (Clarke and Warwick, 2001). Locations clustered closely indicate similarity while those oriented distantly indicate heterogeneity. In this study, we first performed the cluster analysis for grouping of locations based on their physical parameters (bottom salinity, bottom turbidity) in each sampling season (Pre-Monsoon, Southwest Monsoon and Northeast-Monsoon). For cluster/nMDS analysis, the datasets were normalised and Euclidean matrix-based Group average linkage method of cluster was performed. In addition to cluster analysis, similarity profile (SIMPROF) permutation test (999 permutations) was also performed to identify significant assemblages of stations ($p < 0.05$) (Clarke and Gorley, 2006). Cluster/SIMPROF overlaid nMDS plots are presented for visualisation of spatially assembled groups of locations during

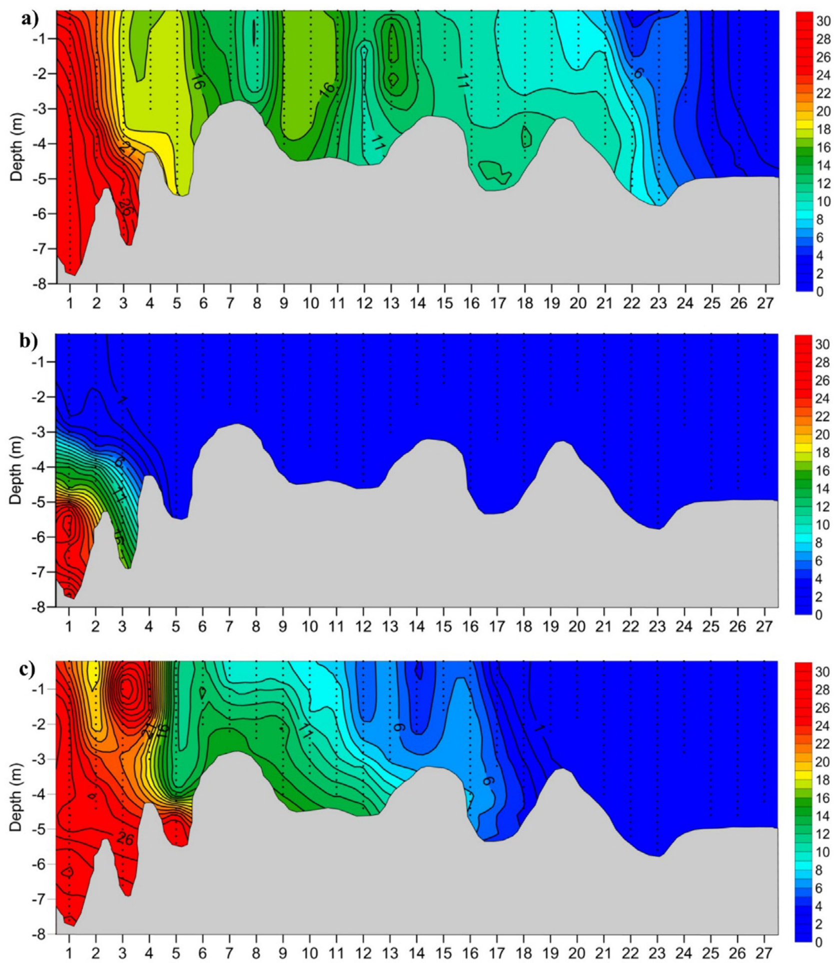

Fig. 2. Vertical distribution of salinity during the (a) Pre-monsoon, (b) Southwest Monsoon and (c) Northeast Monsoon. Bottom axis shows sample stations.

Table 1
Environmental parameters, Tanaidacea and Macrobenthic abundance in the KBW during three seasons. Mean and standard deviations are presented. Abbreviations. B-Bottom. T. abund. — Tanaids abundance, M. abund. — Macrobenthos abundance, Chlorophyll a in mg m^{-3} and Tanaids and macrobenthos abundance in ind.m^{-2}.

Parameters	Pre-monsoon					Southwest monsoon		Northeast-monsoon			
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 1	Cluster 2	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Salinity (B)	28.45 ± 1.33	15.57 ± 2.39	14.25 ± 2.13	10.24 ± 1.13	4.41 ± 2.02	22.38 ± 11.4	0.14 ± 0.1	27.66 ± 2.68	12.99 ± 5.42	3.06 ± 1.58	0.16 ± 0.07
Turbidity (B)	26.19 ± 5.16	23.75 ± 1.02	17.03 ± 7.05	6.87 ± 3.13	3.31 ± 1.23	24.24 ± 0.01	10.14 ± 4.37	11.62 ± 4.42	12.79 ± 5.18	5.72 ± 2.59	6.86 ± 1.87
Clay (%)	9.04 ± 2.02	7.38 ± 4.14	3.89 ± 1.56	4.78 ± 1.6	3.31 ± 1.18	9.47 ± 4.25	6.65 ± 2.64	19.24 ± 2.87	18.42 ± 5.78	13.19 ± 6.7	20.67 ± 8.83
Slit (%)	68.86 ± 9.37	61.53 ± 7.48	41.8 ± 16.98	58.65 ± 21.5	47.49 ± 19.18	42.77 ± 15.9	31.66 ± 11.37	67.84 ± 5.64	67.52 ± 16.47	49.13 ± 23.99	69.67 ± 11.02
Sand (%)	22.1 ± 11.16	31.07 ± 11.57	54.3 ± 19.97	36.56 ± 4.04	48.71 ± 2.04	47.77 ± 20.1	63.69 ± 27.9	12.92 ± 8.04	21.70 ± 8.06	37.69 ± 12.09	9.16 ± 2.51
Chl *a*	4.93 ± 0.75	7.3 ± 1.67	8.68 ± 3.64	6.13 ± 1.32	5.63 ± 2.63	8.06 ± 3.3	9.95 ± 3.01	7.82 ± 2.3	6.11 ± 1.62	8.1 ± 3.34	7.17 ± 1.83
T. abund.	0 ± 0	153 ± 24	107 ± 17	66 ± 13	90 ± 20	30 ± 9	47 ± 14	20 ± 3	110 ± 21	165 ± 92	100 ± 32
M. abund.	373 ± 123	1087 ± 233	785 ± 167	669 ± 133	435 ± 180	340 ± 88	444 ± 143	340 ± 129	479 ± 145	405 ± 113	414 ± 66

Table 2
Diversity index and Pielou's evenness in the KBW during three seasons.

Parameters	Pre-monsoon					Southwest-monsoon		Northeast-monsoon			
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 1	Cluster 2	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Diversity index	2.18	2.20	1.90	0.97	1.92	1.65	1.62	1.55	1.40	1.21	1.44
Pielou' evenness	0.81	0.75	0.80	0.86	0.81	0.67	0.76	0.85	0.88	0.95	0.86

different seasons. In addition, physicochemical and biological parameter values were superimposed as bubbles to visualise their distribution and their differences in spatially assembled locations. Cluster/SIMPROF and nMDS analysis were performed in PRIMER V6.

2.5. Redundancy analysis (RDA)

The relationships between distribution of biological variables (tanaid abundance, macro-faunal abundance) and the environmental variables (bottom salinity, bottom turbidity) were analysed using RDA (CANOCO 4.5). Initially, the data was analysed using Detrended Correspondence Analysis (DCA) to select the appropriate ordination technique. The result of DCA showed axis

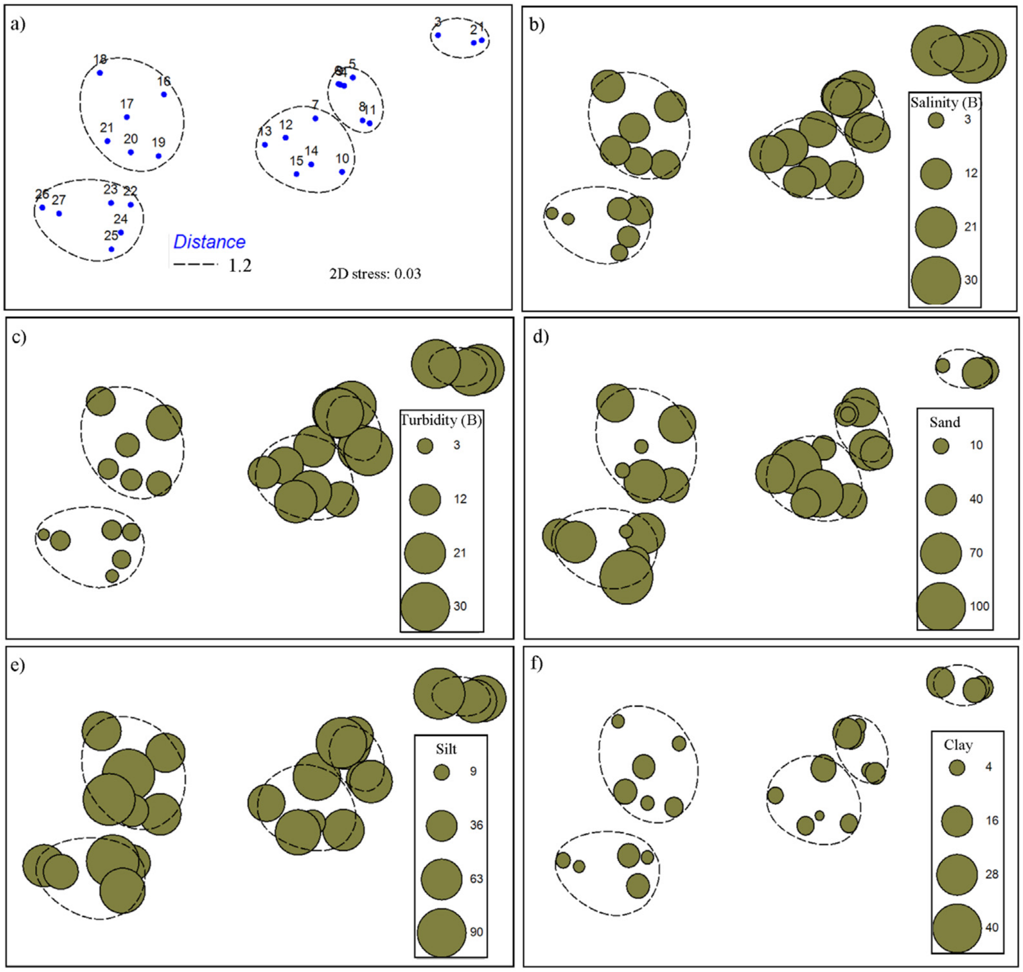

Fig. 3. Cluster/SIMPROF overlaid nMDS plots based on the distribution of the hydrographical parameters during the Pre-monsoon. (a) Clustering of locations, bubble overlaid nMDS plots showing the distribution of (b) bottom salinity, (c) bottom turbidity, percentages of (d) sand, (e) silt and (f) clay. The size of the bubbles represents the proportionate value of a particular parameter.

gradient length < 2, which suggested the use of linear multivariate RDA (Birks et al., 1998; Leps and Smilauer, 2003) analysis for the present data. The biological variables were centred and log-transformed prior to the analysis. The ordination significance was tested with Monte Carlo permutation tests (499 unrestricted permutations) ($p < 0.05$). The results of the RDA were presented in the form of a Triplot, in which the stations were displayed by points while species and quantitative environmental variables were shown by arrows (Leps and Smilauer, 2003).

3. Results

3.1. Seasonal hydrography

The spatial and temporal distributions of salinity in the study region are presented in Fig. 2. Environmental and biological variables in the KBW, during the three seasons, are presented in Table 1. Based on the distribution of salinity (bottom) and turbidity (bottom), all the locations were assembled into separate clusters during different seasons (Figs. 3–5). Regardless of the seasons, the highest bottom turbidity values were always found near the barmouth locations. During the Pre-monsoon, the estuary showed a wide range of salinity variation, resulting in the entire study area being separated into five cluster barmouth, near barmouth, upper, middle and downstream. The spatial differences of the salinity and turbidity between the cluster locations were statistically significant (ANOVA, $P < 0.05$; Supplementary Table 1). The first cluster consisted of locations 1, 2, 3, and these were situated in and around the barmouth. The bottom water in these locations was polyhaline with turbidity between 12.91–24.25 NTU (av. 26.19 ± 5.16 NTU). The second cluster of locations 4, 5, 6, 8, and 11 was characterised by mesohaline bottom salinity and turbidity ranging from 21.71–24.31 NTU (av. 23.75 ± 1.20 NTU). The third cluster representing the downstream region included locations 7, 10, 12–15, which were characterised by mesohaline bottom salinity and turbidity between 10.38–30.14 NTU (av. 17.04 ± 7.05 NTU). The fourth cluster of midstream region consisted of locations 16–21 near the Thanneermukkom bund with mesohaline bottom salinity and turbidity from 4.14 −12.52 NTU (av. 6.88 ± 3.13 NTU). The fifth cluster in the upstream region consisted of locations 22–27, which were characterised by oligohaline salinity and turbidity ranging from 0.79–7.23 NTU (av. 3.31 ± 1.23 NTU).

During the Southwest Monsoon, large volume of freshwater reaches into the KBW, resulting in oligohaline/freshwater conditions in most of the region (near barmouth, downstream, midstream and upstream); the turbidity herein ranged from 3.50–24.21 NTU (av. 10.14 ± 4.37 NTU). The only exception to this situation was the polyhaline condition found in the bottom layers near the barmouth (locations 1 and 2) where the turbidity varied between 24.23–24.24 NTU (av. 24.24 ± 0.01NTU). Spatial differences of salinity and turbidity was comparable between the sampling sites (ANOVA, $P > 0.05$; Supplementary Table

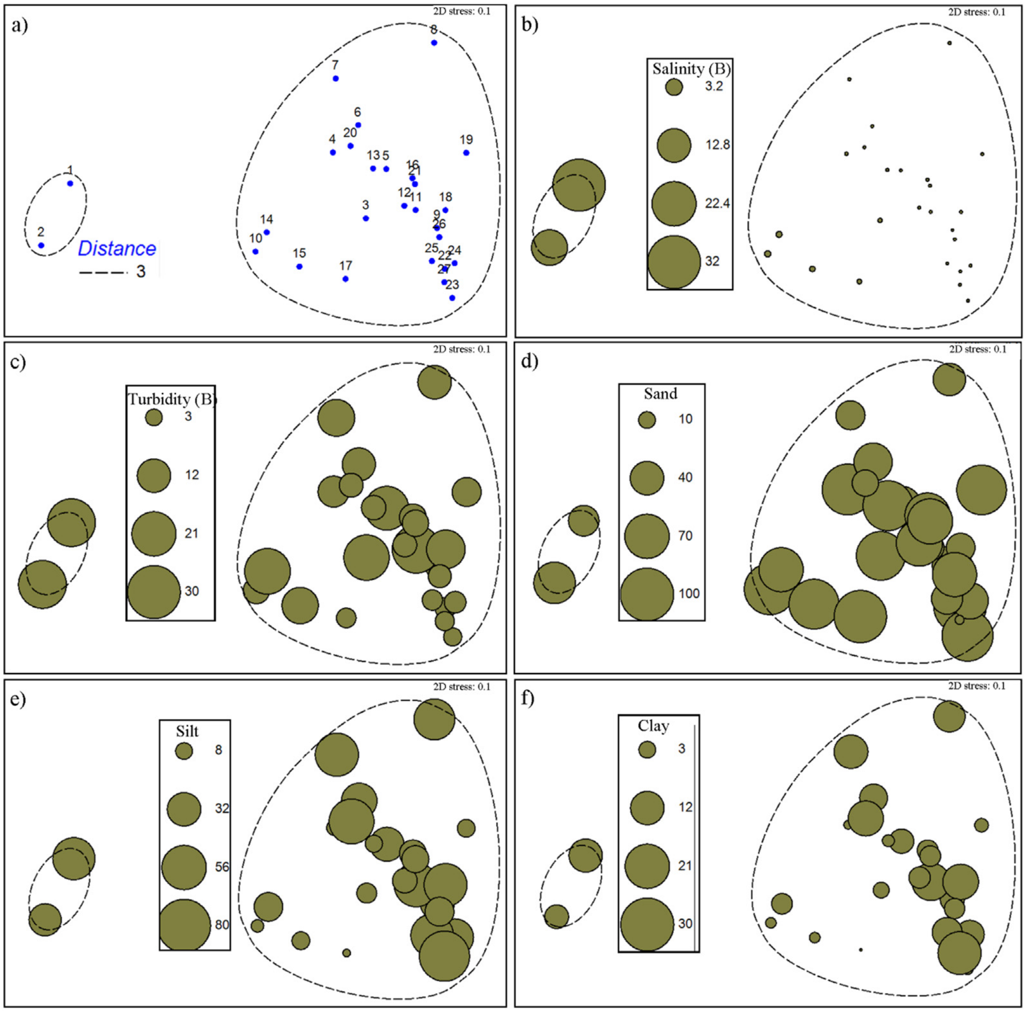

Fig. 4. Cluster/SIMPROF overlaid nMDS plots based on the distribution of the hydrographical parameters during the Southwest monsoon. (a) Clustering of locations, bubble overlaid nMDS plots showing the distribution of (b) bottom salinity, (c) bottom turbidity, percentages of (d) sand, (e) silt and (f) clay. The size of the bubbles represents the proportionate value of a particular parameter.

1). During the Northeast Monsoon, cluster 1 in the barmouth region consisted of locations 1–4 and the bottom waters here were euhaline with turbidity ranging between 6.94–24.21 NTU (av.11.62 ± 4.43 NTU). Cluster 2 in the downstream region was formed of locations 5–13 having mesohaline bottom waters with a turbidity variation between 3.23–24.20 NTU (av.12.79 ± 5.18 NTU). Cluster 3 locations were from the midstream region and consisted of locations 14–17 and 19, 20, 26, 27, which were characterised by limnohaline bottom salinity with turbidity ranging from 2.05–14.73 NTU (av.5.72 ± 2.59 NTU). Upstream regions were represented in cluster 4, which was composed of locations 18, 21–25 characterised by limnohaline bottom salinity; turbidity here varied from 3.42–11.50 NTU (av.6.83 ± 1.87). Spatial differences of salinity and turbidity, between the sampling cluster locations, were found to be statistically significant (ANOVA, $P < 0.05$; Supplementary Table 1).

3.2. Sediment texture

Seasonal changes and percentage contribution of grain size of sediment has been presented in Fig. 6. The sediment characteristics of the clusters of locations during the three different seasons have been described in this section. During the Premonsoon, among the five clusters of locations (Table 1), those in clusters 1, 2 and 4 were dominated by silty sand bottom substratum. Sandy silt bottom prevailed in clusters 3 and 5.

Among the two clusters that formed during the Southwest Monsoon, cluster 1 locations in the barmouth were silty sand, while it was sandy silt in all the remaining locations (cluster 2). During the Northeast monsoon, among the four clusters of locations, clusters 1 and 4 were clayey silt, cluster 2 was silty sand and cluster 3 was sandy silt.

3.3. Sediment chlorophyll *a*

Seasonal distribution of sediment chlorophyll *a* is presented in Figs. 7–9(b). During the Pre-monsoon, the sediment chlorophyll *a* was low in the barmouth region (cluster 1), midstream (cluster 4) and upstream (cluster 5) regions compared to the near barmouth (cluster 2) and downstream (cluster 3) regions (Fig. 8). During the Southwest Monsoon, sediment chlorophyll *a* concentration was higher in cluster 2 (downstream, midstream and upstream) compared to cluster 1 (barmouth). During the Northeast Monsoon, sediment chlorophyll *a* showed high values at the barmouth (cluster 1), followed by downstream (cluster 3), midstream (cluster 4) and upstream regions of the estuary.

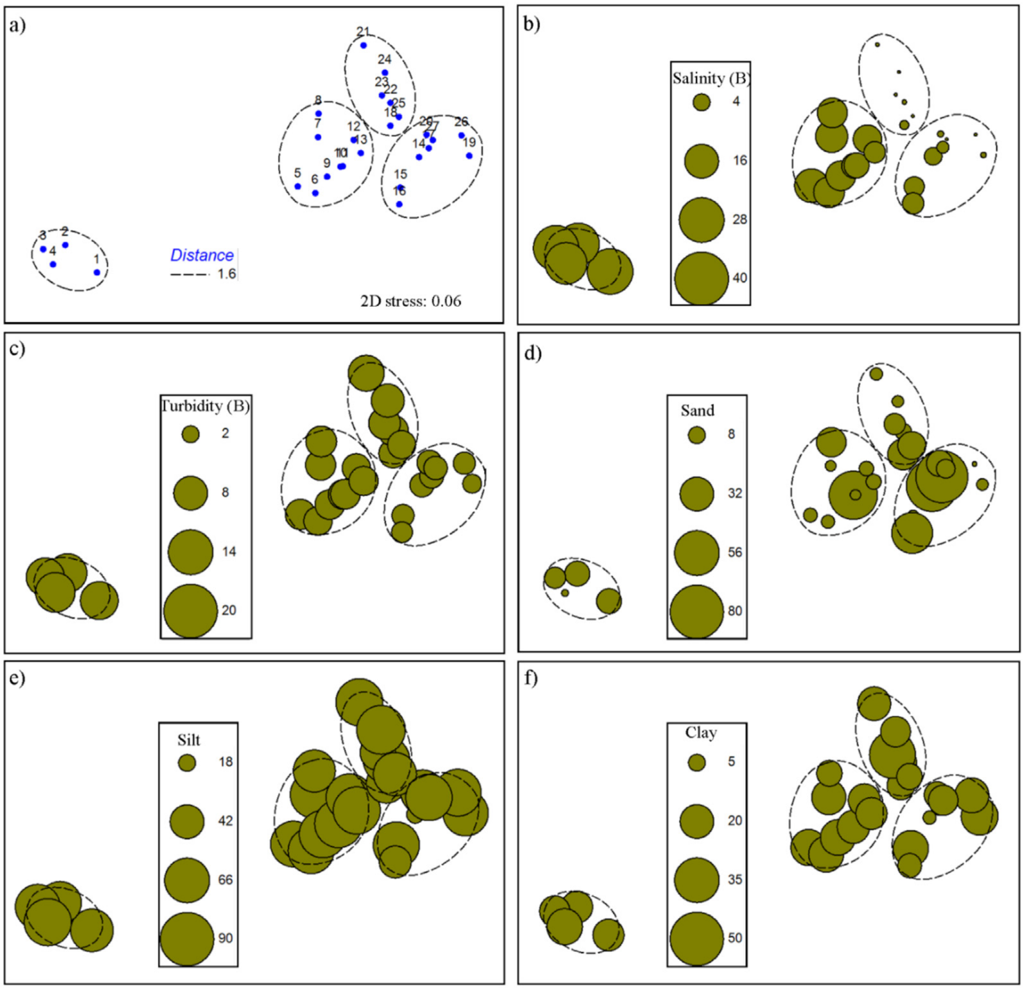

Fig. 5. Cluster/SIMPROF overlaid nMDS plots based on the distribution of the hydrographical parameters during the Northeast-Monsoon. (a) Clustering of locations, bubble overlaid nMDS plots showing the distribution of (b) bottom salinity, (c) bottom turbidity, percentages of (d) sand, (e) silt and (f) clay. The size of the bubbles represents the proportionate value of a particular parameter.

3.4. Macrobenthos abundance

Several groups of organisms contributed to the macrobenthos community including polychaetes, crustaceans, tanaids, bivalves, gastropods, decapods and harpacticoid copepods. The seasonal distribution of macrofaunal abundance is presented in Figs. 7–9(c) and in Table 1. Regardless of sampling site, barmouth locations (cluster 1) had the lowest macrofauna abundance compared to other regions. The diversity and Pielou's evenness indices calculated for all the three seasons are presented in Table 2. In all the sampling seasons, the abundance of macrofauna was high in the mesohaline regions.

3.5. Tanaidacea composition and abundance

Tanaid abundance in the KBW during all the sampling seasons is presented in Figs. 7–9(d) and Table 1. In the KBW, altogether five species of tanaids were found, which include two recently described species, *Pagurapseudopsis kochindica* and *Ctenapseudes indiana*. The other tanaids species found were *P. gymnophobia*, *C.chilkensis,* and *Tanais* sp. and all these species were found during all the three seasons. The overall abundance of tanaids in the KBW was lower during the Southwest Monsoon seasons compared to the other seasons. The percentage contribution of tanaids to the total macrobenthic community during the Pre-monsoon was absence in cluster 1, 16% in cluster 2, 15% in cluster 3, 15% in cluster 4 and 24% in cluster 5. During the Southwest Monsoon, tanaids percentage contribution was 19% in cluster 1 and 14% in cluster 2. During the Northeast Monsoon, they contributed 5% in cluster 1, 18% in cluster 2, 41% in cluster 3 and 24% in cluster 4.

3.6. Redundancy analysis and environmental factors

The RDA Triplot showing the interrelationship between the hydrographical (salinity and turbidity), sediment texture and biological variables (macrofauna abundance, sediment chlorophyll *a*, total and species-wise abundance of tanaids) during the Pre-monsoon, Southwest Monsoon and Northeast Monsoon showed the following features. Salinity, turbidity and sediment texture together could explain 30.1%, 35.4% and 36.1% variations of biological variables during the Pre-monsoon, Southwest and Northeast monsoon seasons, respectively (Fig. 10). During the Pre-monsoon, salinity and turbidity varied spatially and their increasing gradients were oriented on the right side of the RDA plot. The clay and silt axes were oriented on the left side, while the axis of sand was oriented towards the opposite side of the Triplot. The total abundances of macrofauna and tanaidacea, and dominant species of tanaids, all were oriented on the left hand side of the plot along with the silt and clay axes. This indicated the preference of biological variables for the clayey silt sediments. Salinity overlaid attribution plot helped to clearly visualise distribution of macrofauna and total tanaidacea abundance, showing their

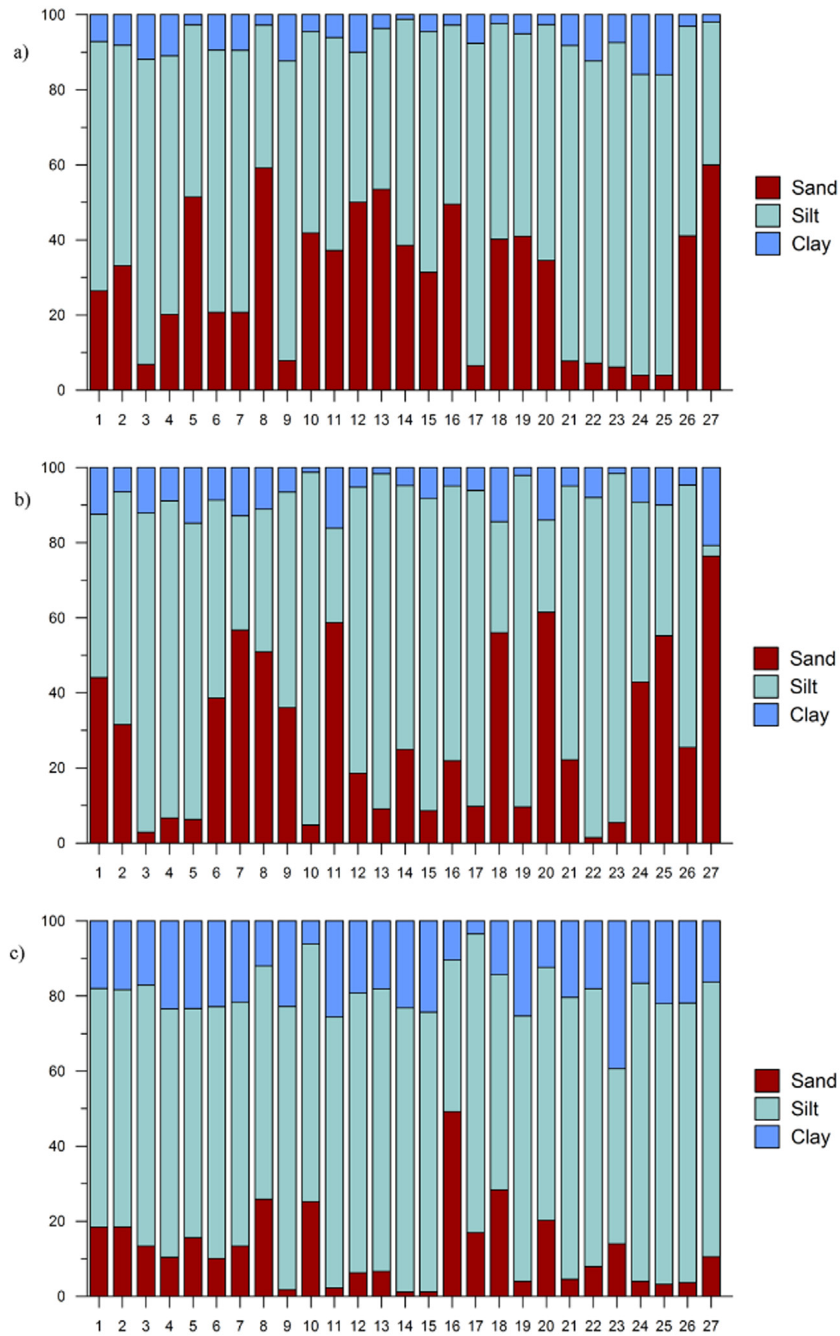

Fig. 6. Sediment texture (% contribution of sand, silt and clay) in the study area during (a) Pre-monsoon, (b) Southwest Monsoon and (c) Northeast-monsoon.

preference for mesohaline levels of salinity. Sediment chlorophyll *a* concentration was slightly higher in the mesohaline levels of salinity, but the differences were clearly comparable.

During the Southwest Monsoon, all the sampling locations except in the barmouth (cluster 1) were grouped together as cluster 2. The surface and bottom salinity axes were oriented on the right-hand side of the plot. The axes of total tanaid abundance were oriented on the left-hand side of the plot, along with increasing gradients of silt and clay (Fig. 11). During the Northeast Monsoon, salinity and turbidity axes were oriented along the left side of the plot (Fig. 12). The increasing gradients of silt and clay axes were oriented towards the right-hand side of plot, whereas the sand axes was oriented towards the left side of the plot. The increasing gradients of macrofauna, total tanaids, and sediment chlorophyll *a* were found on the right side of the plot. The tanaids species and their total abundance were oriented along the axis of the silt and clay, indicating their preference for clayey silt bottom. Salinity overlaid attribution plot showed that high abundance of tanaid and macrofauna were found in the mesohaline regions.

4. Discussion

Estuaries are characterised by steep gradients in physical, chemical and biological factors, wherein hydrographical changes influence the faunal abundance, distribution and diversity (Qasim, 2003). Being located in the tropics, the spatial and temporal variations in temperature are noticeably low in the KBW (Jyothibabu et al., 2006). Salinity and turbidity are the two major environmental variables in an estuarine ecosystem, especially in those influenced heavily by the Asian Monsoonal systems.

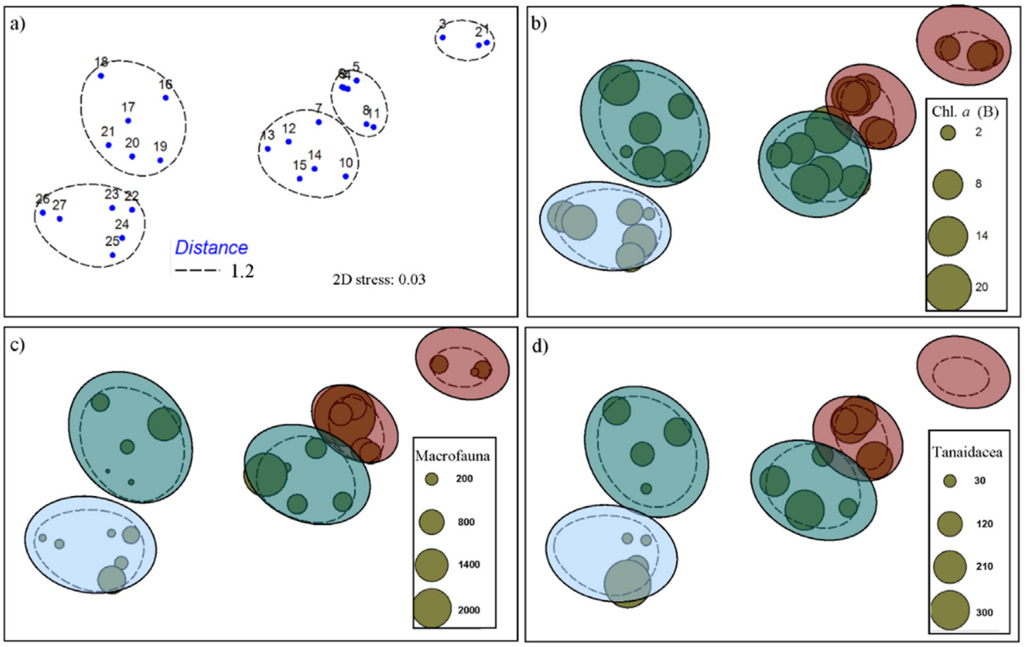

Fig. 7. (a) Cluster/SIMPROF overlaid nMDS plots based on the distribution of the hydrographical parameters during the Pre-monsoon. Spatial distribution of (b) benthic chlorophyll *a*, (c) macrofauna and (d) tanaids abundance overlaid as bubbles in spatially assembled cluster of locations during the Pre-monsoon. The brown, green, blue filled circles represent euhaline/polyhaline, mesohaline and limnohaline levels of salinity respectively.

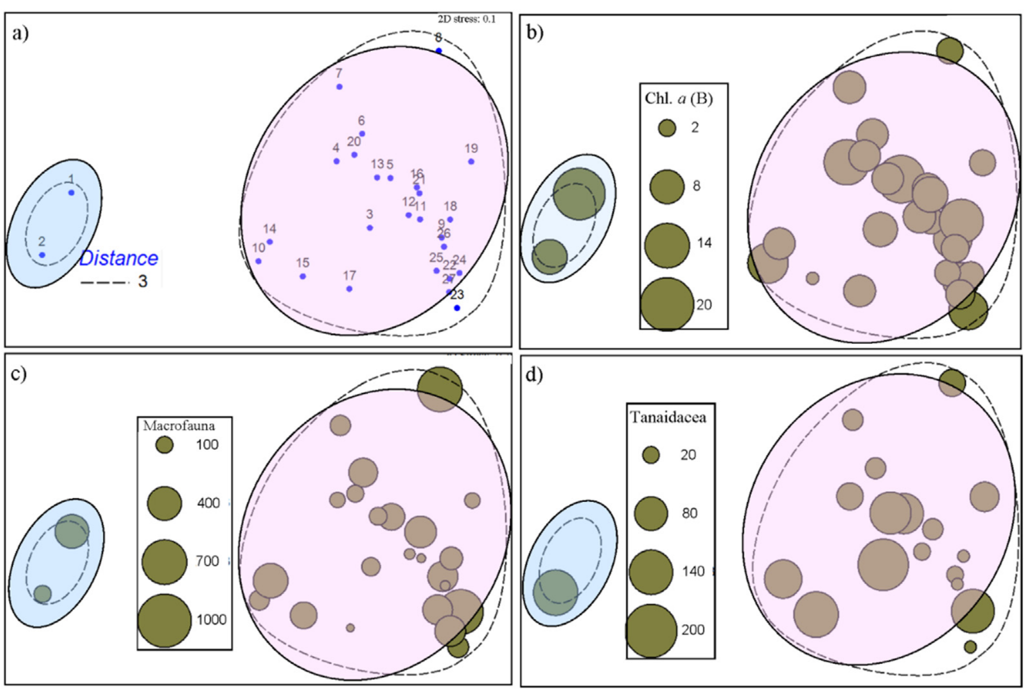

Fig. 8. (a) Cluster/SIMPROF overlaid nMDS plots based on the distribution of the hydrographical parameters during the Southwest Monsoon/Monsoon. Spatial distribution of (b) benthic chlorophyll *a*, (c) macrofauna and (d) tanaids abundance overlaid as bubbles in spatially assembled cluster of locations during the Southwest Monsoon/Monsoon. The blue and pink filled circle represent limnohaline and oligohaline levels of salinity, respectively.

Spatial distribution of salinity in such estuaries mainly depends upon the velocity of the freshwater flux at one end, and the intrusion of saltwater and their mixing at the other end. Salinity variations cause fluctuation in growth, reproduction and survival of many benthic organisms because osmotic and thermal stresses cause changes in the basal metabolic rate, which may decrease the energy available for other activities (Odiete, 1999). Vertical distribution of salinity in all three seasons showed notable spatial changes in the study area, which could influence the macrofaunal distribution as noticed elsewhere (Thilagavathi et al., 2013). Even

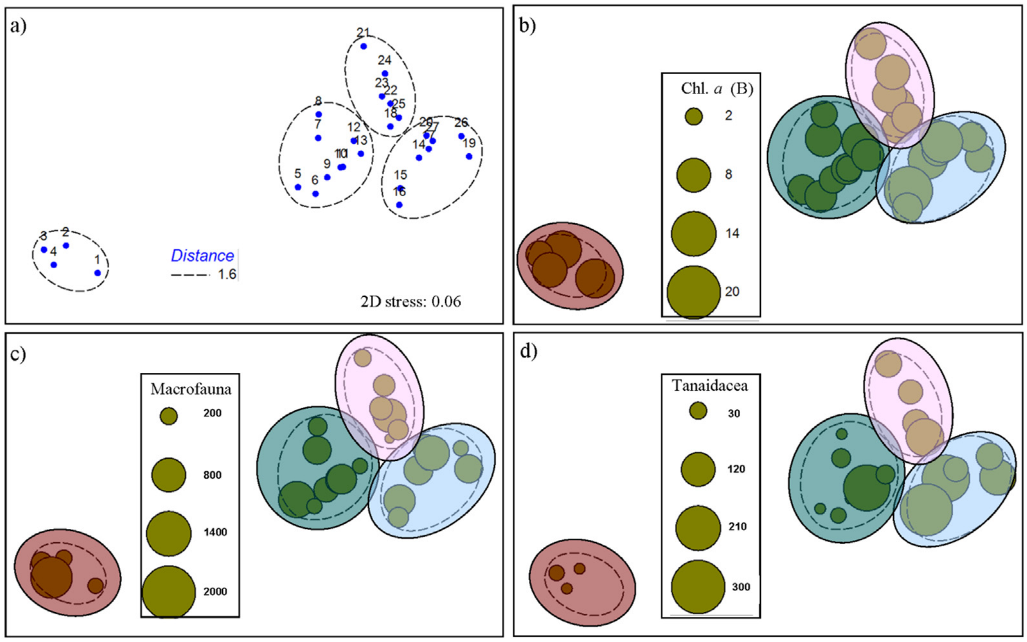

Fig. 9. (a) Cluster/SIMPROF overlaid nMDS plots based on the distribution of the hydrographical parameters during the Northeast-monsoon. Spatial distribution of (b) benthic chlorophyll *a*, (c) macrofauna and (d) tanaids abundance overlaid as bubbles in spatially assembled cluster of locations during the Northeast-Monsoon. The brown green, blue and pink filled circles represent euhaline/polyhaline, mesohaline, limnohaline and oligohaline levels of salinity, respectively.

though the sediment texture plays an important role in the ecology of benthic invertebrates, their distribution in a particular area may depend up on many other factors as well (Siciński, 1998).

Overall, the downstream region near the barmouth/inlet showed the highest salinity ranges during all the three seasons due to intrusion of marine water. Midstream region of the KBW behaved as mesohaline, oligohaline and limnohaline during different seasons. Due to the freshwater input from rivers, the salinity conditions in the upstream region remained limnohaline and oligohaline during all the three seasons (Jyothibabu et al., 2006). It was earlier reported that a decrease in salinity during the Monsoon can also trigger induced spawning in some macrobenthic organisms (Kinne, 1977). Increased water content in the sediments reflects an increase in the fine particles (mud and clay), which can retain more water than coarse particles (sand and gravel). Such fine deposits or particles are commonly constituted of decomposable organic constituents (Gray, 1981). Many tanaids have the ability to form tubes and the tube formation depends on the grain size of the sediments (Hamers and Franke, 2000; Kakui and Hiruta, 2017). RDA evidenced that the tanaid abundance in the present study region had a positive correlation with clayey sediment. This may indirectly corroborate the general view that clayey sediment is suitable for tube formations by tanaids (Fricke et al., 2015; Kakui and Hiruta, 2017).

During the Southwest Monsoon, the estuary receives enormous amounts of freshwater from rivers, which results in the formation of two distinct salinity regions in the system: polyhaline and oligohaline. During the Northeast Monsoon, the estuary showed a wide range of salinity variations, causing the entire region to be segregated into four clusters: barmouth, upper, middle and downstream regions. In estuaries, the oligohaline and freshwater tidal parts are generally characterised by relatively low species richness, dominated with oligochaetes, chironomids, amphipods and molluscs (Montague and Ley, 1993; Odum et al., 1988). The observations of Ferraris et al. (1994) showed that terebellid polychaetes and sipunculids get adversely affected by large salinity fluctuations in estuaries. Benthic organisms often change the physical properties of the sediment and cause modification of fine-scale seabed structures. A common concept in benthic animal-sediment relation is that the feeding type of the infauna in one way is correlated with the sediments (Snelgrove Paul et al., 2000). The complexity of soft-sediment communities is that they may resist any simple pattern with regard to any single factor controlling their settlement and colonisation (Snelgrove and Butman, 1994).

Earlier studies from the KBW largely dealt with the macrofaunal distribution, abundance and species composition in relation to various environmental factors (Desai and Krishnakutty, 1967; Kurian, 1972; Ansari et al., 1994; Harkantra et al., 1980; Remani et al., 1980). In the present study, chlorophyll *a* was found to be higher during the Southwest Monsoon compared to the Northeast and Pre-monsoon seasons (Madhu et al., 2007). Physical factors such as sediment texture have long been considered to be the most important factor in benthic ecology (Johnson, 1971; Gray, 1974). Tanaids are found in a wide variety of marine and brackish water habitats such as sandy and muddy bottom associated with algae, hydroids, and empty seashells (Lang, 1956; Gardiner, 1975; Masunari, 1982, 1983; Johnson and Attramadal, 1982; Toniollo and Masunari, 2007).

Tanaids are important in the benthic food chain, consumed by many fishes and shrimps (Chilton, 1926; George, 1974). This also indicates the potential of tanaids as a live feed in aquaculture. Several authors have tried to correlate the distribution of tanaids with environmental parameters. Leite (1995) presented the view that salinity is not a significant factor in the distribution of the tanaid, *Monokalliapseudes schubarti*. Leite et al. (2003) determined that the abundance of the tanaid, *M. schubarti* may be constrained by the nature of silt and clay particles in the bottom substratum. However, in this study, salinity emerged as a critical parameter impacting the distribution of tanaids in the KBW. In short, this study showed that tanaids can survive at different salinity levels and sediment texture in the KBW, but clearly prefer mesohaline and clayey silt bottom conditions for their optimum growth.

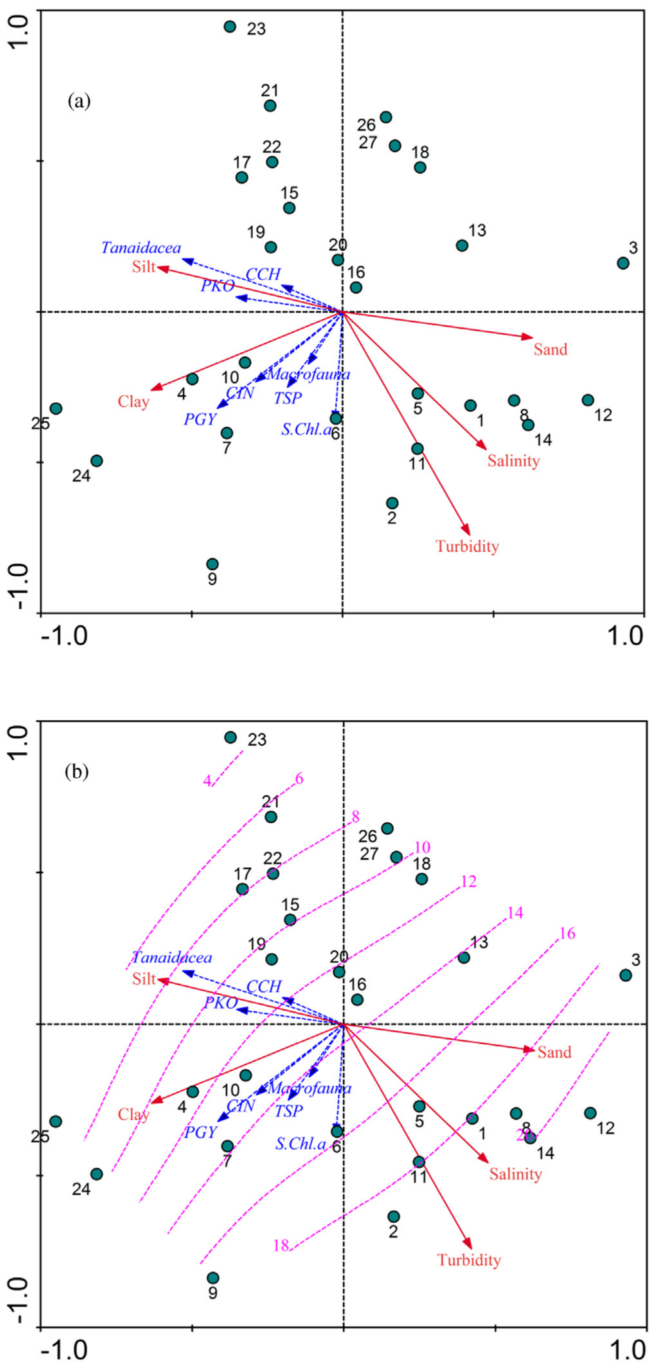

Fig. 10. (a) RDA Triplot visualising the distribution of hydrographical and biological parameters and their interrelation during the Pre-monsoon. (b) Salinity overlaid RDA Triplot plot visualising the distribution of the biological parameters in relation to salinity. S. Chl.*a* — Sediment chlorophyll; CCH — *Ctenapseudes chilkensis*; TSP — *Tanais* sp. PKO — *Pagurapseudopsis kochindica*; PGY — *Pagurapseudopsis gymnophobia*; CIN — *Ctenapseudes indiana*.

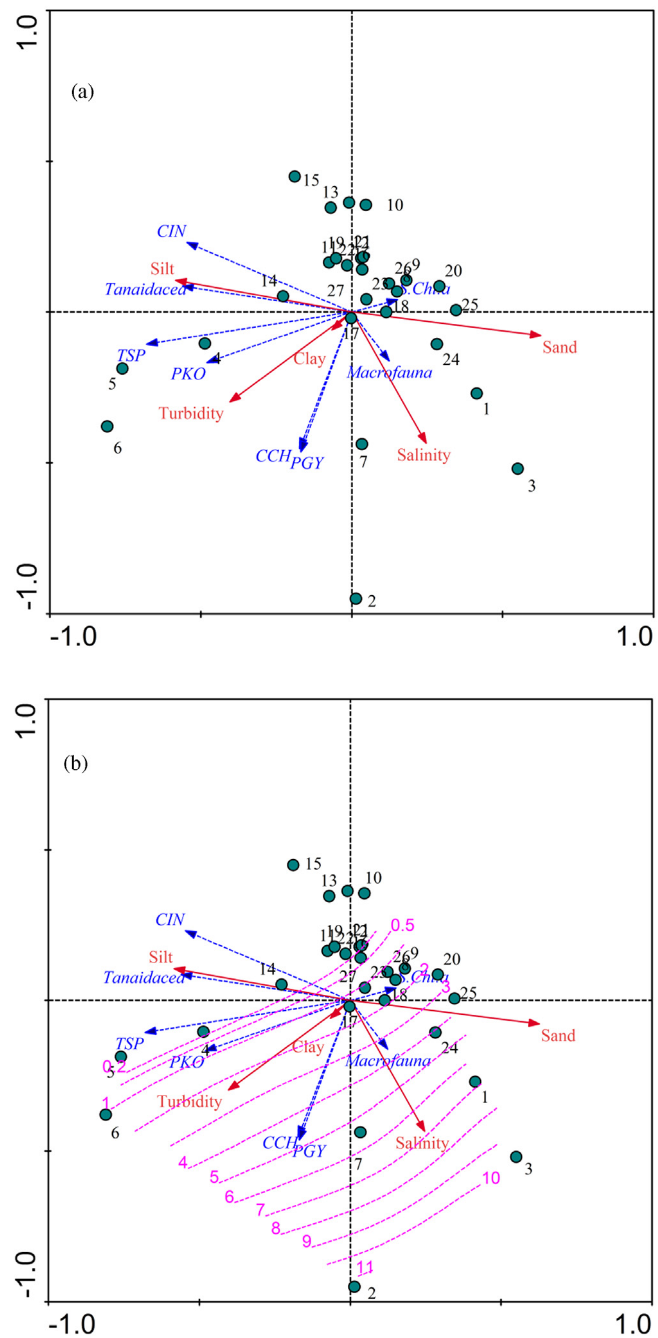

Fig. 11. (a) RDA Triplot visualise the distribution of hydrographical and biological parameters and their interrelation during the Southwest Monsoon/Monsoon. (b) Salinity overlaid RDA Triplot visualising the distribution of the biological parameters in relation to salinity. S. Chl. *a* — Sediment chlorophyll; CCH — *Ctenapseudes chilkensis*; TSP — *Tanais* sp. PKO — *Pagurapseudopsis kochindica*; PGY — *Pagurapseudopsis gymnophobia*; CIN — *Ctenapseudes indiana*.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Pandiyarajan R.S.: Data curation, Validation, Investigation, Formal analysis, Writing - original draft, Writing - review & editing. **Jyothibabu R.:** Data curation, Validation, Supervision, Investigation, Formal analysis, Writing - original draft, Writing - review & editing. **Jagadeesan L.:** Data curation, Validation, Supervision, Investigation, Formal analysis, Writing - original draft, Writing - review & editing. **Arunpandi N.:** Data curation, Validation, Investigation, Formal analysis, Writing - original draft, Writing - review & editing.

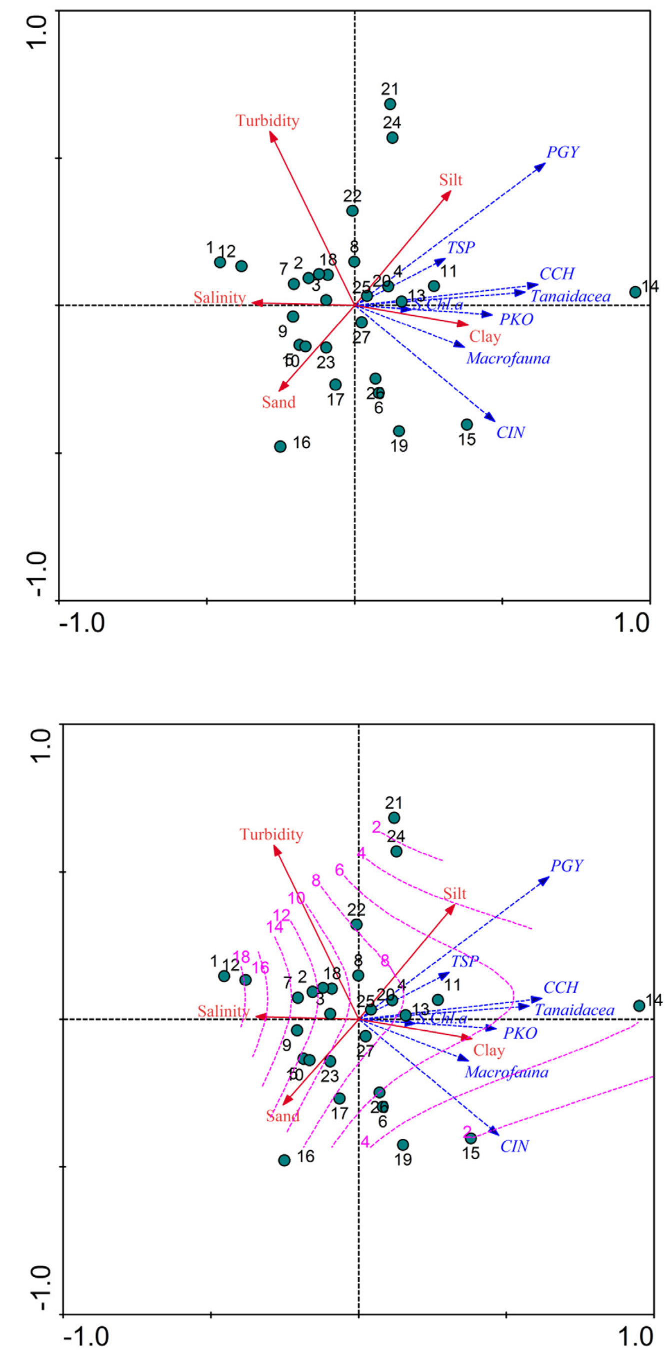

Fig. 12. (a) RDA Triplot visualising the distribution of hydrographical and biological parameters and their interrelation during the Northeast-Monsoon. (b) Salinity overlaid RDA Triplot visualising the distribution of the biological parameters in relation to salinity. S. Chl.*a* — Sediment chlorophyll; CCH — *Ctenapseudes chilkensis*; TSP — *Tanais* sp.; PKO — *Pagurapseudopsis kochindica*; PGY — *Pagurapseudopsis gymnophobia*; CIN — *Ctenapseudes indiana.*

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rsma.2019.101032.

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