Marine Pollution Bulletin 173 (2021) 113142

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Assessment of seasonal variation in distribution and abundance of plankton and ichthyofaunal diversity in relation to environmental indices of Karankadu Mangrove, South East Coast of India

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ARTICLE INFO

Keywords:
Species diversity
Nutrients
Net productivity
Physico-chemical parameters
Ichthyofauna
Plankton
Correlation analysis

ABSTRACT

Karankadu mangrove situated along the Southeast coast of India is known for its unique and extreme species diversity and richness. Ecological functions of this mangrove comprise of nutrient cycling, coastal protection, fish fauna production and carbon sequestration besides providing livelihood to nearby coastal communities. The current study having assessed seasonal fluctuations of various Physico-chemical factors viz., rainfall, pH, surface water temperature, salinity, dissolved nutrients in the water and sediments, primary productivity and plant pigments (chlorophylls a,b,c) during the study period from July 2018 to June 2019, recorded a total of 29 species of zooplankton, 26 species of phytoplankton, and 19 species of fish with observed maximum density at summer and pre-monsoon period of the year. Relationship between the biotic and abiotic components of the ecosystem from the baseline data collected, was established through the statistical analysis performed.

1. Introduction

The world's great biodiversity includes coastal habitats including estuaries, wetlands, mangrove forests, backwaters, sandy stretches, rocky coastlines, salt marshes, and coral reefs characterizing distinct biotic and abiotic processes and properties. Mangroves, being one among these ecologically important ecosystems are characterized by dark green foliage and negatively geotropic roots showcasing maximum modification in its morphology, physiology, pneumatophores, stilt roots, and viviparity, thereby restricting themselves only along with the saline intertidal habitat of sheltered coastline to withstand partially submerged saline conditions. Although mangrove roots are periodically submerged, the branches are a little different from the environment of the surrounding terrestrial forests and therefore share much of their flora and fauna, correlated with the nature of the habitat and Physico-chemical parameters. However, mangroves are often considered crucial for their ability to sequestrate atmospheric carbon efficiently with wide variations existing between diverse mangrove species. The utmost significance of mangroves lies in this potentiality to sequestrate carbon, being the greatest demand of the era, with the world's total mangrove

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https://doi.org/10.1016/j.marpolbul.2021.113142
Received 6 September 2021; Received in revised form 21 October 2021; Accepted 10 November 2021
Available online 19 November 2021

potential in the same estimated to be around 4.0 gigatons (Prasanna et al., 2017). Apart from this, they serve as the energy basis and physical substrate of an ecosystem that is often complex and diversified and includes species of marine and terrestrial origin (Hogarth, 2001). They interact extensively with the aquatic, seaside, upstream, terrestrial, and physical environments to sustain various marine, freshwater, and terrestrial species' flora and fauna, making them the world's most productive ecosystems. For many pelagic crabs and fish that mature in the open sea, they serve as a nursery. The utilization and dependency of many species of fishes, arthropods, amphibians, reptiles, crustaceans, and birds on mangroves during different stages of their life cycle enhances their biodiversity further.

Mangroves, defending the shoreline from wave energy, sand erosion and winds are under great threat due to constant anthropogenic activities, with the latter contributing above 1% of mangrove loss yearly worldwide. This devastation represents a serious risk to the biodiversity of fauna and flora in these regions, diminishing sources of food and revenue for the local people. Moreover, natural catastrophes such as tsunami had also allured attention worldwide for the protection of lives as well as such ecosystems come under the sensitive coastal region category besides the negligence of the same due to existing anthropogenic pressure. Therefore, Mangrove ecosystems are increasingly endangered across the tropical developing nations of the globe and, due to their particular habitat and rich biodiversity, are of great concern to the coastal environment. The prioritized evaluation of the current biodiversity via the preliminary research helps us understand the richness and well-being of mangroves. Moreover, the conservation and management of a remarkable mangrove ecosystem need fruitful knowledge on the present condition of the ecosystem and its organisms.

India represents 2.67% of the world's total mangrove, 58% of which is located on the east shore, subsequently the largest mangrove forest in the world (Gangetic Sunderbans) in western Bengal comprising about 30 to 50 actual mangrove species. Pertaining to the Tamil Nadu coast, studies on the existence of mangrove forests especially Gulf of Mannar mangroves, and their significance have been very much limited. Amidst them, Karankadu mangroves situated along Palk Bay characterized by young mangrove species serves as a remarkable spot for ecotourism and an excellent source for food and breeding ground for fishes.

Studies employing AGC biomass - a useful tool in measuring carbon sequestration potentiality, had highlighted karankadu mangrove to account for 7.92 t ha^{-1} in perspective of global carbon mangrove biomass estimating around 4.03 pg. This therefore evidences the efficacy of the floral species inhabiting karankadu mangrove in sequestering maximum carbon (Prasanna et al., 2017). With respect to diverse microflora having a major involvement in nutrient cycling, accrual formation, and in regulating the chemical environment of an ecosystem (Maria and Sridhar, 2002) besides serving as a rich source of bioactive metabolites with anti-microbial, anti-cancerous, antioxidant properties (Song et al., 2012), nearly 27 and 58 different bacterial and fungal species were identified respectively in the karankadu mangroves further showcasing its significance and contribution in the welfare of mankind (Fernandes et al., 2015; Saseeswari et al., 2016). Pertaining to the significance of this mangrove, the present investigated study thereby attempts to be the first one in exploring the diversity of floral and faunal composition of Karankadu mangrove in relation to physio-chemical parameters the environment besides providing deep insight on heavy metal distribution, with no studies in this aspect to the best of our knowledge.

2. Materials & methods

2.1. Description of the study area

The Karankadu mangrove swamp (Latitude $9^0 36'$N and Longitude $78^0 83'$E) is situated on the southeast coast Palk Bay region of Tamil Nadu, India (Fig. 1). Karankadu village (Ramanathapuram District) is surrounded in the south by Tirunelveli and Thoothukudi Districts, in the north by Pudukkottai District, in the west by Virudhunagar and Sivagangai Districts, and in the east by Mannar Gulf and Bay of Bengal (Sankarappan et al., 2021) encompasses the coastal line spread over in an area of 400 ha. It accounts for the luxuriant growth of mangrove that covers approximately 102 ha along the banks of the estuary at Kottakarai (Prasanna et al., 2017).

2.2. Sampling periodicity

Primary production experiments and procurement of water samples, phytoplankton, zooplankton and fish were carried out in 2 selected mangrove swamp sites, fortnight preferably on every full moon and new moon days over one year between July 2018 to June 2019. The average values of each month were taken for the present study. The data obtained for one year was discussed to find out the seasonal variations in distribution and abundance of plankton and ichthyofauna corresponding to environmental factors.

2.3. Analysis of Physico-chemical parameters

Surface water samples collected throughout the year were used for evaluating physicochemical parameters. The rainfall data have been acquired from a meteorological unit of the Tamil Nadu Government. Following Winkler's technique and Mohr-Knudsen titration process, the dissolved oxygen and salinity were measured respectively. Surface water samples were taken in clean polyethylene bottles for nutrition analysis which were transported immediately to the laboratory storing in an icebox followed by filtration in Millipore filtering system for the analysis of total phosphorus, silicate &nitrate by implementing the conventional approaches stated by Strickland and Parsons (1972). Atmospheric and water temperatures were measured using a mercury-filled conventional centigrade thermometer. In the field, the pH of the water was measured using the Elico pH (model – LI-120) meter.

2.4. Estimation of primary and net productivity

Studies on Primary productivity carried out for 3 h during daytime was measured in surface water on the basis of changes in dissolved oxygen with dark & light bottle technique as illustrated by Strickland and Parsons (1972). From the values of oxygen obtained from the IB, LB, and DB the productivity was estimated with the given formula:

$$\text{Gross primary productivity}\left(\frac{\frac{\text{Mgc}}{\text{M}^3}}{\text{hr}}\right) = \frac{(O_2L.B) - (O_2D.B)}{(PQ)(t_3)} \times 1000$$

Net Primary Productivity (Mgc/M^3/hr) $= \frac{(O_2L.B)-(O_2I.B)}{(PQ)\ (t)} \times 1000$.where O_2 = Oxygen ml/L, 1 ml of O_2 = 0.536 mg carbon, O_2 LB = Oxygen dissolved in a light bottle, O_2 DB=Oxygen dissolved in a dark bottle, O_2 IB = Oxygen dissolved in Initial bottle, PQ = Photosynthetic Quotient (1.2) and t = Incubation hours (3 h). During the study period, primary productivity and net productivity were calculated and the values were tabulated.

2.5. Collection and estimation of plankton samples

Samples of Phytoplankton from the surface water were collected at monthly intervals by horizontal towing of the conical net (with a mouth diameter of 0.35 m) for 30 min made from blotting silk (cloth No. 30, mesh size 48 μm of mesh size) and have been kept in 5% neutralized formalin. Identification of Phytoplankton follows the standard works of (Desikachary, 1972) and (Santhanam et al., 2019). Zooplankton samples from the surface water were collected at monthly intervals by horizontal towing of plankton net for 20 min (with a mouth diameter of 0.35), blotting silk net (cloth No. 10, 158 μm of mesh size). These samples have been kept in 5% formalin for use in qualitative analysis utilizing a

Fig. 1. Location map of Karankadu mangrove ecosystem.

plankton plastic slide counting (Sedgewick raftor). Since the capacity of the counting chamber was 1 ml, the preserved plankton sample collected from 200lit of water was diluted to 100 ml followed by transfer of 1 ml to the counting chamber for its subsequent observation under the binocular microscope. The phytoplankton components were counted in all 100 small squares to calculate the numbers per M^3 of water filtered. Identification was performed following the standard study of Kasturirangan (1963) and Perumal et al. (2009).

2.6. Collection and identification of fishes

For the purpose of determining the fishery potential, a cast net with a length of 2.5 m was used throughout the course of the research, with a mesh size of 7 mm base and 15 mm apex. During each collection at the sample location, the net was deployed 10 times. The obtained samples have been classified upto species level by using the description and keys given by (Day, 1994) and (Ramaiyan et al., 1987).

2.7. Statistical analysis

Data was collected during all the four seasons (summer, monsoon, pre-monsoon, & post-monsoon) of the study year and correlation analysis was performed between both abiotic and biotic factors to establish significant relationship between them. Univariate measurements [Margalef's species richness (R), Shannon-Wiener diversity index (H′), Simpson dominance (D), & Pielou's evenness (J')] were determined with PRIMER ("Plymouth Routines in Multivariate Ecological Research, Version 5").

2.7.1. Species richness index (d)

To assess the community structure, the Species richness index (d) according to (Margalef, 1951) has been employed. The following equation was used and results were reported in two decimal places.

$$d = (S-1)/lnN$$

Here: S = Number of species in a population, N = Total number of individuals in S species, d = Species richness index.

2.7.2. Shannon and Weiner diversity index (H)

$$\mathrm{H} = \sum [(p_i) \times ln(p_i)]$$

where Diversity Index is represented by H, i = Counts denoting the species ranging between 1 – n and Pi = Proportion that the species signifies in terms of No. of individuals corresponds to the total No. of individuals in the sample area.

2.7.3. Species equitability (j)

The following equation derives species equitability or evenness (Pielou, 1969):

$$J = H/ln(S)$$

where J = Equitability index, S=No. of species in a sample area, H = Shannon, and weaver index

2.7.4. Correlation coefficient values (r)

The Pearson correlation coefficient (r) for the association between certain physicochemical parameters and biotic structure reported in the research was calculated using this formula:

$$r = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{\left[n\sum X^2 - (\sum X)^2\right]\left[n\sum Y^2 - (\sum Y)^2\right]}}$$

Here, X & Y = Variables under coefficient of correlation, r = Coefficient of correlation

3. Results

3.1. Physico-chemical parameters

Total precipitation of 299.4 mm was reported for the study period with monthly rainfall (mm) varying from 18.6 to 111. Rainfall was completely absent during January, February, March, April, May, and June 2019. In the north-eastern monsoon (November 2018) the highest rainfall (111 mm) and the lowest (18.6 mm) was recorded in December 2018. The air temperature throughout the research period ranged between 28.4 and 35.4 °C. The minimum and maximum temperature were noted in the monsoon season (Dec 2018) and summer season (June 2019) of the year respectively. The atmospheric temperature demonstrated a strong association with water temperature (r = 0.870). The surface water temperature varies between 26.1 °C to 31.4 °C. In monsoon (Nov 2018), the minimum surface water temperature (26.1 °C) was reported, while during summer, the maximum surface water temperature (30.9 °C) was reported (May 2019) (Table 1). Further, water temperature was linked positively with salinity (r = 0.884) and pH (r = 0.896) and negatively associated with dissolved oxygen (r = −0.825).

The monthly mean water pH levels ranged between 7.4 and 8.4. In the summer season (May 2019), maximum pH levels were measured in contrast with the lowest values reported in the monsoon seasons (November 2018). Statistical studies revealed that pH correlations are positive with salinity (r = 0.961) and water temperature (r = 0.896), while oxygen dissolved has a negative association (r = −0.793). The minimum salinity observed in monsoon (November 2018) throughout the post-monsoon period steadily increased and reached the maximum (32.8%) in the summer season (June 2019). Salinity exhibited strong association between pH (r = 0.961) and temperature (r = 0.884) in contrast to inverse association with dissolved oxygen (r = − 0.824). Dissolved oxygen (DO) varied between 3.7 and 6.1 mg/L. The minimum DO in May 2019 and the highest in November 2018 were reported. Statistical analysis showcased negative correlation of dissolved oxygen with salinity (r = −0.824), water temperature (r = −0.825), & pH (r = −0.793) (Table 4)

3.2. Dissolved nutrients

Seasonal variations in the total phosphorus recorded were minimum (0.8 μg/L) in May 2019 whereas maximum (3.1 μg/L) in November 2018. Positive correlation was obtained between phosphorous and DO (r = 0.815), phosphorus and salinity (r = −0.914). Negative correlation was obtained with pH (r = −0.892). Minimum nitrate content (5.2 μg/L) was reported in the month of May 2019, in contrast to November 2018 registering a maximum value of 13.5 μg/L.

The nitrate has a strong association with DO (r = 0.808) whereas the inverse association with salinity (r = −0.893) and pH (r = −0.867) in statistical analysis. A minimum value of 9.8 μg/L (June 2019) whereas a maximum value of 76.1 μg/L (October 2018) was obtained (Table 1). Statistical analysis revealed that the silicate has a strong association with DO (r = 0.775) whereas the inverse association with water temperature (r = − 0.787), pH (r = −0.855), and salinity (r = −0.887) as presented in (Table 4). The mean seasonal temperature, salinity, pH, phosphorus, dissolved oxygen, silicate as well as nitrate content have not been consistent during the research period.

3.3. Primary productivity

Gross primary production at Karankadu mangroves ranged from 29.4 mgC/m^3/h to 134.6 mgC/m^3/h. Minimum (29.4 mgC/m^3/h) and maximum (134.6 mgC/m^3/h) gross primary production were registered during monsoon (December 2018) and summer (May 2019) seasons respectively (Table 1). Statistical analysis revealed that the gross primary production had a strong association with water temperature (r = 0.860), atmospheric temperature (r = 0.906), pH (r = 0.934), salinity (r

Table 1
Seasonal variations of physico-chemical parameters, primary production and chlorophyll concentration in Karankadu Mangroves.

Physico - chemical parameters	Jul. 2018	Aug.	Sep.	Oct.	Nov.	Dec.	Jan. 2019	Feb.	Mar.	Apr.	May	June
Rainfall (mm)	22.2	36.4	35.2	76	111	18.6	0.0	0.0	0.0	0.0	0.0	0.0
Atmospheric Temperature (^{0}c)	31.4	32.3	31.4	30.3	29.6	28.4	30.2	30.8	33.7	34.2	33.9	35.4
Water Temperature (^{0}c)	28.3	27.9	28.1	28.2	26.1	26.9	28.2	29.1	28.9	30.8	31.4	31.1
pH	7.9	7.8	7.6	7.5	7.4	7.5	7.5	7.8	7.9	8.1	8.4	8.2
Salinity (ppt)	26.5	20.1	18.2	11.7	11.5	12.8	16.5	19.6	26.7	31.4	32.1	32.8
DO (mg/L)	4.5	5.3	5.1	5.6	6.1	4.7	4.3	4.4	4.1	3.8	3.7	3.9
Phosphate (μg/L)	1.1	1.7	1.6	2.7	3.1	2.6	1.9	1.5	1.6	1.2	0.8	0.9
Nitrate (μg/L)	6.8	7.6	8.6	12.8	13.5	12.5	8.1	7.5	7.8	6.4	5.2	5.6
Silicate (μg/L)	26.7	20.5	36.6	76.1	72.5	69.6	31.3	26.3	20.6	15.2	10.1	9.8
Gross Primary productivity (mgC/m^3 hr^{-1})	76.3	41.5	36.4	30.2	38.5	29.4	42.6	52.8	95.3	108.1	134.6	98.2
Net Primary production (mgC/m^3 hr^{-1})	69.3	36.3	28.3	26.5	31.3	26.7	25.6	54.3	60.9	104.6	115.2	58.6
Chlorophyll a (mg/m^3)	8.6	7.2	7.7	3.6	4.2	3.5	4.3	7.8	8.1	9.4	10.5	10.1
Chlorophyll b (mg/m^3)	1.32	0.86	2.8	0.26	0.72	0.31	0.52	0.86	0.98	0.63	1.85	1.98
Chlorophyll c (mg/m^3)	6.7	6.4	2.5	2.7	2.1	1.8	3.35	3.63	3.83	6.4	4.4	3.7

= 0.932) and negative association with oxygen ($r = -0.793$), nitrate ($r = -0.755$), phosphate ($r = -0.775$) and silicate ($r = -0.738$). Net primary production varied from 25.6 mgC/m^3/h to 115.2 mgC/m^3/h. The minimum and maximum net primary production was noted in the monsoon and summer season respectively. The correlation co-efficient (r) of net primary productivity showed positive correlation with water temperature ($r = 0.804$), atmospheric temperature ($r = 0.820$), pH (0.887), salinity ($r = 0.851$), gross primary productivity ($r = 0.934$) and negative association with oxygen ($r = -0.719$), nitrate ($r = 0.696$), phosphate ($r = 0.728$) and silicate ($r = -0.633$) as displayed in (Table 4)

3.3.1. Chlorophyll 'a', 'b', 'c'

The chlorophyll 'a' content of the water showed lower values of 3.5 mg/m^3 in December 2018 with higher values of 10.5 mg/m^3 in May 2019. Statistical analysis revealed that the chlorophyll 'a' had a positive association with atmospheric temperature ($r = 0.888$), water temperature ($r = 0.827$), pH (r = 0.934), salinity ($r = 0.940$), gross primary productivity ($r = 0.842$) and net primary productivity ($r = 0.801$) and negative association with oxygen ($r = -0.695$), nitrate ($r = -0.899$), phosphate ($r = -0.931$) and silicate ($r = -0.890$). The Chlorophyll 'b' level varied between 0.26 mg/m^3 (October) and 1.98 mg/m^3 (June). The seasonal mean values of Chlorophyll 'b' computed showed its peak during summer with minimum values during monsoon periods. Statistical analysis showed its positive association with atmospheric temperature ($r = 0.462$), water temperature ($r = 0.381$), pH ($r = 0.448$), salinity ($r = 0.456$), chlorophyll 'a'($r = 0.637$), gross primary productivity ($r = 0.333$) and net primary productivity ($r = 0.227$) and negative association with oxygen ($r = -0.228$), nitrate ($r = -0.508$), phosphate ($r = -0.580$) and silicate ($r = -0.505$). A wide fluctuation in Chlorophyll 'c' concentration was noticed throughout the study period. The Chlorophyll 'c' concentration varied from 1.8 mg/m^3 in December 2018 to 6.7 mg/m^3 in July 2019. The seasonal variation of Chlorophyll 'c' showed minimum values during monsoon and maximum values during summer periods (Table 1). Statistical analysis showed its positive association with atmospheric temperature ($r = 0.552$), water temperature ($r = 0.425$), pH ($r = 0.576$), salinity ($r = 0.624$), chlorophyll 'a'($r = 0.6009$), chlorophyll 'b'($r = 0.028$), gross primary productivity ($r = 0.486$) and net primary productivity ($r = 0.585$) in contrast to negative correlation with oxygen ($r = -0.380$), nitrate ($r = -0.667$), phosphate ($r = -0.635$) and silicate ($r = -0.621$) (Table 4)

3.3.2. Phytoplankton

3.3.2.1. Species composition. Phytoplankton species composition indicated a 26-total number of species comprising 15 diatoms, 4 dinoflagellates, 5 cyanophyceae, and 2 Chlorophyceae. Generally, the diatoms are graded at the top rank in abundance followed by cyanophyceae, dinoflagellates &Chlorophyceae. The present study recorded the following diatoms species including *Asterionella japonica*, *Bacillaria paradoxa*, *Biddulphia biddulphina*, *Chaetoceros affinis*, *C. diversum*, *Coscinodiscus centralis*, *C. gigas*, *C. radiatus*, *C. oculus*, *Nitzschia seriata*, *Odontella sinensis*, *Rhizosolenia styliformis*, *Skeletonema costatum*, *Thalassiothrix frauenfedii* and *Triceratium favus*. The dinoflagellates species included *Ceratium tripos*, *C. fuscus*, *Peridinium conicum*, and *P. depressum*. The Cyanophyceae (blue-green) and the Chlorophyceae species encountered include *Anabaena sp.*, *Anabaena sp.*, *Nostoc sp.*, *Spirulina sp.*, *Oscillatoria sp.*, *Trichodesmium* sp. and *Chlorella sp.*, *Spirogyra* sp. respectively.

3.3.2.2. Population density. The density of phytoplankton ranged between 6315 m^{-3} in November 2018 and 9325 m^{-3} in January 2019. Throughout the study period, the seasonal average population density levels attained maximum and minimum in the post-monsoon, summer, and monsoon seasons as presented in (Fig. 2).

3.3.2.3. Species diversity & richness. The species diversity (H^1) of phytoplankton fluctuated between 2.672 and 3.031 in May 2019 and November 2018 respectively. The species richness (d) varied from the lowest of 1.887 in April 2019 to the highest of 2.516 in January 2019. The diversity and richness indices of phytoplankton were comparatively high during the summer and pre-monsoon than the monsoon season (Table 2).

3.3.2.4. Species evenness. Lowest value (0.9088) of species evenness (J) was recorded during the month of February 2019 in contrast to higher value (0.9666) in November 2018 as presented in (Table 2). Positive correlation was established between phytoplankton and physico-chemical parameters like Water temperature ($r = 0.586$), atmospheric temperature ($r = 0.430$), pH (0.423), salinity ($r = 0.426$), gross primary productivity ($r = 0.471$), net primary productivity ($r = 0.370$), chlorophyll 'a' ($r = 0.361$), chlorophyll 'b'($r = 0.114$) and chlorophyll 'c' ($r = 0.143$). Negative association was obtained between phytoplankton and oxygen ($r = -0.734$), nitrate ($r = -0.609$), phosphate ($r = -0.505$), silicate ($r = -0.624$) (Table 4).

3.3.3. Zooplankton

3.3.3.1. Species composition. A total of 29 species during the research period constituting 7 species of tintinnids, 6 rotifers species, 2 species of Chaetognatha with decapod, and foraminifera constituting one species each was found besides 6 types of eggs and larvae recorded. Among 12 species of copepods, 8 species were calanoid with 3 harpacticoids and 1 cyclopoid. Major components constituted tintinnids including *Tintinnopsis tocantinensis*, *T. cylindrical*, *T. gracilis*, *T. beroidea*, *T. tubulosa*, *T. minuta*, *Favella brevis* with calonoid species of copepods, namely *Acartia gracilis*, *A. centrura*, *A. spinicauda*, *Acrocalanus similis*, *A. gibber*, *Eucalanus crassus*, *Paracalanus aculeatus*, *P. parvus*; harpacticoid species such as

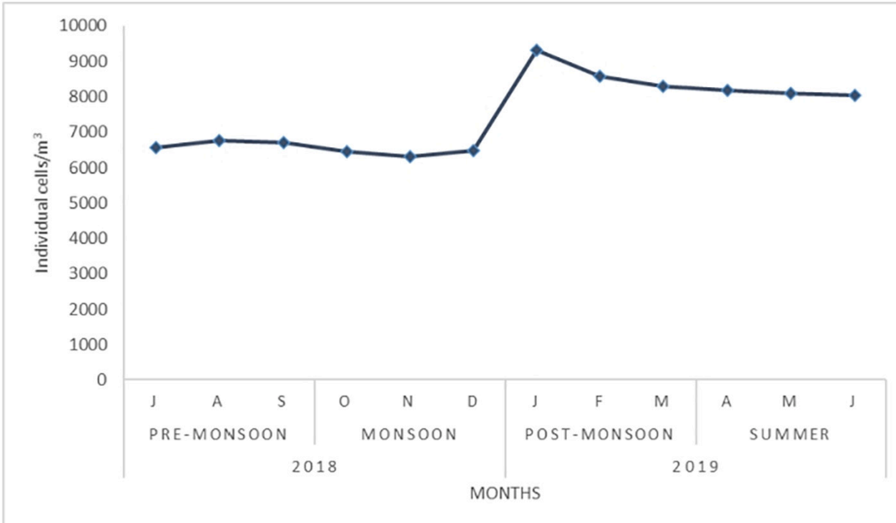

Fig. 2. Monthly fluctuations of phytoplankton density recorded in Karankadu mangroves.

Euterpina sp., *Macrosetetella Sp.*, *Microsetella* sp. and cyclopoids species namely *Oithona brevicornis* among the zooplankton population. The rotifers species namely *Brachionus calyciflorus*, *B. caudatus*, *B. Rubens*, *B. plicatilis*, *B. angularis, and Kertatella tropica* have been noted in the monsoon as well as post-monsoon season. The decapod, *Lucifer hanseni*, Chaetognaths (*Sagitta enflata* and *S. bedoti*), and forminifera (*Globigerina sp.*,) appeared during the summer and early premonsoon period. Veliger larvae of bivalve and gastropod have been noted in the post-monsoon, summer & pre-monsoon periods. The prawn mysis and crab zoea appeared in the pre-and post-monsoon season. Copepod nauplii were found year-round and remained high in the summer besides fish eggs and larvae noticed throughout the year.

3.3.3.2. Population density. Zooplankton population density varied significantly from 24,855 individuals/m^3 to 57,775 individuals/m^3, within the study year. The seasonal mean population density was often greatest during the summer and pre-monsoon whereas with the lowest population density in the monsoon season as presented in (Fig. 3).

3.3.3.3. Species diversity and richness. Species diversity fluctuated between 2.913 in December 2018 to 3.149 in September 2018. The diversity indices were high in the pre-monsoon period in comparison to other seasons. The species richness (d) ranged from a minimum of 1.978 in December 2018 to a maximum of 2.735 in September 2018 coincided with pre-monsoon followed by monsoon season whereas the low value of species richness was reported in the post-monsoon, followed by summer season (Table 2).

3.3.3.4. Species evenness. Species evenness (J^1) reported a minimum value (0.9209) in June 2019 to a maximum value of (0.957) in December 2018 (Table 2). Zooplankton with physio-chemical parameters like Water temperature ($r = 0.864$), atmospheric temperature ($r = 0.918$), pH (0.938), salinity ($r = 0.974$) gross primary productivity ($r = 0.867$), net primary productivity ($r = 0.792$), chlorophyll 'a' ($r = 0.952$), chlorophyll 'b' ($r = 0.525$), chlorophyll 'c' ($r = 0.694$) and phytoplankton ($r = 0.455$) observed positive correlation. In contrast it exhibited inverse association with DO ($r = -0.758$), nitrate ($r = -0.946$), phosphate ($r = -0.9506$) and silicate ($r = -0.938$) (Table 4).

3.4. Diversity of ichthyofauna

3.4.1. Species composition

Fish diversity comprised 19 species representing 5 orders, 17 families, and 19 genera. The order Perciformes dominated by 13 species followed by Clupeiformes and Siluriformes with 2 species and, Gonorphynchiformes and Beloniformes with one species each. In the sampling site, percentage-wise fish catch pertained to order Perciformes (71.75%) followed by Siluriformes (9.6%), Gonorphynchiformes (8.9%), Clupeiformes (8.13%), and Beloniformes (1.55%). Of the 19 species identified in this study, *Mugil cephalus* served as the dominant species contributing about 12.01% with *Liza parsia* as the second dominant species accounting for about 9.68%. Subsequent ranks of dominance pertained to *Chanos chanos*, *Leiognathus equulus*, *Mystus gulio*, *Siganus caniculatus*, *Terapon jarbua*, *Gerres filamentous*, *Thryssa mystax*, *Etroplus suratensis*, *Lates calcarifer*, *Oreochromis mossambicus*, *Sardinella longiceps*, *Ambassis commersoni* (2.71%); *Sillago sihama*, *Lutjanus argentimaculatus*, *Caranx ignobilis* and *Arius jella* accounting 8.91%, 8.52%, 7.75%, 7.36%, 5.81%, 5.42%, 4.26%, 3.48%, 2.32%, and 1.93% respectively. *Hemirampus marginatus* (1.55%) remained as least percentage amidst total catch (Table 3).

3.4.2. Fish population density

The mean population density in the summer was maximal (13.18% in May 2019) and post-monsoon periods (10.47% in March 2019) and minimum during monsoon (3.49% in November 2018), followed by the pre-monsoon period (5.81% in September 2018) (Table 3).

3.4.3. Species diversity and richness

The species diversity (H^1) of ichthyofauna fluctuated between 2.025 in October 2018 to 2.811 in July 2018. The diversity indices for ichthyofauna were high in the summer period when compared to other seasons. The species richness (d) varied from a low value of 3.04 in October 2018 to a high value of 5.218 in July 2018. Generally, high species richness corresponds with summer followed by pre-monsoon time whereas, in the monsoon, low species richness was reported (Table 2).

3.4.4. Species evenness

The species evenness (J^1) reported a minimum value (0.9525) in March 2019 to a maximum value (0.9837) in September 2018. The seasonal mean evenness throughout pre-monsoon and the monsoon, summer and post-monsoon seasons were high all across the research period (Table 2). Relating Ichthyofauna with Physico-chemical parameters and nutrients, a positive correlation was obtained between water temperature ($r = -0.903$), atmospheric temperature ($r = -0.850$), pH ($r = -0.941$), Salinity ($r = -0.972$), gross primary productivity ($r =$

Table 2
Diversity Index of Phytoplankton, zooplankton and fishes in Karankadu Mangroves.

Sampling Seasons	Sampling Months	Phytoplankton				Zooplankton				Fishes			
		Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')	Simpson dominance (D)	Shannon diversity (H')	Margalef richness (d)	Pielou'sevennes (J')	Simpson dominance (D)	Shamo-ndiversity (H')	Margalef richness (d)	Pielou'sevennes (J')	Simpson dominance (D)
Pre-monsoon	July	2.73	2.048	0.9273	0.9252	3.111	2.59	0.9238	0.9481	2.811	5.218	0.9727	0.9723
	August	2.827	2.267	0.9287	0.9317	3.063	2.332	0.94	0.9471	2.513	4.328	0.9796	0.975
	September	2.826	2.156	0.9434	0.9326	3.149	2.735	0.9259	0.951	2.523	4.431	0.9837	0.981
Monsoon	October	3.018	2.508	0.9627	0.9457	3.053	2.539	0.9264	0.9452	2.025	3.04	0.974	0.9556
	November	3.031	2.514	0.9666	0.9468	3.077	2.556	0.9337	0.9467	2.043	3.186	0.9826	0.9722
	December	2.995	2.507	0.955	0.9433	2.913	1.978	0.957	0.9402	2.342	3.789	0.9767	0.967
Post-monsoon	January	2.93	2.516	0.9219	0.9354	2.986	2.086	0.9522	0.9425	2.406	3.736	0.9683	0.9532
	February	2.85	2.429	0.9088	0.9293	3.031	2.173	0.9537	0.9448	2.453	3.882	0.9562	0.9481
	March	2.8	2.217	0.9197	0.9273	3.068	2.319	0.9416	0.9468	2.641	4.551	0.9525	0.9544
Summer	April	2.683	1.887	0.9283	0.921	3.033	2.197	0.9422	0.946	2.777	4.862	0.9607	0.9602
	May	2.672	1.889	0.9244	0.9201	3.066	2.372	0.9301	0.947	2.787	4.821	0.9643	0.9608
	June	2.679	1.891	0.927	0.9212	3.035	2.357	0.9209	0.9419	2.751	4.862	0.9517	0.9564

−0.938), net primary productivity ($r = -0.867$), phytoplankton ($r = -0.596$) and zooplankton ($r = -0.920$). In contrast a negative correlation was obtained with oxygen ($r = -0919$) nitrate ($r = -0.878$), phosphate ($r = -0.894$) and silicate ($r = -0.859$) (Table 4).

4. Discussion

On the basis of monsoon rain, seasons were differentiated into four main categories as Monsoon (October–December), Post monsoon (January–March), Summer (April–June), and Pre-monsoon (July–September) annually. Seasonal deviations, as observed in the Physico-chemical parameters of the mangrove ecosystem is under the chief control of southwest monsoonal rainfall. Temperature plays a significant role in influencing Physico-chemical parameters, production, distribution, and abundance of organisms in the shallow ecosystems of the aquatic environment (Vajravelu et al., 2018). Accordingly, the present study witnessed significant variations in the aforementioned parameters with respect to changes in temperature. Highest temperature was recorded in the months of summer and pre- monsoon season, whereas minimum values were recorded during monsoon periods.

This variation in temperature attributes to the marked changes in evaporation and solar radiation of the seasons (Day, 1951). In terms of surface water temperature and salinity, maximum values were obtained during summer against monsoon. Fluctuation in water temperature attributes to the associated changes with atmospheric temperature, rainfall and freshwater discharge influx of the inshore waters. Similarly, salinity fluctuations were driven by many factors like inputs of freshwater and seawater, inundation, tides, evaporation, rainfall and groundwater seepage (Sverdrup et al., 1942). This also favors earlier reports of (Ajith Kumar et al., 2006; Anand and Kumarasamy, 2013; Babu et al., 2013; Pate et al., 2018; Ashok Prabu et al., 2008; Saravanakumar et al., 2008; Silambarasan et al., 2016). On the other hand, minimum values of pH and maximum values of dissolved oxygen, recorded during monsoon pertains to the monsoonal rainfall and flow of freshwater from rivers. Results of this study are in accordance to the findings of (Sri Dattatreya et al., 2018; Rajan and Saranya, 2017; NethajiMariappan et al., 2016; Ashok Prabu et al., 2008; Santhanam et al., 2019; Silambarasan et al., 2016; Sherly Cross et al., 2018; Tripathy et al., 2005; Vasanthakumar et al., 2013). Pertaining to nutrients, elevated level of phosphate, nitrate, and silicate during monsoon period with declining levels slowly from pre-monsoon period reaching a minimum at summer attributes to the uptake of phosphate by phytoplankton and by the heavy influx of river water carrying a large volume of nitrate and silicate particles. Further statistical analysis revealing a negative correlation between these nutrients and salinity supports the furnishings of (Aruljothi and Sampathkumar, 2020; Sri Dattatreya et al., 2018; Dhanya et al., 2017; Manju et al., 2012; Vasanthi and Sukumaran, 2017; Vijaya Kumar and Kumara, 2014). The current study recorded net primary productivity to be in pattern with gross primary productivity with earlier being maximum during summer attributing to clear water, high water temperature, salinity, and high density of phytoplankton. However minimum gross production recorded during monsoon with low salinity and water temperature involves the contribution of green algae, for example, *Chlorella Sp*., and *Spirogyra Sp*., and blue-green algae, for example, *Anabaena sp*, *Nostoc sp*., *Oscillatoria sp*., *Spirulina sp*., and *Trichodesmium sp*., with minimum diatoms and dinoflagelletes. With a viewpoint to assess phytoplankton biomass by means of chlorophyll 'a' concentration (Qasim, 1978), the current study recorded the concentration of chlorophyll 'a', 'b','c' to be maximum during summer in contrast to later being at its peak during pre-monsoon period. Moreover, the concentration of chlorophyll'b' was low in comparison to other pigments confirming the earlier reports of (Geetha et al., 2009; Manju et al., 2012; Senthilkumar et al., 2008). The correlation test further displayed a positive relationship of these chlorophyll pigments with Physico-chemical parameters and gross and net primary production. Studies focusing on the abundance, distribution, composition, and

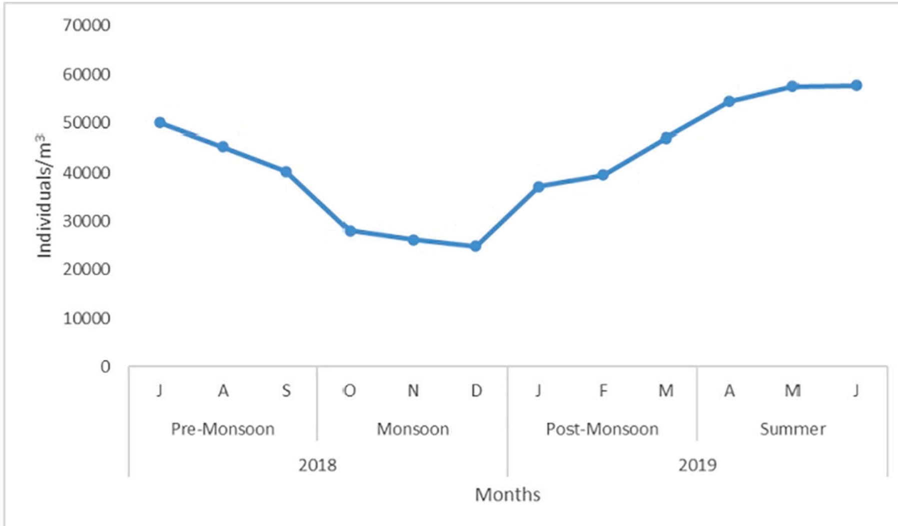

Fig. 3. Monthly fluctuations of zooplankton density recorded in Karankadu mangroves.

Table 3
Fish Fauna Diversity in Karankadu mangroves.

Name of the fish	Pre monsoon			Monsoon			Post Monsoon			Summer			Total
	Jul. 2018	Aug.	Sep.	Oct.	Nov.	Dec.	Jan. 2019	Feb.	Mar.	Apr.	May	June	
Sardinella longiceps	1	1	1						1	1	1	1	7
Thryssamystax	2	1	1				1	1	2	2	2	2	14
Chanoschanos	2	1	2		1	1	2	3	2	3	4	2	23
Liza parsia	2	2	1	1		2	3	2	3	3	2	4	25
Mugil cephalus	3	2	1	2	1	2	2	3	4	4	3	4	31
Ambasiscommersoni	1								1	2	2	1	7
Silago sihama	1	1							1	1	1	1	6
Lates calcarifer	1	1	1			1	1	1	1	1	2	1	11
Caranxignobilis	1								1	1	1	1	5
Lutjanus argentimaculatus	1							1	1	1	1	1	6
Oreochromis mossambicus			1	2	2	2	1	1					9
Etroplussuratensis	1	1	1	1	1	1	1	2	2	1	1	1	14
Leiognathusequlus	2	2	2	1	1	1	2	2	1	2	3	3	22
Siganuscaniculatus	2	1	1		1	1	2	3	1	3	2	2	19
Teraponjarbua	1	1	1	1		1	1	1	2	2	2	2	15
Gerresfilamentosus	1	1	1	1	1	1	1	1		2	2	3	15
Mystusgulio	2	1	1	1	1	1	2	1	3	2	3	2	20
Arius jella	1								1	1	1	1	5
Hemirampusmarginatus	1									1	1	1	4
TOTAL	26	16	15	10	9	14	19	22	27	33	34	33	258
Percentage	10.08	6.20	5.81	3.88	3.49	5.43	7.36	8.53	10.47	12.79	13.18	12.79	

seasonal changes of plankton pertain to its significance in serving as a fertility index as a landing of fish besides the index of fertility remains directly proportional to the plankton quantity in an aquatic system. Based on this high and low density of phytoplankton observed during summer and monsoon period respectively supports findings of (Aruljothi and Sampathkumar, 2020; Saravanakumar et al., 2008; Sherly Cross et al., 2018; Silambarasan et al., 2016) with low density attributing to heavy rainfall, decreased salinity, p^H and temperature. Diatoms dominated 77.5% amidst 10.9% of dinoflagellates, 9.6% of blue-green algae, and 1.9% of green algae from collected 26 species. Correlation studies established a negative relationship between the abundance of phytoplankton and inorganic nutrient concentration where low levels of dissolved nutrients have been recorded during peak phytoplankton periods indicate the utilization of nutrients by them. In contrast, a positive correlation was obtained for water temperature and salinity staying in line with results of (Chandran et al., 1982; Dayala et al., 2014; Gowda et al., 2001; Rajasekar et al., 2010; Silambarasan et al., 2016). Therefore, the seasonal distribution of phytoplankton seems to rely significantly on the degree of variation in Physico-chemical factors including pH, dissolved oxygen, salinity, & temperature. Among 29 species of zooplankton recorded copepod dominated throughout the study period followed by tintinnids and rotifers. Pertaining to tintinnids, *Favella brevis* was the dominant one. The total biomass of tintinnids demonstrating a strong seasonal pattern with the maximum in post-monsoon as well as summer whereas minimum in monsoon seasons attributes to water temperature, salinity, and chlorophyll-a concentration during the summer season. On the other hand, the lowest abundance during monsoon was due to a non-conductive environment as endorse by (Godhantaraman, 2001) from Pichavaram mangroves where seasonal changes in its biomass were correlated with the interactive impacts of temperature as well as food availability. In contrast to rotifers being present only during monsoon, copepods and decapods were found abundantly in the summer and pre-monsoon period showcasing their tolerance to high salinity strictly. This agrees with the report of this abundance of chaetognaths and foraminifera in high saline months when the stock of zooplankton was greater (Mohamed and Rahman,

Table 4
Correlation Co-efficient (r) between environmental parameters, phytoplankton, zooplankton and ichthyofauna diversity.

	Water Temp.	*Atmos. Temp.*	*pH*	*Salinity*	*DO*	*Phosphate*	*Nitrate*	*Silicate*	*GP*	*NP*	*Chlorophyll a*	*Chlorophyll b*	*Chlorophyll c*	*Phytoplankton*	*Zooplankton*	*Fish Fauna*
Water Temp.	1.0000															
Atmos.Temp.	0.8710	1.0000														
pH	0.8963	0.9108	1.0000													
Salinity	0.8842	0.9129	0.9619	1.0000												
DO	−0.8256	−0.6697	−0.7935	−0.8240	1.0000											
Phosphate	−0.8409	−0.8052	−0.8921	−0.9146	0.8159	1.0000										
Nitrate	−0.8178	−0.8088	−0.8675	−0.8932	0.8085	0.9795	1.0000									
Silicate	−0.7876	−0.8207	−0.8558	−0.8879	0.7756	0.9398	0.9791	1.0000								
GP	0.8607	0.9064	0.9347	0.9327	−0.7933	−0.7758	−0.7550	−0.7387	1.0000							
NP	0.8048	0.8209	0.8871	0.8510	−0.7198	−0.7282	−0.6968	−0.6331	0.9343	1.0000						
Chlorophyll a	0.8271	0.8882	0.9344	0.9400	−0.6958	−0.9319	−0.8998	−0.8901	0.8427	0.8017	1.0000					
Chlorophyll b	0.3816	0.4624	0.4481	0.4568	−0.2288	−0.5803	−0.5086	−0.5053	0.3339	0.2276	0.6370	1.0000				
Chlorophyll c	0.4251	0.5522	0.5760	0.6247	−0.3805	−0.6359	−0.6670	−0.6214	0.4865	0.5851	0.6009	0.0285	1.0000			
Phytoplankton	0.5862	0.4308	0.4235	0.4625	−0.7347	−0.5054	−0.6093	−0.6241	0.4719	0.3703	0.3618	−0.0047	0.1430	1.0000		
Zooplankton	0.8640	0.9188	0.9390	0.9743	−0.7587	−0.9506	−0.9465	−0.9381	0.8679	0.7922	0.9529	0.5258	0.6946	0.4559	1.0000	
Fish Fauna	0.9036	0.8503	0.9413	0.9721	−0.9193	−0.8949	−0.8788	−0.8595	0.9386	0.8677	0.8785	0.3473	0.5527	0.5962	0.9208	1.0000

1987).The abundance of 19 fish species reported in the current study varied with seasons in the following order of summer > pre-monsoon > post monsoon>monsoon. Fish abundance in the summer and pre-monsoon period attributes to salinity and depth of the water being vital for the same (Mahesh and Saravanakumar, 2015). Similarly, the lowest number of ichthyofauna during monsoon was suggested due to declined salinity during a heavy influx of freshwater and low p^H being responsible for low density (Kumaran et al., 2012). Higher diversity values in fish thereby elucidate the healthy nature of Karankadu Mangroves.

5. Conclusion

Baseline data presented on the biotic and abiotic components of the studied mangrove ecosystem reveals several interesting relationship between them, thereby reflecting the healthy functioning of the ecosystem. The study reports richness, diversity and productivity of the recorded biotic species to be maximum during the summer and pre-monsoon seasons of the year in contrast to the physico-chemical parameters that attain its peak during the monsoon season. Present study serving as a preliminary database of Karankadu mangrove shall encourage future studies destined in formulating better management measures to safeguard the existing rich biodiversity of the biome and for its sustainable development.

CRediT authorship contribution statement

Kannayiram Muthukumaravel, Vasanthi Natarajan, Balasubramani Ravindran, Mohammed Saiyad Musthafa: Conceptualization and design.

Kumara Perumal Pradhoshini, Thimmarayan Raja: Data curation, Writing- Original draft preparation.

Kantha Devi Arunachalam: Visualization, Investigation.

M.Abdul Jaleel: Software, Validation

Ramamoorthy Ayyamperumal, Shankar Karuppannan, Rajakrishnan Rajagopal, Ahmed Alfarhan, Murugesan Chandrasekaran, Soon Wang Chang, Balasubramani Ravindran, Mohammed Saiyad Musthafa: Writing- Reviewing and Editing

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.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean Government (MSIT) (No. 2020R1G1A1012069). The authors acknowledge King Saud University, Riyadh, Saudi Arabia for funding this research through Researchers Supporting Project No: RSP 2021/11.

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