Available online at: www.mbai.org.in doi:10.6024/jmbai.2022.64.1.2293-04

Seasonal and spatial variability of zooplankton diversity in North Eastern Arabian Sea along the Maharashtra coast

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Received: 23 July 2021 Accepted: 22 Apr 2022 Published: 05 May 2022

Original Article

Abstract

The study focused on the variations in seasonal diversity of zooplankton between the polluted coastal environments of Mumbai and the comparatively less polluted coastal waters of Ratnagiri. The study was carried out from August 2014 to May 2017. Zooplankton was collected from hauls at 20 m and 40 m depth contours off Mumbai and Ratnagiri coast. The results indicated that Species Richness d, Shannon H and Simpson 1-λ at Mumbai stations were low compared to Ratnagiri stations. The values were higher in post-monsoon (POM) and pre-monsoon (PRM) than in monsoon (MON) season. Two-way ANOVA revealed a significant difference ($P<0.05$) for values of 'd', 'H' and 1-λ' between Mumbai and Ratnagiri. Post-Hoc Tukey test showed a significant difference ($P<0.05$) between values of 'd', 'H' and 1-λ' during MON and POM, MON and PRM. However, no significant difference ($P>0.05$) was observed between POM and PRM. Cluster analysis showed a 35% similarity in diversity between MON and the other two seasons. SIMPER analysis of similarity showed average dissimilarity of 44.77 between the diversity of Mumbai and Ratnagiri. The study indicated seasonal variations in the zooplankton diversity in coastal regions of Mumbai and Ratnagiri. The impact of pollution and anthropogenic activities could have reduced zooplankton diversity and abundance in the coastal environment of Mumbai compared to the less polluted waters of Ratnagiri.

***Keywords**: Zooplankton, diversity, Arabian sea, Mumbai, Ratnagiri*

Introduction

Zooplankton are drifting organisms in water, which are not able to maintain their position against the physical movement of water. The community of zooplankton is an assemblage of different animals which includes many taxonomic groups, mainly the invertebrates. Zooplankton constitutes an efficient trophic level in the utilization of the habitat and transfer of energy from primary to secondary level forming an important link in the food chain and are thus significant in assessing the productivity of the sea as secondary producers (Nair, 2001). Zooplankton communities are used for assessing the productivity and health status of ecosystems (Thirunavukkarasu *et al*., 2013) while some of the species can be used as potential indicators for different water masses and environmental changes like water quality parameters and climate change (Russell, 1939). Coastal, marine areas are extremely variable due to changes in the circulatory patterns of water and land-based influences e.g. rivers, and sewage flow, which induce great temporal variability (Walsh, 1988). Zooplankton production along the neritic and inshore waters is influenced mainly by seasonal variations related to monsoon and upwelling (Nair, 2001). Changes in the water quality parameters will directly affect the abundance and composition of the zooplankton population (Gaonkar *et al*., 2010).

Coastal areas are constantly under threat by sewage and effluent discharges from the metropolis and industrialized zones affecting their ecology. In addition to that, environmental variations can also influence the changes in zooplankton abundance and diversity (Calbet *et al*., 2001). Several studies have indicated that the discharges from industrial and domestic outfalls have degraded the coastal environment of Mumbai (Ramaiah and Nair, 1997; Dhage *et al*., 2006; Vijay *et al.* 2010a, b; Shirodkar *et al*., 2012; Bawa *et al*., 2014; Vijay *et al*., 2015). Compared to Mumbai, Ratnagiri is a small town, and although untreated sewage enters coastal waters, it is relatively free from industrial effluents. However, the less population density of Ratnagiri compared to Mumbai generates a very negligible sewage load resulting in less polluted waters. The open waters off Ratnagiri are relatively free from anthropogenic fluxes of pollutants and the water quality is good (CSIR-NIO, 2018).

Many studies on marine zooplankton were conducted along the Maharashtra coast *viz.* Nair *et al.* (1983); Madhupratap *et al.* (1990); Ramaiah and Nair (1993), Gajbhiye *et al.* (1991), Nair and Ramaiah (1995), Santhakumari *et al.* (1995); Goswami and Shrivastava (1996); Ramaiah and Nair (1997); Gaonkar *et al.* (2010); Kulkarni and Mukadam (2015) and Kadam and Tiwari (2015). But comparative studies on seasonal variability in zooplankton diversity in the nearshore waters of Mumbai and Ratnagiri were not attempted to date. Therefore, the present study focussed on the variations in the seasonal diversity of zooplankton between the polluted coastal environment of Mumbai and the comparatively less polluted coastal waters of Ratnagiri.

Material and methods

Study area

Mumbai is a highly urbanized and industrialized metropolis hence its coastal waters receive domestic wastes and industrial effluents (fertilizers, automobile, petroleum, leather, food, chemical and nuclear industries) through major influxes from Bassein creek, Manori creek, Versova creek, Mahim creek, Vashi creek and Dharamtar creek (Ramaiah and Nair, 1997). Ratnagiri is a small town that receives domestic wastes and industrial effluents like fish discards and fish related wastes from fish landing centres (CSIR-NIO, 2018) in coastal waters. The major influx in Ratnagiri coastal waters comes from Kalbadevi creek and Bhatye creek. Sampling stations were in two depth zones of 20 m and 40 m, off Mumbai and Ratnagiri coasts. Geocoordinates of the sampling locations: Mumbai- Station I (at 20 m depth contour) 18° 51' 49.2" N 72° 41' 31.1" E, Station II (at 40 m depth contour) 18° 55' 38.9" N 72° 32' 36.9" E; Ratnagiri - Station I (at 20 m depth contour) 17° 03' 26.3"N 73° 12' 43.3"E, Station II (at 40 m depth contour) 17° 03' 59.7"N 73° 06' 48.7" E (Fig. 1).

Sampling and analysis

Monthly sampling was done at both the stations of Mumbai and the Ratnagiri coasts. Samples were collected from August 2014 to May 2017 (30 trips) for Ratnagiri stations, while at Mumbai it was done from January 2015 to May 2017 (25 trips). At both the locations, sampling during June and July could not be conducted due to rough weather and the non-availability of a boat because of the monsoon fishing ban. Zooplankton samples were collected onboard a mechanized fishing boat by

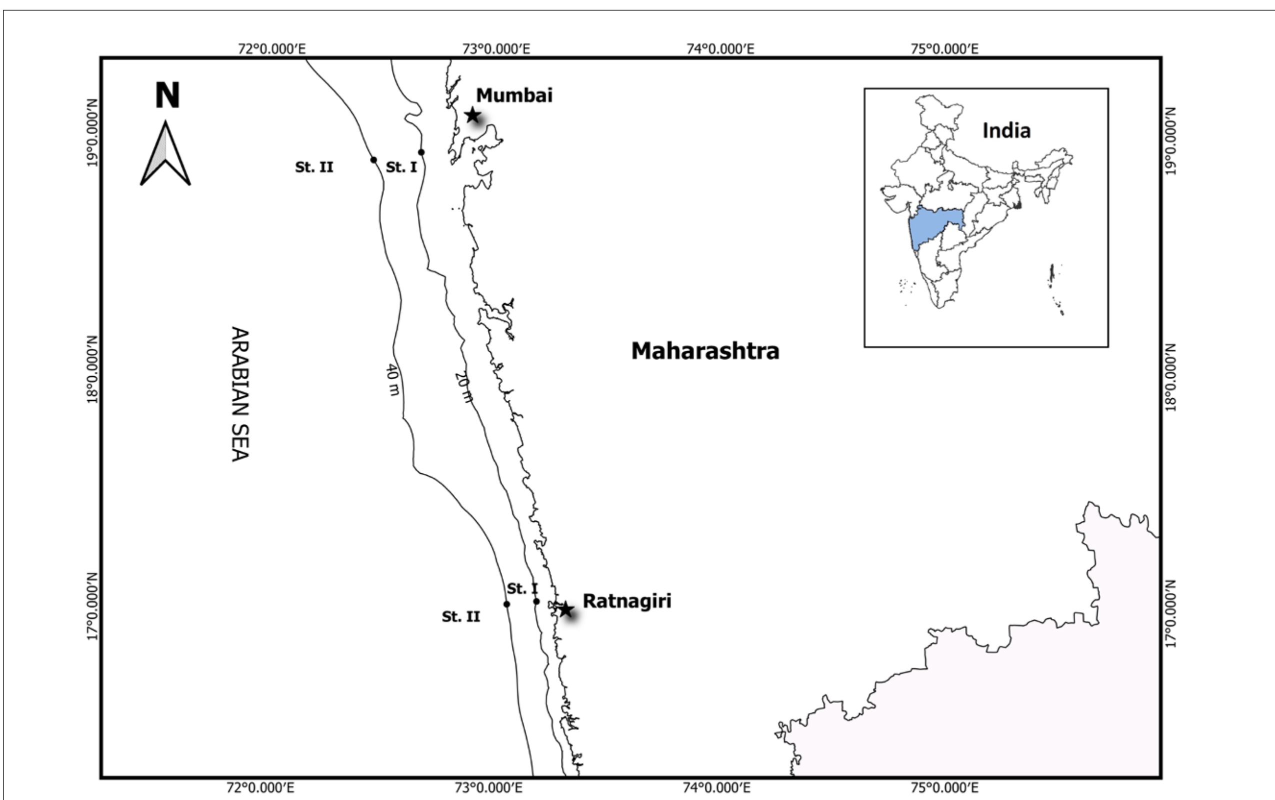

Fig.1. Location map of the study area

oblique surface hauls using a Heron Tranter net (mouth area 0.25 m^2 and mesh size of 100 μ) fitted with TSK flow meter (Madhupratap *et al*., 1990; Gajbhiye *et al*., 1991; Gaonkar *et al*., 2010). The collected samples were preserved in 5% formaldehyde. Subsamples (25%) were taken from original samples using a Folsom Plankton splitter and enumerated for qualitative and quantitative analysis of zooplankton following various identification manuals (Kasturirangan, 1963; Conway *et al*., 2003; Al-Yamani *et al*., 2011).

Water samples from sampling locations were collected in one litre plastic container and kept at -4 °C in an icebox till further analysis in the laboratory. Sea surface temperature, pH, dissolved oxygen, salinity and total dissolved solids were recorded in situ using WTW 320i multiparameter water testing kit. Turbidity was measured by Eutech (TN-100) turbidity meter. Chlorophyll *a* and Biochemical Oxygen Demand (BOD) were analyzed following APHA (2005).

Data analysis

The zooplankton data collected every month were grouped into three seasons viz. Pre-monsoon (PRM) (February to May), Monsoon (MON) (August to September) and Pos-tmonsoon (POM) (October to January) for analysis (Srinath *et al*., 2003). Season wise diversity indices *viz.* species richness (Margalef 'd'), Pielou's evenness J, Shannon 'H' and Simpson 1-Λ were estimated. To ensure normality of means and homogeneity of variances the data were transformed to square roots. The data were then converted to a lower triangular similarity matrix using Bray and Curtis (1975) coefficients. These similarity matrices were then subjected to the clustering technique. Clustering was performed following the group average method (Pielou, 1984). Funnel plots were prepared for studying taxonomic distinctness (Clarke and Warwick, 2001). All diversity analysis was carried out using PRIMER version-7 software. Diversity indices were subjected to two-way ANOVA using IBM SPSS 25 Statistical Analysis software.

Results

Physico-chemical parameters

Sampling stations off Mumbai recorded, sea surface temperatures ranging from 25.0 to 31.80 ($\pm$ 1.86) °C showing low temperatures in monsoon and post-monsoon seasons and highest in the pre-monsoon season, pH ranged from 7.34 to 8.33 ($\pm$ 0.25), salinity ranged from 29.20 to 30.60 ($\pm$ 1.55) ppt with lowest in monsoon season compared to other two seasons. Dissolved oxygen was in the range of 3.98 to 6.10 ($\pm$ 0.56) mg/l. Chlorophyll *a* concentration ranged from 1.35 to 5.37($\pm$ 0.91) mg C/m^3. Total dissolved solids ranged from 5.98 to 48.80($\pm$ 11.49) mg/l. Values of turbidity were high in the monsoon season and ranged from 1.08 to 18.70 ($\pm$ 4.09) NTU. The range of BOD values was between 0.30 and 3.00 ($\pm$ 0.71) mg/l.

In the case of Ratnagiri stations, sea surface temperatures ranged between 26.0 and 32.50 ($\pm$ 1.68) °C with low temperatures in monsoon and post-monsoon seasons, pH ranged between 7.42 and 8.45 ($\pm$ 0.20). Salinity showed a similar trend as observed in Mumbai which ranged between 29.30 and 36.20 ($\pm$ 1.62) ppt. Dissolved oxygen was in the range of 3.88 and 6.40 ($\pm$ 0.60) mg/l. Chlorophyll *a* concentration ranged between 1.90 and 6.0 ($\pm$ 0.91) mg C/m^3. Total dissolved solids ranged between 3.89 to 49.70 ($\pm$ 8.91) mg/l. Turbidity followed a similar pattern as that of Mumbai stations but the values were low in comparison to Mumbai, which ranged between 0.33 and 8.03 ($\pm$ 1.81) NTU. The BOD values were low in comparison to Mumbai stations and ranged from 0.22 and 1.96 ($\pm$ 0.46) mg/l.

Diversity of zooplankton

The zooplankton population density was studied at two stations each of Mumbai and Ratnagiri. In Mumbai, zooplankton density was lower at station II than at station I except in April. The peaks were observed in the months of January and October (Fig. 2). In the case of Ratnagiri, population density at station II remained higher than at station I in January, February, May and August. The peak densities were observed in the months of March and December (Fig. 3). Zooplankton collected from the Mumbai coast comprised 27 genera and 37 species with Copepods being the dominant group followed by *Hydrozoans*, *Chaetognaths* and *Lucifer* sp. (Fig. 4). Zooplankton collected from the Ratnagiri coast comprised 31 genera and 43 species with a similar pattern of dominant groups as that of Mumbai (Fig. 5). The species recorded in sampling stations of both regions are given in Table 1. Season wise and region wise Species Richness 'd', Shannon Weiner 'H' and Simpson (1-Λ') diversity indices are depicted in Fig. 6. The values of d, H and 1-Λ were higher in POM and PRM seasons than MON. Location-wise the

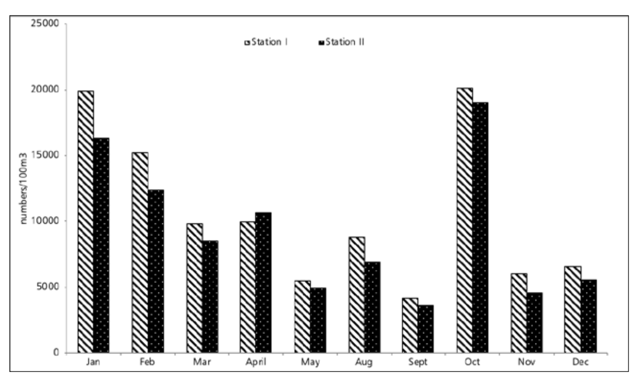

Fig. 2. Zooplankton population density (nos/100m^3) off Mumbai

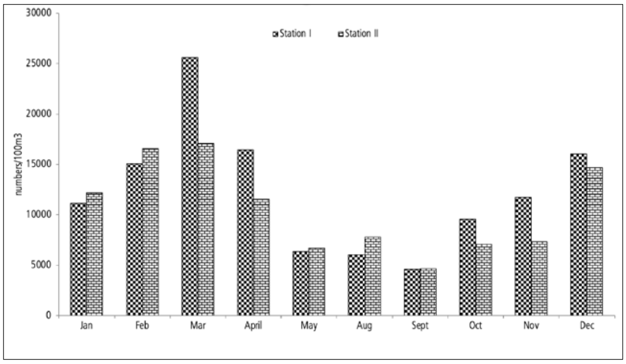

Fig. 3. Zooplankton population density (nos/$100m^3$) off Ratnagiri

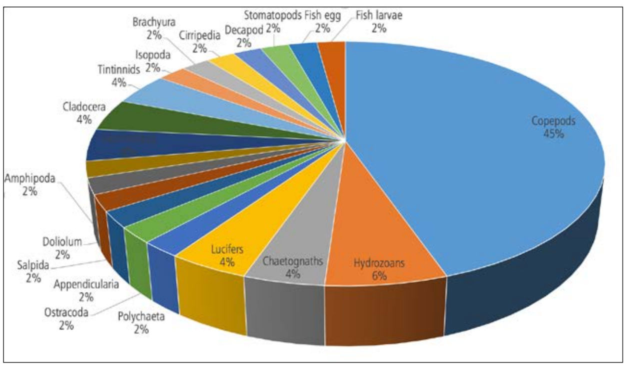

Fig. 4. Composition of zooplankton groups off Mumbai coast

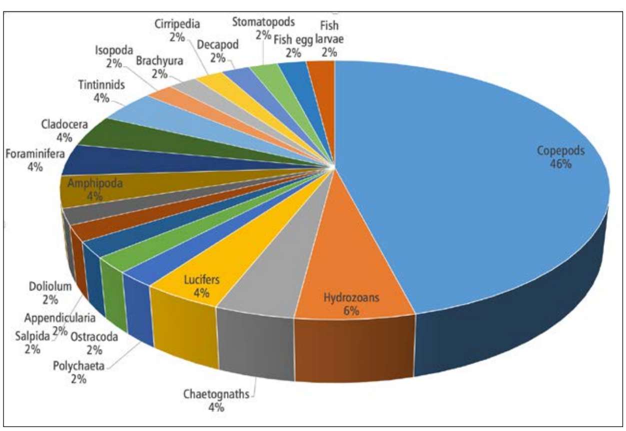

Fig. 5. Composition of zooplankton groups off Ratnagiri coast

values were higher for stations of Ratnagiri than of Mumbai. Two-way ANOVA revealed a significant difference ($P<0.05$) for values of 'd', 'H' and 1-Λ' between Mumbai and Ratnagiri locations. Post-Hoc Tukey test showed a significant difference ($P<0.05$) between the values during MON and POM, MON and PRM. However, no significant difference ($P>0.05$) was observed between the values during POM and PRM. Species evenness J' showed no significant difference ($P>0.05$) between Mumbai and Ratnagiri.

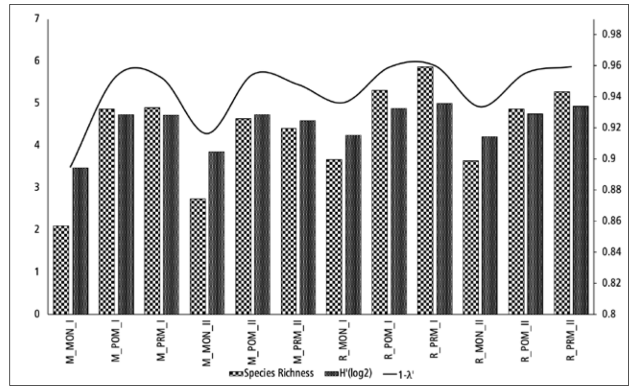

Fig. 6. Seasonal diversity of zooplankton off Mumbai (M) and Ratnagiri (R); I- Station I, II-Station II

The K-Dominance plot clearly shows the diversity pattern in the two 2 stations in 3 different seasons where percentage cumulative dominance values are plotted against log species rank. Due to less number of species observed during the MON season, the curve for Mumbai at stations I and II rapidly rises and lies above the curves of POM and PRM seasons. Whereas, due to the occurrence of a larger number of species with the dominance of many species, the curves representing PRM and POM seasons remain on the lower sides, extending further and slowly rising (Fig. 7). In the case of stations at Ratnagiri, a similar trend of the curve representing MON season has been observed for stations I and II (Fig. 8).

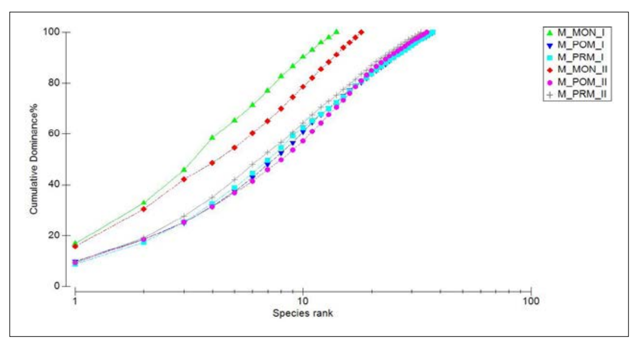

Fig. 7. Zooplankton species dominance plot of Mumbai, I- Station I, II-Station II

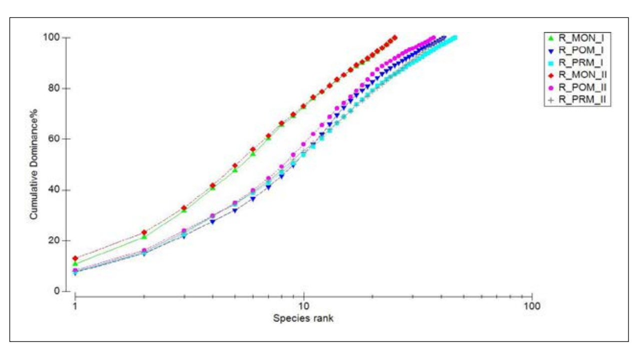

Fig. 8. Zooplankton species dominance plot of Ratnagiri. I- Station I, II-Station II

Table 1. List of species recorded off Mumbai and Ratnagiri

Groups	Species Name	MUM		RTN	
		ST1	ST2	ST1	ST2
Copepods	*Paracalanus aculeatus*	+	+	+	+
	Canthocalanus pauper	+	+	+	+
	Paracalanus parvus	+	+	+	+
	Acartia centrura	+	+	+	+
	Acartia spinicauda	+	+	+	+
	Acartia spp.	+	+	+	+
	Acrocalanus similis	+	+	+	+
	Acrocalanus spp.	+	+	+	+
	Tortanus barbatus	+	+	+	+
	Tortanus sp.	-	-	+	+
	Centropages furcatus	+	+	+	+
	Centropages orsinii	+	+	-	-
	Centropage stenuiremis	+	+	+	+
	Temora turbinata	+	+	+	+
	Temora sp.	-	-	-	+
	Eucalanus crassus	+	+	+	+
	E. subcrassus	+	+	+	+
	Euchaeta marina	+	+	+	+
	Euterpina spp.	+	+	+	+
	Microsetella sp.	+	+	+	+
	Oithona sp.	+	+	+	+
	Oncaea sp.	-	-	+	+
	Corycaeus sp.	+	+	+	+
Hydrozoans	*Lensia subtilis*	-	-	+	+
	Lensia subteloides	+	+	+	+
	Aequorea conica	+	+	+	-
Chaetognaths	*Sagitta enflata*	+	+	+	+
	Sagitta bedoti	+	+	+	+
Sergestids/ Lucifers	*Lucifer hanseni*	+	+	+	+
	Lucifer penicillifer	+	+	+	+
Polychaetes	*Pelagobia spp*	+	+	+	+
Ostracoda	*Cypridina dentata*	+	+	+	+
Appendicularia	*Oikopleura dioica*	+	+	+	+
Salpida	*Thalia democratica*	-	-	+	+
Doliolum	*Dolioletta gegenbauri*	+	+	+	+
Foraminifera	*Ammonia falsobeccarii*	+	+	+	+
	Ammoniia tepida	+	+	+	+
Amphipods	*Hyperia* sp.	+	+	+	+
	Gammarus sp.	-	-	+	+
Cladocerans	*Penilia avirostris*	+	+	+	+
	Evadne tergestina	-	-	+	+
Tintinnids	*Favella* sp.	+	+	+	+
	Tintinniopsis sp.	+	+	+	-
Isopods	*Sphaeroma* sp.	+	+	+	-
Brachyurans	*Crab zoea*	+	+	+	+
Cirripedia	*Cypris larvae*	+	+	+	+
Lobster	*Phyllosoma larvae*	-	-	-	+
Molluscans	*Bivalve*	+	-	+	+
	Gastropod	+	+	+	-
Chordata	*Fish egg*	+	+	+	+
	Fish larvae	+	+	+	+
Decapods	*Penaied larave*	+	+	+	+
Crustacea	*Zoea*	+	+	+	+
Stomatopods	*Alima larave*	+	+	+	-

+: Present,–: Absent

Cluster analysis showed a 35% similarity between diversity during MON and the other two seasons. In MON there is a 46% similarity in diversity between Mumbai and Ratnagiri at stations I and II. The diversity of PRM season at stations I and II is 65% similar to the diversity of POM of Mumbai and Ratnagiri (Fig. 9). The SIMPER analysis was done for the identification of species responsible for the dissimilarity between locations. The average dissimilarity between Mumbai and Ratnagiri locations is 44.77. About 62% of the dissimilarity was contributed by 15 species. The analysis showed that the major groups responsible for dissimilarity were copepods followed by Appendicularians, Chaetognathas and Cladocerans (Table 2).

Taxonomic distinctness index of zooplankton species assemblage (Δ^+ and Λ^+) were tested for departure from the simulated 95% confidence funnel. All stations fell within the

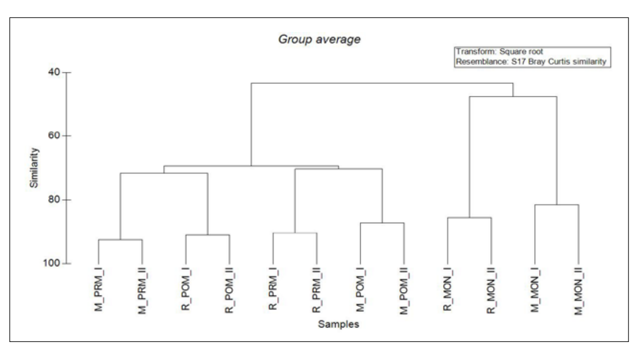

Fig. 9. Cluster analysis of zooplankton species assemblage at Mumbai and Ratnagiri in different seasons. I- Station I, II-Station II

Table 2. SIMPER analysis of dissimilarity between locations: Mumbai and Ratnagiri

Groups: Mumbai and Ratnagiri

Average dissimilarity = 44.77

Species	Group Mumbai Average abundance	Group Ratnagiri Average abundance	Average dissimilarity	Contribution (%)
Acartia spinicauda	86.78	124.14	2.92	6.52
Paracalanus parvus	85.34	76.81	2.51	5.61
Acrocalanus similis	100.19	76.78	2.5	5.59
Acrocalanus spp.	33.25	73.34	2.45	5.47
Acartiaspp	35.17	64.29	2.08	4.64
Tortanus barbatus	51.55	94.36	1.86	4.14
Eucalanus crassus	54.12	61.33	1.84	4.11
Oikopleura dioica	27.62	69.58	1.8	4.02
Centropages furcatus	50.05	28.28	1.72	3.83
Acartia centrura	40.5	16.61	1.58	3.53
Paracalanus aculeatus	48.55	50.22	1.55	3.46
Canthocalanus pauper	118.02	98.95	1.47	3.28
Centropage stenuiremis	12.44	42.17	1.34	3.00
Sagitta enflata	29.43	38.63	1.18	2.63
Penilia avirostris	6.91	33.65	1.11	2.47

95% confidence funnel (Fig. 10 and 12). Average Taxonomic distinctness (Δ^+) was the highest in POM at station II, while it was the lowest in PRM at station II in Mumbai. This shows that the taxonomic distance between species during POM was the highest at station II. The lowest value at station II during PRM suggests that there are more closely related species during PRM as compared to other seasons. Variation in Taxonomic Distinctness (Λ^+) ranged between 551.97 to 883.83 which suggests a diverse range of taxonomic distances between species of different seasons and stations. Therefore, the unevenness of taxonomic tree structure is the highest in MON at Station I and lowest in MON at station II off Mumbai. However, the Λ^+ during MON at station I falls out of the expected limits the value lies outside of the funnel plot (Fig. 11). In Ratnagiri, Average Taxonomic distinctness (Δ^+) was highest in POM at station I while it was lowest in PRM at station II. Variation in Taxonomic Distinctness (Λ^+) ranged between 479.93 to 608.36. The unevenness of taxonomic tree structure is highest at PRM season at station II and lowest in MON at station I of Ratnagiri (Fig.13).

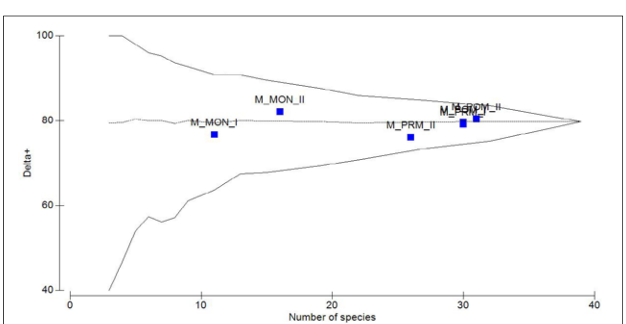

Fig. 10. Average Taxonomic Distinctness (Δ^+) of zooplankton diversity of Mumbai in different seasons and stations and its deviation from the normal distribution.I- Station I, II-Station II

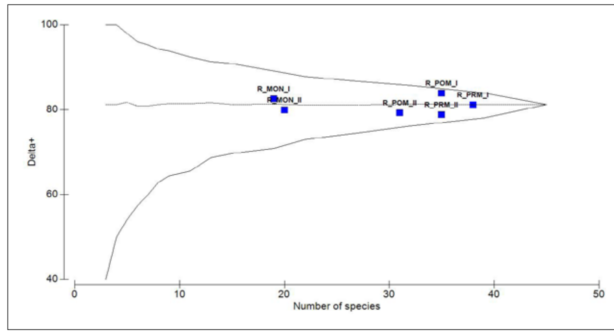

Fig. 11. Variation in Taxonomic Distinctness (Λ^+) of zooplankton diversity of Mumbai in different seasons. I- Station I, II-Station II

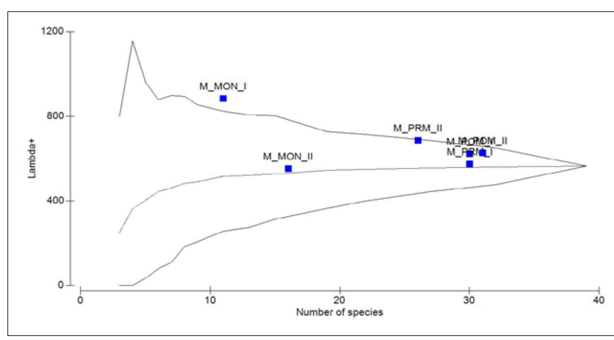

Fig. 12. Average Taxonomic Distinctness (Δ^+) of zooplankton diversity of Ratnagiri in different seasons and stations and its deviation from the normal distribution. I- Station I, II-Station II

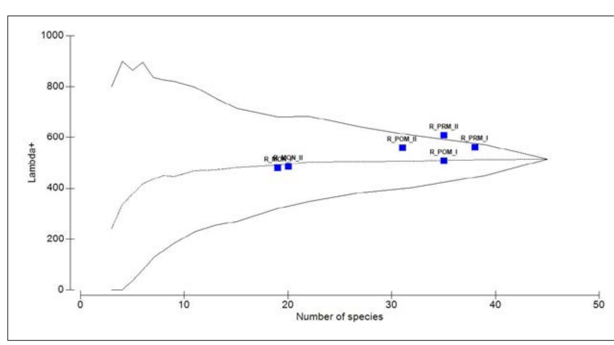

Fig. 13. Variation in Taxonomic Distinctness (Λ^+) of zooplankton diversity of Mumbai in different seasons. I- Station I, II-Station II

Discussion

In the present study, the zooplankton population density was at a peak in the month of January and October in Mumbai, while in the case of Ratnagiri the peak was observed in the month of March and December. Generally, in coastal waters of India zooplankton distribution is bimodal with two peaks during the post-monsoon and pre-monsoon (Nair, 1977). In the nearshore waters of Karwar, zooplankton biomass showed a major peak in October / December and a second peak in February (Nair, 1978) while the nearshore waters of Thal and Mumbai showed a peak from October to December (Nair *et al.*, 1983). Joseph (2003) observed zooplankton peaks in nearshore waters of Mumbai during October. The findings of the present study are in line with the study conducted by Nair (1978), Nair *et al.* (1983) and Joseph (2003).

Coastal waters on the west coast of India are influenced by the seasonal variation of the south-west monsoon during which fresh water influx from rivers and estuaries lowers the salinity (Nair, 2001). Salinity is attributed as an important factor regulating the distribution of copepod species in nearshore areas (Lindo, 1991; Mallin, 1991; Kouwenberg, 1994, Huang and Zheng, 1987). Diversity indices (H and 1-Λ') were low at Mumbai and Ratnagiri during MON than in POM and PRM seasons which may be due to decreased salinity during monsoon. Values of salinity in the present study were low during monsoon which may have impacted the diversity indices (H and 1-Λ') at both locations, of Mumbai and Ratnagiri than in post-monsoon and pre-monsoon seasons. Dominance plots of Mumbai and Ratnagiri showed less species dominance during the monsoon season than other seasons which signifies the impact of seasons on zooplankton diversity and abundance. Cluster analysis also supported the above finding by showing very less similarity (35%) between diversity during monsoon and the other two seasons for both locations. The Seasonal environmental variations would have influenced the zooplankton diversity and abundance in the present study. However, the effect of pollutants and sewage / anthropogenic inputs on zooplankton diversity cannot be ignored. Zingde (1999) discussed the indiscriminate release of liquid and solid wastes containing sewage as a major contaminant, which degrades the ecology of inshore as well as offshore marine areas resulting in fluctuations in chlorophyll a and zooplankton standing stock. Dhage *et al.* (2006) observed high BOD values and adverse impact of sewage dispersal due to diffusers in coastal regions of Mumbai. Increased population and industrialization resulted in stress on coastal waters of the Mumbai region causing increased nutrients due to domestic and industrial sewage drains and outfall points (Shirodkar *et al.*, 2012). The west coast of Mumbai receives partially treated sewage from wastewater treatment facilities through ocean outfalls, discharges from creeks and various open drains and *nallahs* (Vijay *et al.*, 2010a, b). The presence of organic matter in the coastal waters of Mumbai is due to sewage disposal (Vijay *et al.*, 2015). In the present study, high BOD values in Mumbai region than in Ratnagiri indicates high organic/sewage loads in the coastal waters of Mumbai. Zooplankton composition in Mumbai showed less species richness than in Ratnagiri. Diversity indices were also low in Mumbai in comparison to Ratnagiri. The two-way ANOVA showed a significant difference ($P<0.05$) between Mumbai and Ratnagiri for Species Richness (d') and Diversity indices (H', 1-Λ'). SIMPER analysis of the diversity of locations showed average dissimilarity of 44.77 between Mumbai and Ratnagiri. Major zooplankton groups responsible for dissimilarity were Copepods, Appendicualrians, Chaetognaths and Cladocerans contributing about 62% of dissimilarity between Mumbai and Ratnagiri.

The study provides an overview of the changes in zooplankton abundance in the coastal waters of Maharashtra. Strong spatial and seasonal changes were observed in the zooplankton abundance. From the study, it is observed that environmental parameters are one of the factors that influence the changes in zooplankton abundance. Zooplankton are bioindicators of ecosystem functioning and future research needs to focus on finding the indicator species of zooplankton groups for biological monitoring and assessment.

Acknowledgements

The authors are thankful to Dr. A. Gopalakrishnan, Director, Central Marine Fisheries Research Institute, Kochi and Dr V.V. Singh, Scientist-in-Charge, Mumbai RS of CMFRI for providing facilities to conduct the research. Thanks are also due to the Department of Biosciences, Mangalore University for permitting the research work for Doctoral studies. Special thanks to the CMFRI staff who participated on board and crew members of the fishing boats for assistance in sampling.

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