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International Journal for Modern Trends in Science and Technology, 7(09): 60-70, 2021

ISSN: 2455-3778 online
DOI: https://doi.org/10.46501/IJMTST0709011
Available online at: http://www.ijmtst.com/vol7issue09.html

Seasonal Composition and Diversity of Zooplankton in Pichavaram Mangrove Forest, Southeast Coast of India

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To Cite this Article
M. Saravanakumar, P. Murugesan, P. Damotharan and R. Punniyamoorthy. Seasonal Composition and Diversity of Zooplankton in Pichavaram Mangrove Forest, Southeast Coast of India *International Journal for Modern Trends in Science and Technology* 2021, *7* pp. 60-70. https://doi.org/10.46501/IJMTST0709011

Article Info
Received: 08 August 2021; Accepted: 07 September 2021; Published: 11 September 2021

ABSTRACT

In the present study, the zooplankton diversity and distribution was studied in relation to seasonal variation of environmental parameters in the Pichavaram mangrove forest. Samples were seasonally collected (i.e., post-monsoon: January-2018 and monsoon: December-2018) from seven stations. A total of 48 zooplankton species belonging to two groups macro-zooplankton and micro-zooplankton were recorded during this study. A total of 48 species of zooplankton belonging to different groups were identified. Copepod was found to be the most dominant group and it contributed more than 50% of the total zooplankton collected in this study. The maximum number of zooplankton species (35) and diversity value (H') 3.867 was recorded in the stations near coastal zone (P-7) during summer and minimum species number (24) and maximum species richness (d) 7.652 was recorded in stations near to freshwater zone (P-2) during monsoon. The species evenness (J') 0.866 was also recorded maximum at stations near river mouth (P-7). BIO-ENV (Biota-Environmental matching) and CCA results confirmed that the environmental parameters such as Temperature, Salinity, Dissolved Oxygen, Silicate, Chlorophyll, Primary Productivity, Total Biomass and Phaeopigments as the most influencing environmental parameters, which regulates zooplankton assemblage. The results of present study help to develop an understanding on the zooplankton distribution in mangrove forests, which will form a reliable tool in bio-monitoring studies.

KEYWORDS: Zooplankton, Density, Diversity, Distribution, Pichavaram, Mangroves.

1.INTRODUCTION

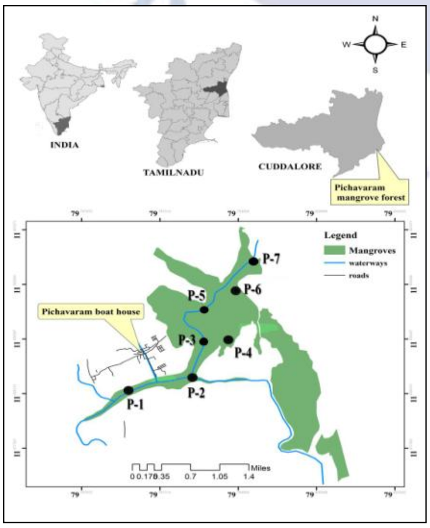
Zooplankton constitutes a diverse assemblage of microscopic organisms that occupy a crucial intermediate position in the food webs of freshwater, estuarine, and marine ecosystems. In transferring energy from primary producers (photosynthetic protists, bacteria, and single-celled plants) to macroscopic invertebrates and fishes, zooplankton has the capacity to shape the dynamics of entire ecosystems. Zooplankton is one of the four selected bio-indicators (benthic diatom, zooplankton, littoral macro-invertebrate, and benthic macro-invertebrate), used for assessment in ecological health monitoring [1]. They serve as a good indicator of changes in water quality because it is strongly affected by the environment quality [2-4]. The relationship between phytoplankton and higher trophic levels is not straightforward, as zooplankton is the main energy pathway from phytoplankton to fish [5-7]. Zooplankton floats in the water and cannot progress against currents and it is represented by all marine phyla, either permanently as holoplankton (e.g., copepods) or temporarily as meroplankton (e.g., fish larvae). Zooplankton is also critical in the transfer of energy between pelagic and benthic systems [8], and for carbon export from surface waters to the deep ocean [9]. The rate of zooplankton production can be used as a tool to estimate the exploitation of fish stocks of an area [10].

Studies on estuarine zooplankton population have been made extensively by various researchers from both east and west coast of India [11-18]. However, an understanding and interpretation of zooplankton diversity in mangrove ecosystem in relation to environmental variables (using univariate and multivariate indices) is still scanty and consequently such studies are warranted. Based on the above facts, the present study was undertaken to study the seasonal variation in species composition, diversity and distribution of zooplankton from various zones in Pichavaram mangrove forest, Tamil Nadu, southeast coast of India.

2.MATERIALS AND METHODS

Study area

The present study was carried out in the tidal zone of Pichavaram mangrove forest (latitude 11°20' to 11°30' north and longitudes 79°45' to 79°55' east), This mangrove forest attracts large number of tourists The Pichavaram mangrove wetland has 51 islets and the total area of the Vellar-Pichavaram-Coleroon estuarine complex is 2335.5 ha. Fishing villages, croplands and aquaculture ponds surrounds the Pichavaram area. Seven sampling stations were fixed for this study and the details of stations are shown below (Fig. 1).



Station Code	Latitude	Longitude
P-1	11°25'43.00"N	79°46'33.06"E
P-2	11°25'53.05"N	79°47'12.00"E
P-3	11°25'52.04"N	79°47'39.01"E
P-4	11°26'19.00"N	79°47'20.03"E
P-5	11°26'55.04"N	79°47'25.06"E
P-6	11°26'56.04"N	79°47'42.09"E
P-7	11°27'27.90"N	79°47'55.10"E

Fig. 1. Map showing the sampling stations in Pichavaram mangrove Forest

Geological information

Pitchavaram mangrove is influenced by mixing of three types of waters; (1) neritic water from the adjacent Bay of Bengal through a mouth called Chinnavaikal, (2) brackish water from the Vellar and Coleroon estuaries and (3) freshwater from an irrigation channel (Khan Sahib canal), as well from the main channel of the Coleroon River. The mangrove covers an area of about 1100 ha, of which 50% is covered by forest, 40% by waterways and the remaining filled by sand-flats and mud flats [19. The tides are semi-diurnal and vary in amplitude from about 15 to 100 cm in different regions during different seasons, reaching a maximum during monsoon and post-monsoon and minimum during summer [20]. The rise and fall of the tidal waters is through a direct connection with the sea at the Chinnavaikal mouth and also through the two adjacent estuaries. The depth of waterways ranges from about 0.3 to 3 m [20].

Water quality analysis

The physico-chemical parameters such as Temperature (Hand held thermometer), Salinity (Hand Refractometer - ATAGO Japan) and pH (pH pen- LI-120 Eutech Instrument Singapore) were recorded *in situ* by using the standard instruments and DO was estimated using Winkler's method as described by [21]. The water samples were collected in 1L polypropylene bottles by using a Niskin water sampler and Total Nitrogen (TN), Total Phosphorus (TP), Silicate (SiO_3) were analysed by following the method described by [22]. Chlorophyll-*a* (Chl-*a*) and Phaeopigments were analyzed by spectrophotometric method by following [23-24]. Total Suspended Solids (TSS) was determined by filtration and gravimetric technique [25]. The samples were analyzed in triplicates for physicochemical parameters and data quality was ensured through careful standardization and procedural blank measurements.

Sample collection and preservation

Zooplankton samples were collected from the above selected seven stations during January 2018 - December 2018 at morning low tide (6:30 -10:00am) to catalogue the zooplankton species variety and to determine the predominant environmental parameters, which influences the distribution of zooplankton in Pichavaram mangrove Forest. Zooplankton samples were collected using a zooplankton net of 70μm mesh size. A flow meter (HydroBios) was used to determine the volume of water filtered. The collected zooplankton samples were transferred to polypropylene bottles, labeled detective of time, date and sampling sites and were then preserved in 5% formalin.

Identification

Subsequently, the organisms were stored, counted and identified up to group level using stereomicroscope (KL-300LED Carl Zeiss) up to lowest possible taxonomic level by consulting the following standard works [26-33].

Data analysis

The data on environmental variables and biological variables were subjected to simple correlation and they were also treated with multivariate methods namely CCA (Canonical Correspondence Analysis) and BIO-ENV (Biota-Environment matching) by using PRIMER-7 (Plymouth Routines In Multivariate Ecological Research) statistical package [34].

3.RESULTS

Water quality analysis

The mean and standard deviation (SD) of physico-chemical parameters of water and sediment samples are summarized in Table. 1. Water Depth range varied from 1.0 ± 0.18 to 3.5 ± 0.40 (m) with minimum at P-1 during summer and maximum at P-7 during pre-monsoon; Water temperature varied from 26.85 ± 0.59 to 30.66 ± 1.18 (°C) with minimum at P-1 during monsoon and maximum at P-7 during summer; water pH showed minimum of 7.74 ± 0.36 at P-1 during monsoon and maximum of 8.34 ± 0.26 at P-7 during summer; salinity showed a wide range of fluctuation with minimum (10.55 ± 0.94 ppt) at P-1 during monsoon and maximum (34.57 ± 1.44 ppt) at P-7 during summer. Dissolved oxygen ranged between 5.39 ± 0.28 mg/l at P-1 during monsoon and 3.65 ± 0.93 mg/l at P-5 during summer. The TSS ranged between 84.15 ± 0.95 ppm at P-7 during post-monsoon and 126.15 ± 1.83 ppm at P-4 during monsoon. Total Nitrogen varied between 4.19 ± 0.47 at P-4 during summer and 5.53 ± 0.92 at P-2 during monsoon. Total Phosphate content ranged from 1.29 ± 0.16 to 2.09 ± 0.15 µmol/l and the maximum was recorded at P-1 during monsoon and minimum at P-5 during summer. Silicates content varied from 65.15 ± 1.35 to 81.23 ± 1.08 µmol/l and the minimum at P-2 during monsoon and maximum at P-7 during summer. Chlorophyll-*a* varied from 1.953 ± 0.17 to 2.738 ± 0.37 mg/m^3 with the minimum value was recorded at P-3 during summer and the maximum at P-6 during monsoon. Phaeopigments content ranged from 2.109 ± 0.36 (P-3 during summer) to 4.189 ± 0.48 mg/m^3 (P-6 during monsoon). Total biomass varied from 2.155 ± 0.17 to 4.106 ± 0.33 $ml/100m^3$ with the minimum value was recorded at P-3 during summer and maximum at P-6 during monsoon. Primary Productivity content ranged from 117.48 ± 1.64 (P-3 during summer) to 162.14 ± 1.47 $mgCm^{-3}d$-1 (P-3 during monsoon).

Table 1. Physico-chemical characteristics (mean and SD) recorded in various sampling stations of the Pichavaram mangrove Forest

Variables	P-1	P-2	P-3	P-4	P-5	P-6	P-7
Depth (m)	1.0 ± 0.18	1.3 ± 0.21	1.5 ± 0.24	1.9 ± 0.16	2.2 ± 0.27	2.4 ± 0.31	3.0 ± 0.40
Temp. (°C)	26.85 ± 0.59	27.1 ± 0.63	27.64 ± 0.72	28.45 ± 0.95	29.11 ± 1.04	29.63 ± 0.85	30.66 ± 1.18
pH	7.74 ± 0.36	7.83 ± 0.22	7.86 ± 0.44	7.83 ± 0.50	8.05 ± 0.62	8.17 ± 0.37	8.34 ± 0.26
Salinity (ppt)	10.55 ± 0.94	15.36 ± 1.31	18.44 ± 1.59	20.91 ± 1.68	19.59 ± 1.05	30.32 ± 1.15	34.57 ± 1.44
DO (mg/l)	5.39 ± 0.28	4.64 ± 0.19	3.85 ± 0.62	4.33 ± 0.45	3.65 ± 0.93	4.21 ± 0.71	4.26 ± 0.38
TSS (ppm)	99.47 ± 1.07	105.21 ± 1.87	110.48 ± 1.95	126.15 ± 1.83	124.39 ±1.05	118.07 ± 2.14	84.15 ± 0.95
TN (µmol/l)	4.82 ± 0.68	5.53 ± 0.92	4.26 ± 0.75	4.19 ± 0.47	4.35 ± 0.60	5.02 ± 0.31	4.36 ± 0.30
TP (µmol/l)	2.09 ± 0.15	1.46 ± 0.18	1.58 ± 0.10	1.65 ± 0.11	1.29 ± 0.16	1.47 ± 0.12	1.54 ± 0.16
Silicate (µmol/l)	69.62 ± 1.07	65.15 ± 1.35	69.23 ± 1.16	78.34 ± 0.92	74.9 ± 1.15	80.21 ± 1.61	81.23 ± 1.08
Chl-*a* (mg/m^3)	2.185 ± 0.15	2.472 ± 0.31	1.953 ± 0.18	2.071 ± 0.22	1.953 ± 0.16	2.738 ± 0.37	1.927 ± 0.16
TB ($ml/100m^3$)	2.845 ± 0.19	2.715 ± 0.20	2.155 ± 0.17	2.963 ± 0.21	3.187 ± 0.25	4.106 ± 0.33	2.634 ± 0.50
Phaeopigments (mg/m^3)	2.531 ± 0.38	2.631 ± 0.57	2.109 ± 0.36	2.748 ± 0.19	2.445 ± 0.28	4.189 ± 0.48	3.853 ± 0.22
PP ($mgCm^{-3}d$-1)	124.35 ± 1.37	137.16 ± 2.19	117.48 ± 1.64	157.36 ± 1.83	144.06 ± 2.15	162.14 ± 1.47	135.73 ± 1.87

(**Footnote: Temp** –Temperature; **DO** – Dissolved Oxygen; **TSS** – Total Suspended Solids; **Chl-*a*** – Chlorophyll-*a*; **PP** – Primary Productivity; **TB** – Total Biomass; **TN** – Total Nitrogen; **TP** – Total Phosphate; **SiO_3** – Silicate**)**

Biological characteristics

Zooplankton

During the survey, 7 groups of macro zooplankton namely, Calanoid copepod, Cyclopoid copepod, Harpacticoid copepod, Hydroidomedusae, Ciliata, Foraminifera, Other Crustacean forms and 7 groups of micro zooplankton namely, Mollusca, Cladocera, Decapoda, Pteropoda, Chaetognatha, Rotatoria and Annelida were recorded. Among the above macro zooplankton groups, Calanoid copepod was found to be the most dominant group with 11 species. The Ciliata was found to be the second dominant group with 6 species. Cyclopoid copepod and Harpacticoid copepod were found as next dominant groups with 5 species each and Hydroidomedusae with 4 species. Foraminifera, Chaetognatha and 'Other Crustacean forms' came next in the order with 3 species each; Mollusca and Rotatoria with 2 species each. Decapoda, Pteropoda, Cladocera, Annelida with 1 species each.

The common Calanoid copepod, Cyclopoid copepod, Harpacticoid copepod, Hydroidomedusae, Ciliata, Foraminifera and Other Crustacean species are; *Eutintinnus tennuis, Rhabdonella lohmani, Obelia* sp., *Phialella quadrata, Globigernia bulloides, Acartia erythraea, Acrocalanus gibber, A. gracilis, Centropages furcatus, Nannocalanus minor, Paracalanus parvus, Pseudodiaptomus serricaudatus, Temora turbinate, Clytmnestra scutellata, Euterpina acutifrons, Longipedia* sp., *Macrosetella* sp., *Corycaeus danae, Corycaeus catus, Oithona rigida, O. similis, Oncaea venusta, Barnacle nauplii, Crustacean nauplii* and Copepod nauplii. Mollusca, Cladocera, Decapoda, Pteropoda, Chaetognatha, Rotatoria and Annelida species such as *Favella brevis, Favella philipiensis, Tintinnopsis tocantinensis, T. tubulosa, Polychaete larvae, Daphina* sp., *Lucifer hanseni, Bivalve veliger, Gastropod veliger, Sagitta* sp., *S. bipunctata, S. enflata S. bipunctata* and *S. enflata* showed consistency in their occurrence in the samples collected in various stations. The list of zooplankton recorded in the study area during January 2018 – December 2018 is presented in Table 2.

Table 2. Zooplankton recorded in various stations of Pichavaram mangrove forest

S. No.	Zooplankton	P-1	P-2	P-3	P-4	P-5	P-6	P-7
	Ciliata							
1	*Eutintinnus tennuis*	+	+	+	+	+	+	+
2	*Favella brevis*	-	+	+	+	+	-	-
3	*Rhabdonella lohmani*	-	+	-	+	+	-	-
4	*Tintinnopsis* sp.	+	-	+	-	-	+	+
5	*Tintinnopsis tocantinensis*	+	+	+	+	+	+	+
6	*Tintinnopsis butzschi*	+	+	-	-	+	+	+
	Foraminifera							
7	*Globigernia* sp.	-	+	-	+	+	+	+
8	*Globigerina bulloides*	+	-	+	+	+	+	+
9	*Globorotalia opima*	+	+	+	+	+	+	+
	Hydroidomedusae							
10	*Obelia* sp.	+	+	-	+	-	+	+
11	*Cladonema* sp.	-	+	+	+	+	-	-
12	*Podocoryne* sp.	-	+	-	+	-	-	-
13	*Phialella quadrata*	+	-	+	+	-	+	+
	Annelida							
14	Polychaete larvae	+	+	+	+	+	+	+
	Calanoid copepod							
15	*Acartia danae*	-	+	+	+	+	+	+
16	*Acartia erythraea*	+	+	+	+	+	+	+
17	*Acartia spinicauda*	+	-	+	+	+	+	+
18	*Acrocalanus gibber*	-	+	+	+	+	+	-
19	*Acrocalanus gracilis*	+	+	+	-	+	-	+

20	*Centropages furcatus*	-	+	+	+	+	+	+
21	*Labidocera* sp.	-	+	+	+	-	+	+
22	*Nannocalanus minor*	-	-	-	+	+	+	+
23	*Paracalanus parvus*	+	+	-	-	-	-	+
24	*Pseudodiaptomus serricaudatus*	-	+	+	+	-	+	+
25	*Temora turbinata*	+	+	+	+	+	-	+
	Harpacticoid copepod							
26	*Clytemnestra scutellata*	-	+	+	+	+	+	+
27	*Euterpina acutifrons*	+	+	+	+	+	+	+
28	*Longipedia* sp.	+	+	+	+	+	+	+
29	*Macrosetella* sp.	+	-	+	-	-	-	+
30	*Microsetella* sp.	+	+	+	+	+	+	+
	Cyclopoid copepod							
31	*Corycaeus crassiusculus*	+	+	-	+	-	+	+
32	*Corycaeus catus*	+	+	-	+	-	+	+
33	*Oithona rigida*	-	-	+	-	+	+	-
34	*Oithona similis*	-	-	+	+	+	-	+
35	*Oncaea venusta*	+	-	+	+	+	+	-
	Cladocera							
36	*Daphina* sp.	+	+	+	+	+	+	+
	Decapoda							
37	*Belzebub hanseni*	+	+	+	+	+	+	+
	Other Crustacean forms							
38	Barnacle nauplii	+	+	-	+	+	-	-
39	Crustacean nauplii	+	-	+	-	+	+	+
40	Copepod nauplii	-	+	-	-	+	+	+
	Mollusca							
41	Bivalve veliger	+	+	-	-	-	-	+
42	Gastropod veliger	-	+	+	+	+	+	+
	Pteropoda							
43	*Cresis* sp.	-	-	+	-	-	+	+
	Chaetognatha							
44	*Sagitta* sp.	+	+	-	+	+	+	+
45	*Sagitta bipunctata*	-	-	+	-	-	+	-
46	*Sagitta enflata*	-	+	-	+	+	-	+
	Rotatoria							
47	*Brachionus* sp.	+	+	+	+	+	+	+
48	*Brachionus calyciflorus*	+	-	+	-	-	+	-

+: Present; - : Absent

Population density

The maximum abundance was at station P-7 (~3.0 m) with 5954 Nos/m^3 during summer and the minimum at P-1 (~1.0 m) with 4546 Nos/m^3 during monsoon. During the present study, seasonally, the maximum number (35 species) of zooplankton species was recorded during summer at stations near coastal waters and minimum (24 species) was recorded during monsoon at stations near freshwater zone.

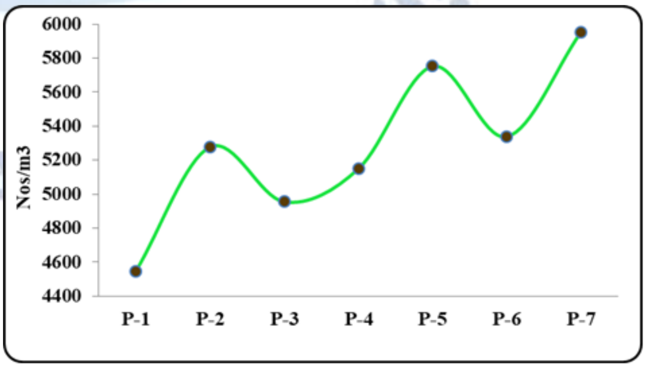


Fig. 2. Population density of zooplankton recorded in various stations of Pichavaram mangrove forest

Percentage contribution

Among the various taxa, Calanoid copepod emerged as the dominant group by constituting 21% and followed by Harpacticoid copepod with 13%, Ciliata with 12%, Cyclopoid copepod and Hydroidomedusae with 9% each and Foraminifera with 8%, Chaetognatha and Other Crustacean forms with 5% each and Rotatoria with 4%, Mollusca, Annelida, Decapoda and Cladocera with 2% each and Pteropoda with 2% of the total percentage composition (Fig. 3).

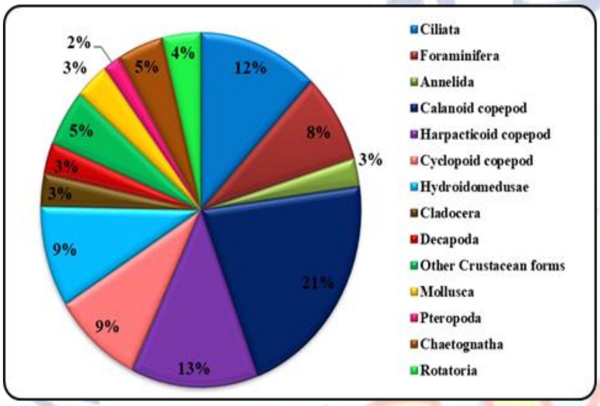


Fig. 3. Percentage contribution of zooplankton (order-wise) recorded in various stations of Pichavaram mangrove forest

Diversity indices

The Shannon diversity (H') values calculated for zooplankton abundance showed minimum (2.732) at P-1 during monsoon and maximum (3.867) at P-7 during post-monsoon season; Margalef species richness (d) showed minimum (5.383) at P-6 during pre-monsoon and maximum (7.652) at P-2 in summer; Pielou's species evenness (J') varied between 0.525 and 0.866 with maximum at P-7 during summer and minimum at P-1 during monsoon and Simpson dominance varied from 0.519 to 0.817 with maximum at P-1 during monsoon and minimum at P-6 in summer (Fig. 3).

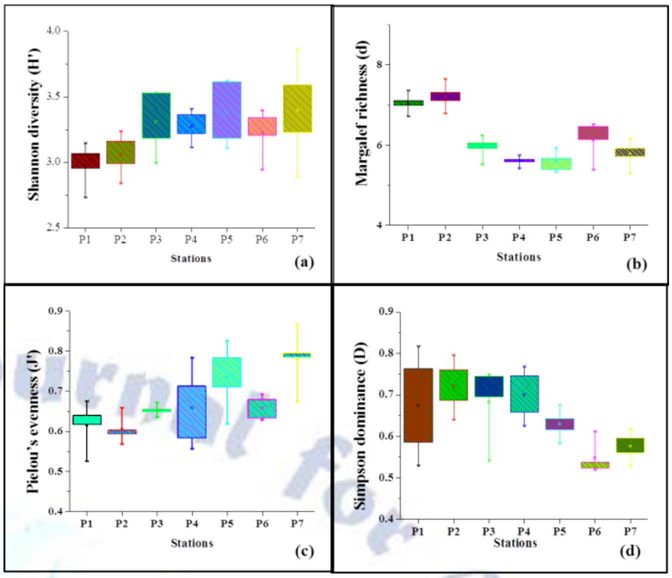


Fig. 3. Diversity indices a-Shannon diversity (H'); b-Margalef richness (d) c- Pielou's evenness (J') and d-Simpson Dominance (D) calculated for the zooplankton species abundance recorded in various stations of Pichavaram mangrove forest

Cluster/MDS Analysis

Further, to study the similarity/dissimilarity between stations, zooplankton abundance of seven different stations was approached to cluster analysis and MDS (non-metric Multi-Dimensional Scaling) ordination (Fig. 4 & 5). The dendrogram showed that the stations close to coastal zone P-5, P-6 and P-7 formed separate cluster with similarity percentage of 82% and similarly the stations in tidal zone P-4, P-3 and P-2 clustered together separately with 78% similarity. The station near freshwater zone P-1 formed as outlier with 74% similarity. The MDS plot also confirmed the groupings observed in the cluster analysis. The stress value, which is overlying on the top-right corner of the MDS plot is also very minimal (0.01), signaling a good ordination pattern of zooplankton abundance.

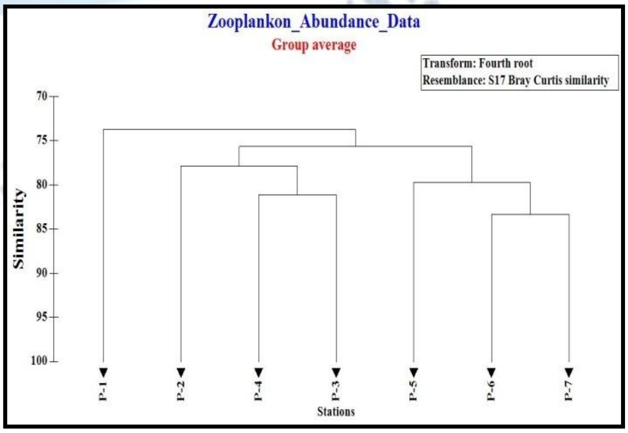


Fig. 4. Dendrogram for the zooplankton abundance recorded in various stations of Pichavaram mangrove forest

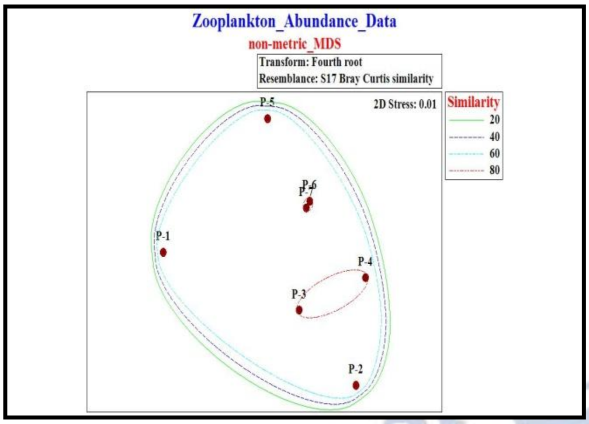


Fig. 5. MDS drawn for the zooplankton abundance recorded in various stations of Pichavaram Mangrove Forest

Canonical Correspondence Analysis (CCA)

Canonical Correspondence Analysis plot was drawn to study the relationship between the environmental variables and zooplankton species composition. The environmental parameters such as temperature, salinity, W. pH, DO, silicate, Chl-*a*, Primary Productivity, Total biomass and Phaeopigments in stations near coastal waters (P-4, P-5, P-6 and P-7) had positive correlation with zooplankton species like *Eutintinnus tennuis* (Eute), *Favella brevis* (Fabr), *Globigerina bulloides* (Glbu), *Polychaete larvae* (Pola), *Acartia danae* (Acda), *Acrocalanus gibber* (Acgi), *Centropages furcatus* (Cefu), *Nannocalanus minor* (Nami), *Paracalanus parvus* (Papa), *Temora turbinata* (Tetu), *Corycaeus catus* (Cori), *Bivalve veliger* (Bive), *Gastropod veliger* (Gave), *Flaccisagitta enflata* (Flen) and *Brachionus calyciflorus* (Brca) whereas other environmental parameters in stations near freshwater zone (P-1, P-2 and P-3) and zooplankton species were negatively correlated.

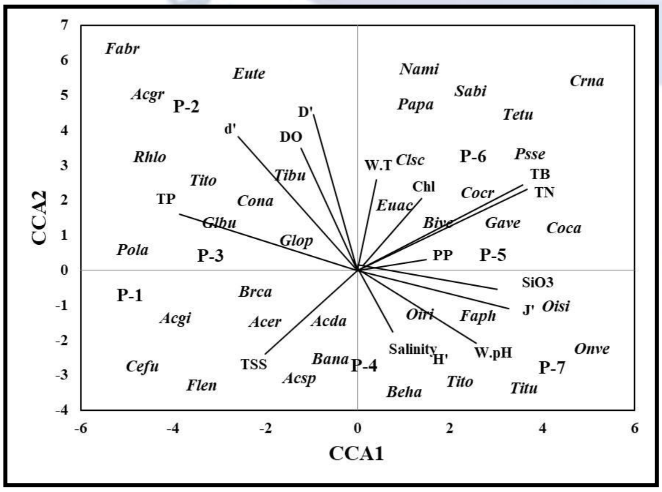


Fig. 9. CCA showing correlation between zooplankton species composition and environmental variables in various stations of Pichavaram Mangrove Forest

BIO-ENV (Biota-Environment matching)

BIO-ENV procedure was employed to measure the agreement between the rank correlations of the biological (Bray-Curtis similarity) and environmental (Euclidean distance) matrices, twelve environmental variables (Temperature, pH, Salinity, DO, Total Suspended Solids, Total Nitrogen, Total Phosphate, Silicate, Chlorophyll-a, Primary Productivity, Total Biomass and Phaeopigments) were allowed to match the biota. Among the above parameters, a combination of eight environmental parameters namely Temperature, Salinity, Dissolved Oxygen, Silicate, Chlorophyll, Primary Productivity, Total Biomass and Phaeopigments got manifested as best match (pω = 0.972) in determination of zooplankton distribution. Water pH, Salinity, Dissolved Oxygen, Total Nitrogen, Chlorophyll, Primary Productivity and Phaeopigments formed the next best (pω = 0.946) combination of environmental parameters (Table 3).

Table 3. Harmonic rank correlations (ρω) between zooplankton abundance and environmental similarity matrices in various stations of Pichavaram mangrove forest

No. of variables	Best variable combinations	Correlation (ρω)
8	Temperature – Salinity – Dissolved Oxygen – Silicate – Chlorophyll – Primary Productivity – Total Biomass – Phaeopigments	0.972
7	Water pH – Salinity – Dissolved Oxygen – Total Nitrogen – Chlorophyll – Primary Productivity – Phaeopigments	0.946
6	Water pH – Salinity – Dissolved Oxygen – Total Nitrogen – Total Phosphate – Chlorophyll	0.910
5	Dissolved Oxygen – Chlorophyll – Water pH – Salinity – Silicate	0.865
5	Silicate – Temperature – Salinity – Chlorophyll – Primary Productivity	0.819

4.DISCUSSION

Variations in the physicochemical properties of water bring about changes in the composition and abundance of aquatic organisms. Different environmental factors play important roles in the development and abundance of zooplankton [35]. The distribution of planktonic organisms are found across a wide range of environmental conditions, yet the presence of some species is limited by factors such as dissolved oxygen, pH, temperature, salinity, or other physical and chemical properties [36-39]. The high rate of zooplankton productions influences enrichment of organic matter and plays a vital role in secondary and tertiary productions. Several families of finfish and shellfishes consume zooplankton wholly or partly in various stages of their life histories [36].

In the present study, abundance and distribution zooplankton was found to be dependent on water quality and coexisting biotic communities at given point of time. The temperature and plankton productivity are positively correlated [38]. During the study period the zooplankton was predominantly by copepods (54%). [40] Reported copepoda as a dominant group in mangrove forests in Bangladesh. On the contrary, [41-44] found Rotifera as a dominant group of zooplankton in Sundarban mangroves in Bangladesh. A distinct seasonal fluctuation of zooplankton population was observed in this study, which could be due to the seasonal variation in physico-chemical parameters. Similar observations were reported by [45-47] from elsewhere. [48] Halda River in Bangladesh showed similar zooplankton composition.

Seasonal variation in zooplankton population density was found statistically significant ($p>0.001$). The population density of zooplankton was found more during pre-monsoon followed by summer and post-monsoon. The bulk of the zooplankton consisted of Copepods, Cilliates, Crustacean Rotifers, Cladocerans and Larval groups. The high zooplankton population density during premonsoon and summer could be due to stable condition of hydrochemical parameters [49-51]. The density and species composition of zooplankton showed gradual increase from post-monsoon to premonsoon implying that drop down in salinity reduce zooplankton composition and density [52]. In addition the species composition and density reduced during monsoon season which clearly indicates the stenohaline nature of zooplankton [53]. Further, the addition of freshwater during monsoon season due to heavy rainfall might have contributed to less population density.

During the present study, a total of 48 species of zooplankton belonging to different groups were identified. Calanoid copepod was found to be the most dominant group with 11 species. The Ciliata was found to be the second dominant group with 6 species. Cyclopoid copepod and Harpacticoid copepod was found as next dominant group with 5 species each and Hydroidomedusae with 4 species. Foraminifera, Chaetognatha and 'Other Crustacean forms' came next in the order with 3 species each; Mollusca and Rotatoria with 2 species each. Decapoda, Pteropoda, Cladocera, Annelida with 1 species each. Earlier investigations made by [54-56] also reported the similar order of abundance. Several studies pertaining to zooplankton diversity have reported the same groups as dominant in both east and west coast of India [57-58].

The diversity index analysis revealed highest value during postmonsoon, summer and premonsoon. Richness values were found maximum during monsoon and minimum during summer season. The higher diversity values during postmonsoon, summer and premonsoon is described in earlier reports and it may be due to stable hydro-chemical parameters, which favors phytoplankton productivity and thereby increasing the population density and species composition of zooplankton [59]. Similarly recent studies conducted in Indian coastal waters also reported high species richness and evenness values during pre-monsoon and less on monsoon season [60].

Canonical Correspondence Analysis and BIO-ENV revealed that the environmental variables such as temperature, salinity, W. pH, DO, silicate, Chl-*a*, Primary Productivity, Total biomass and Phaeopigments in stations near coastal waters (P-4, P-5, P-6 and P-7) had positive correlation with zooplankton species like *Eutintinnus tennuis*, *Favella brevis*, *Globigerina bulloides*, *Polychaete larvae*, *Acartia danae*, *Acrocalanus gibber*, *Centropages furcatus*, *Nannocalanus minor*, *Paracalanus parvus*, *Temora turbinata*, *Corycaeus catus*, *Bivalve veliger*, *Gastropod veliger*, *Flaccisagitta enflata* and *Brachionus calyciflorus* whereas other environmental parameters in stations near freshwater zone (P-1, P-2 and P-3) and zooplankton species were negatively correlated. The CCA results clearly suggested that the distribution pattern of zooplankton is highly influenced by environmental parameters like temperature, DO and Chlorophyll-*a*. [61] Reported that temperature and DO can positively influence the production and abundance of zooplankton species. It has also been reported that temperature and salinity majorly affect the abundance and distribution of zooplankton species [62-65].

Further, the cluster/dendrogram analysis showed that the stations close to coastal zone formed separate cluster with similarity percentage of 82% and similarly the stations in tidal zone formed a separate cluster with 78% similarity. The station near freshwater zone formed a separate cluster at the next level with 74% similarity. The MDS plot also paralleled the trend as observed in the cluster analysis. The results of above analysis confirmed significant differences in species composition between stations near coastal, tidal and freshwater zone and this might be due to various factors such as eutrophication, freshwater influx and tidal mixing of coastal and estuarine waters. The high similarity percentage values obtained during the cluster analysis indicated that all stations consisted of a relatively similar species, which may be because all stations belong to same tropical mangrove ecosystems with almost similar environmental conditions [56, 66].

5.CONCLUSION

In the present study, efforts were made to explore the zooplankton diversity as well as to determine current status of zooplankton composition in Pichavaram mangrove forest, southeast coast of India. It was found that the faunal composition of zooplankton remained significantly diverse. Copepods emerged as the most dominant group contributing >50% of total population. Occurrence of freshwater zooplankton species signified estuarine influence on the distribution of zooplankton. The results of this study confirmed that the environmental parameters such as salinity, chlorophyll *a* and nutrients of the ambient medium regulate the zooplankton composition and abundance in this region. This study forms part of the larger exercise only on taxonomy, abundance and periodicity of zooplankton in tropical mangrove ecosystem. However, more such studies are required to make a complete list of zooplankton available in mangrove ecosystem and also to understand the influence of water quality parameters on the distribution and assemblage of zooplankton in tropical mangrove environment.

Acknowledgements

The authors are thankful to the Director and Dean of the Faculty of Marine Sciences, Annamalai University, for providing necessary facilities.

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