Building evidence for conservation globally

Journal of Threatened Taxa

Open Access

10.11609/jott.2022.14.2.20539-20702
www.threatenedtaxa.org

26 February 2022 (Online & Print)
14(2): 20539-20702
ISSN 0974-7907 (Online)
ISSN 0974-7893 (Print)

ISSN 0974-7907 (Online); ISSN 0974-7893 (Print)

Publisher
Wildlife Information Liaison Development Society
www.wild.zooreach.org

Host
Zoo Outreach Organization
www.zooreach.org

No. 12, Thiruvannamalai Nagar, Saravanampatti - Kalapatti Road, Saravanampatti,
Coimbatore, Tamil Nadu 641035, India
Ph: +91 9385339863 | www.threatenedtaxa.org
Email: sanjay@threatenedtaxa.org

For Focus, Scope, Aims, and Policies, visit https://threatenedtaxa.org/index.php/JoTT/aims_scope
For Article Submission Guidelines, visit https://threatenedtaxa.org/index.php/JoTT/about/submissions
For Policies against Scientific Misconduct, visit https://threatenedtaxa.org/index.php/JoTT/policies_various

continued on the back inside cover

Cover: *Geodorum laxiflorum* Griff.—inflorescence (Orchidaceae) © Ashish Ravindra Bhoyar.

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 February 2022 | 14(2): 20615–20624

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.7663.14.2.20615-20624

#7663 | Received 16 September 2021 | Final received 28 December 2021 | Finally accepted 22 February 2022

OPEN ACCESS

COMMUNICATION

Seasonal variations influencing the abundance and diversity of plankton in the Swarnamukhi River Estuary, Nellore, India

Krupa Ratnam [1*], V.P. Limna Mol [2], S. Venkatnarayanan [3], Dilip Kumar Jha [4], G. Dharani [5] & M. Prashanthi Devi [6*]

[1,3,4,5] Ocean Science and Technology for Islands, National Institute of Ocean Technology, Ministry of Earth Sciences, Govt. of India, Chennai, Tamil Nadu 600100, India.

[2] School of Ocean Science and Technology, Kerala University of Fisheries and Ocean Studies, Panangad, Kochi, Kerala 682506, India.

[1,6] Department of Environmental Science and Management, School of Environmental Sciences, Bharathidasan University, Tiruchirappalli, Tamil Nadu 620024, India.

[1] ratnamkrupa@gmail.com, [2] limnaa@gmail.com, [3] venkatnarayanan.srinivas@gmail.com, [4] dilipjhaniot@gmail.com, [5] dhara@niot.res.in, [6] prashanthidevi@gmail.com (* corresponding authors)

Abstract: An integrated approach was used to study the seasonal influence on the abundance and diversity of phytoplankton and zooplankton in the Swarnamukhi River Estuary (SRE) and the adjacent coast covering five stations by collecting monthly samples from the years 2014 to 2017. A total of 54 phytoplankton species conforming to four families and 58 zooplankton species conforming to nine families were recorded. Phytoplankton abundance and richness were high during pre-monsoon (PRM - 56410 cells/L) followed by monsoon (MON – 42210 cells/L). A similar trend was observed in the case of zooplankton, where abundance was recorded high during PRM (124261 ind./m^3) followed by MON (111579 ind./m^3). Moreover, phytoplankton and zooplankton were dominated by the diatoms and copepods, respectively. Both phytoplankton and zooplankton exhibited significant temporal ($F= 26.4$, $p < 0.05$) and spatial ($F= 32.1$, $p < 0.05$) variations. The higher density and abundance were recorded in the inner stations compared to the open sea. The present study reveals that the SRE have a rich diversity which could be attributed to a higher nutrient influx in the inner stations. The anthropogenic discharge from the surrounding aqua farms, agricultural land, and human settlement area could cause concerns for the local flora and fauna if a proper mitigation plan is not evolved through long-term monitoring study in this coastal region.

Keywords: Abundance, diversity, estuary, indices, Nellore, Phytoplankton, zooplankton.

Editor: Anonymity requested.

Date of publication: 26 February 2022 (online & print)

Citation: Ratnam, K., V.P.L. Mol, S. Venkatnarayanan, D.K. Jha, G. Dharani & M.P. Devi (2022). Seasonal variations influencing the abundance and diversity of plankton in the Swarnamukhi River Estuary, Nellore, India. *Journal of Threatened Taxa* 14(2): 20615–20624. https://doi.org/10.11609/jott.7663.14.2.20615-20624

Funding: The authors are grateful to the Ministry of Earth Sciences (MoES), Govt. of India, for providing funding to carry out the present study.

Competing interests: The authors declare no competing interests.

Author details & **Author contributions:** See end of this article.

Acknowledgements: We are thankful to Dr. G. A. Ramadass, the Director, NIOT, MoES, Govt. of India, Chennai, for the approvals and constant support. Thanks to Dr. R. Kirubagaran, Scientist-G (Retd.), NIOT, for his encouragement. We also thank our colleagues Dr. S. Rajaguru, Dr. S. Venkatesh, Mr. P. Sathish Kumar and Dr. Vikas Pandey and the staff and students of Department of Environmental Science and Management, School of Environmental Sciences, Bharathidasan University, Tiruchirappalli, India. Authors also thank the anonymous reviewers and editors for refining the manuscript.

INTRODUCTION

Estuaries act as transitional zones and support the coastal economy in the form of fishing, aquaculture, transport, and tourism activities. They are also known to be highly productive ecosystems that provide shelter and breeding grounds for various marine aquatic organisms (Nybakken & Bertness 2005). Unlike salt marshes and backwaters, estuaries are complex and highly dynamic and their structure and function are influenced by anthropogenic inputs (e.g., aquaculture, agriculture, and industrial discharges) from the land and get transferred to the sea (Shenai-Tirodkar et al. 2016). Such anthropogenic activities can alter the physicochemical properties of water and immensely influence the migration, richness, distribution, diversity, and feeding of the associated marine aquatic organisms (Unanam & Akpan 2006). Plankton are aggregates of organisms (plants and animals) passively floating, drifting, or somewhat motile occurring in aquatic ecosystems (Lalli & Parsons 1993). Phytoplankton is grazed upon by zooplankton and other higher aquatic organisms (nektons) (Calbet 2008). Nutrient enrichment through, riverine inputs, and discharge from anthropogenic activities can significantly alter the phytoplankton growth and in turn affect the zooplankton grazing pressure (Berdalet et al. 1996). Therefore, plankton assemblages are usually helpful in assessing the water quality as they quickly respond to the environmental changes, hence; act as ecological indicators of an ecosystem (Hays et al. 2005; Longhurst 2007).

In the Indian scenario, most of the estuarine ecosystems are under stress due to natural and anthropogenic inputs from the surrounding environment. With the increase in nearby aquaculture, agricultural, and anthropogenic activities, the effluent discharges find their way into the nearby coastal areas which provides an advantageous environment to the organisms for proliferation. Similar activities have been reported in the Swarnamukhi River Estuary (SRE) region, fewer studies have been carried out to assess the tidal variations (Reddi et al. 1993), hydrographic properties of water (Sreenivasulu et al. 2015), contamination studies on the presence of heavy metal in seawater, sediments, & organisms (Reddy et al. 2016; Sreenivasulu et al. 2018; Jha et al. 2019), and the benthic organisms (Pandey et al. 2021). However, an elaborate study for the plankton communities is not available for the SRE region. A long-term study (2014–2017) was conducted to analyze the planktonic (phytoplankton and zooplankton) assemblages. This study can serve as baseline information for future ecological assessment related to the SRE and other similar tropical ecosystems.

MATERIALS AND METHODS

Study area

The SRE region (14.072–14.077 °N and 80.126–80.154 °E), situated in the Vakadu Mandal of Nellore district, Andhra Pradesh. This estuarine runs about 1.5 km in length perpendicular to the Bay of Bengal with an average depth of 1.0 m and an area of 6.25 km^2 (Reddi et al. 1993). Nellore receives the majority of the rainfall during the north-east monsoon (October to December) than the south-east monsoon (Kannan et al. 2016). Altogether, five sampling stations were fixed; four stations covering SRE and a reference station in the open sea (OS) about a kilometer from the shore. The coordinates were fixed using GPS (Garmin) covering the study area and the surrounding coast. The selected sampling stations are shown in (Figure 1), covering the Buckingham canal (BC), near to (SR1), away from mouth (SR2), mouth (SRM), and open sea (OS). The monthly sampling was carried out covering low and high tides at all the stations. The data was categorized seasonally as pre-monsoon [PRM (January–May)], monsoon [MON (June–September)], and post-monsoon [POM (October–December)] from May 2014 to December 2017 for analysis (5 stations × 43 months × 2 tides = 430 samples).

Temperature and rainfall

The temperature and rainfall data for the sampling period were obtained from the Indian Meteorological Department, Ministry of Earth Sciences, Government of India. The obtained data (monthly) was plotted for better interpretation (refer to Figure 2).

Biological parameters

For phytoplankton sampling, 5.0 L of surface seawater samples (in triplicate) were collected in a polyethylene container and preserved with 4% formalin and Lugol's iodine. Phytoplankton analysis was carried out using Utermöhl (1931) sedimentation technique. The samples were allowed to settle in a measuring cylinder for a period of 48 hours and siphoned (using a 10 µ mesh) to obtain 50 mL concentrate (Hasle,1978). For phytoplankton enumeration, 1 mL of the concentrated sample was taken onto a Sedgewick rafter plankton counting chamber and the total number of organisms was examined under a compound microscope. Phytoplankton was identified using standard identification keys (Subrahmanyan

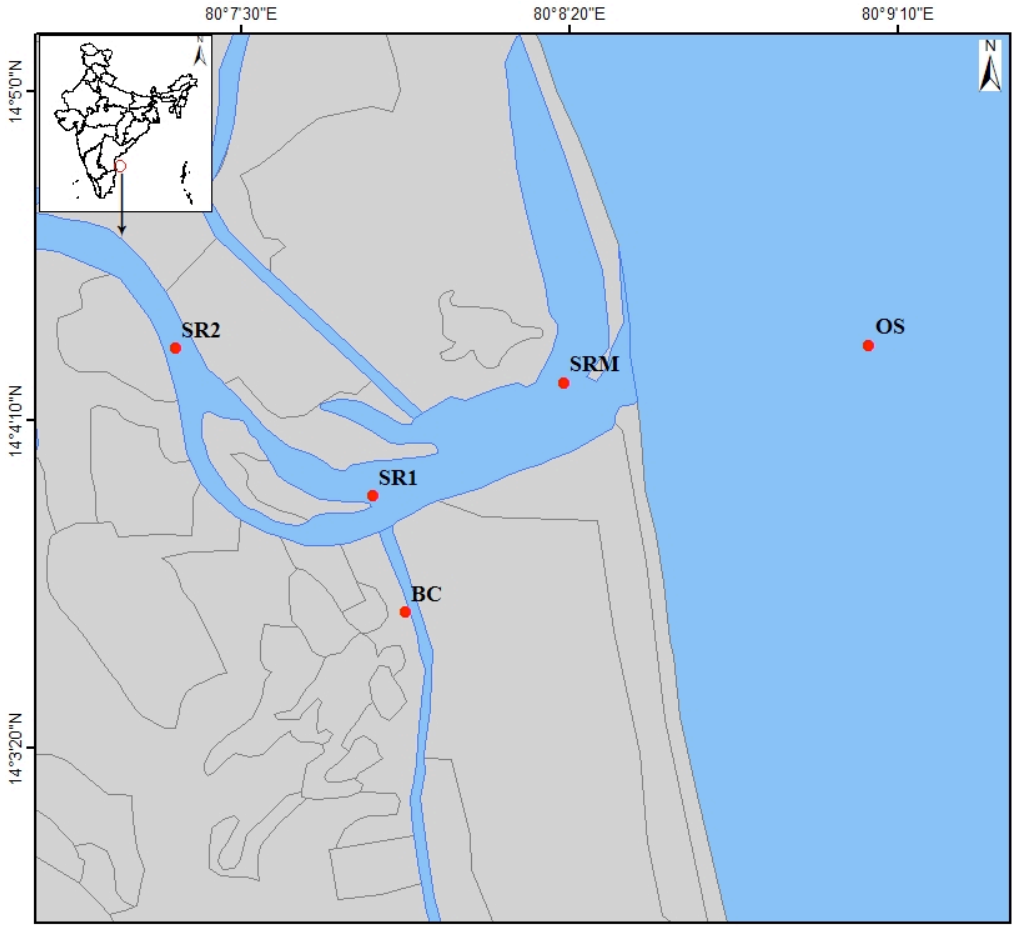

Figure 1. Sampling stations at Pamanji, Nellore.

1946, 1959; Santhanam et al. 1987; Tomas 1997). For chlorophyll-*a* (chl-*a*) analysis, 1,000 mL of the water sample was filtered through Whatman GF/F filter paper and chl-*a,* was extracted by following the modified acetone extraction method (Parson et al. 1984). The extracted chl-*a* samples were analyzed using a spectrofluorometer (make Hitachi model F-4600) and obtained results were expressed in mg/m^3. The surface zooplankton samples were collected using a zooplankton net (150 µm mesh size, 0.5 m diameter, 1.8 m length) fitted with a digital flow meter (make Hydro-Bios). The surface hauls were made from the stern side of the boat running at a speed of 1 km/hr and the collected plankton was transferred to 500 mL polythene containers and preserved using 5% buffered formalin. In the laboratory, triplicate subsamples were taken onto a Sedgewick rafter plankton counting chamber and the total numbers of organisms were enumerated under the compound microscope (Nikon model SMZ 1500). The zooplankton was identified following the standard identification key of Kasturirangan (1963) and Santhanam & Srinivasan (1994). The zooplankton biomass was determined by the settled volume method, where the collected sample was allowed to settle and the obtained biomass was expressed as mL/m^3.

Statistical analysis

PRIMER v6.1 was used for univariate indices, e.g., species richness (S), abundance, Margalef's diversity (d), Shannon-Wiener diversity index (H', $\log_2$), Simpson's diversity (1-λ), and Pielou's evenness (J') (Clarke & Gorley 2006). The sitewise variation between the environmental parameters were analyzed using one way analysis of variance (ANOVA) in Microsoft Excel 2007. To determine the phytoplankton diversity and dominance in different seasons and the stations, univariate diversity indices were applied. The abundance of phytoplankton and zooplankton was represented using a box plot using SPSS v10 software.

RESULTS AND DISCUSSION

Temperature and rainfall

The rainfall data were analyzed for the years 2014–2017 and it indicates that maximum rainfall was recorded from September to December (Figure 2). It ranged 6.2–221.1 mm (2014), 8.0–767.2 mm (2015), 10.6–149.0 mm (2016), and 1.1–218.0 mm (2017). Maximum rainfall of 767.2 mm was recorded in November 2015. The lowest rainfall was recorded in 2016 during the north-east monsoon (December 149.0 mm). The atmospheric temperature (AT) ranged 22.1–40.2 °C, 21.4–39.7 °C, 22.0–39.5 °C, and 21.8–40.9 °C in 2014, 2015, 2016, and 2017, respectively. The AT peaked during the summer, i.e., April and May. The SRE region is continuously fed with tidal water and keeps the ecosystem comparatively in good condition; however, every year during the MON when the precipitation is less, the mouth of the river gets closed for a few months (Sreenivasulu et al. 2016; Pandey et al. 2021). During this period, the concentration of some of the parameters changed drastically due to stagnation. It has been reported that the rainfall can significantly affect the phytoplankton composition in the river (Jeong et al. 2007), estuaries (D'silva et al. 2012), and reservoirs (Zhou et al.,2012) worldwide.

Phytoplankton diversity, density, and chlorophyll-a

A total of 54 phytoplankton species include 38 diatoms, nine dinoflagellates, three green algae, and four blue-green algae. Diatoms (Bacillariophyceae) were the dominant group consisting of 70%, 69%, and 76% in PRM, MON, and POM, respectively. The next dominant was dinoflagellates (dinophyceae) registering 20%, 14%, and 18%, in PRM, MON, and POM, respectively. Green algae (Cyanophyceae) were recorded during PRM (6%) and MON (7%) seasons. Blue-green algae (Chlorophyceae) were 4%, 10, and 6%, in PRM, MON, and POM, respectively (Figure 3).

During the study period, the highest phytoplankton density was recorded in the SRM (56,410 cells/L) and it was lowest in the OS (2,440 cells/L). Phytoplankton density in the inner riverside stations, BC, SR2, and SR1 ranged 9,605–50,160 cells/L, 7,785–56,340 cells/L, and 10,500–55,850 cells/L, respectively. In SRM and OS, phytoplankton density ranged 10,033–56,410 cells/L and 2,440–37,100 cells/L, respectively. The mean phytoplankton density recorded in the inner stations BC, SR2, and SR1 were 19,785, 21,005, and 18,815 cells/L, respectively (Figure 4a). In the SRM and OS region, the mean phytoplankton density was 20000 and 17864 cells/L, respectively. The maximum density recorded in PRM, MON, and POM was 56,410, 42,210, and 24,480 cells/L, respectively. The phytoplankton density in PRM ranged 13,647–23,217 cells/L, in MON it ranged 18,585–22,746 cells/L, and in POM it ranged 9,492–16,973 cells/L (Figure 4a). Among diatoms, *Rhizosolenia* sp. was the dominant species in all the stations, followed by *Thalassiosira subtilis* and *Navicula* sp. The *Protoperidinium* sp. dominated the dinoflagellates community followed by *Ceratium* sp. and *Prorocentrum* sp. during the study period. All the three species of green algae (*Chlorella* sp., *Oocystis* sp., and *Pediastrum* sp.) were present during MON, while only *Chlorella* sp. and *Oocystis* sp. were represented during PRM and none of the three species mentioned above were present during POM. Among the four blue-green algae recorded during the study, *Trichodesmium* sp. and *Spirulina* sp. were observed during PRM, *Microcystis* sp. and *Oscillatoria* sp. were observed during POM, and all the four species were present during the MON. The SRE received precipitation during the POM (north-east monsoon) which could enhance the land-driven run-off from the aqua farms, agricultural land, and domestic discharge which consequently could have attributed higher nutrient inputs helping phytoplankton to proliferate and bloom. Higher phytoplankton density in the inner stations could be attributed to higher nutrient input in those stations from the surrounding regions (aquaculture runoff) (Mckee et al. 2000; Roberts & Prince 2010).

The chl-*a* in PRM ranged 2.11 ± 0.12 mg/m^3 (OS & SRM)–10.71 ± 2.08 mg/m^3 (BC). In MON, it ranged 2.10 ± 0.49 mg/m^3 (OS)–8.46 ± 1.76 mg/m^3 (BC). In POM, it ranged 0.78 ± 0.17 mg/m^3 (SRM)–3.41±0.24 mg/m^3 (BC) (Figure 4b). The data indicates that the phytoplankton exhibited significant variations between seasons ($F= 26.4$, $p < 0.05$), while variation was insignificant between the stations ($F= 1.026$, $p > 0.05$). The diversity indices between the five stations did not vary significantly ($F= 1.026$, $p > 0.05$). An increase in phytoplankton abundance and chl-*a* was on par with previous studies observed during the PRM and MON (Achary et al. 2014; Baliarsingh et al. 2016).

Univariate diversity indices have shown variations between the three different seasons (Table 1). Throughout the study, maximum phytoplankton species were recorded in the BC station in the monsoon (45 species). Marglef's species richness (d) was the highest in MON, followed by PRM whereas it was lowest in POM. This could be attributed to the high species diversity in MON compared to the other two seasons. Pielou's evenness (J') and Simpson's dominance (D)

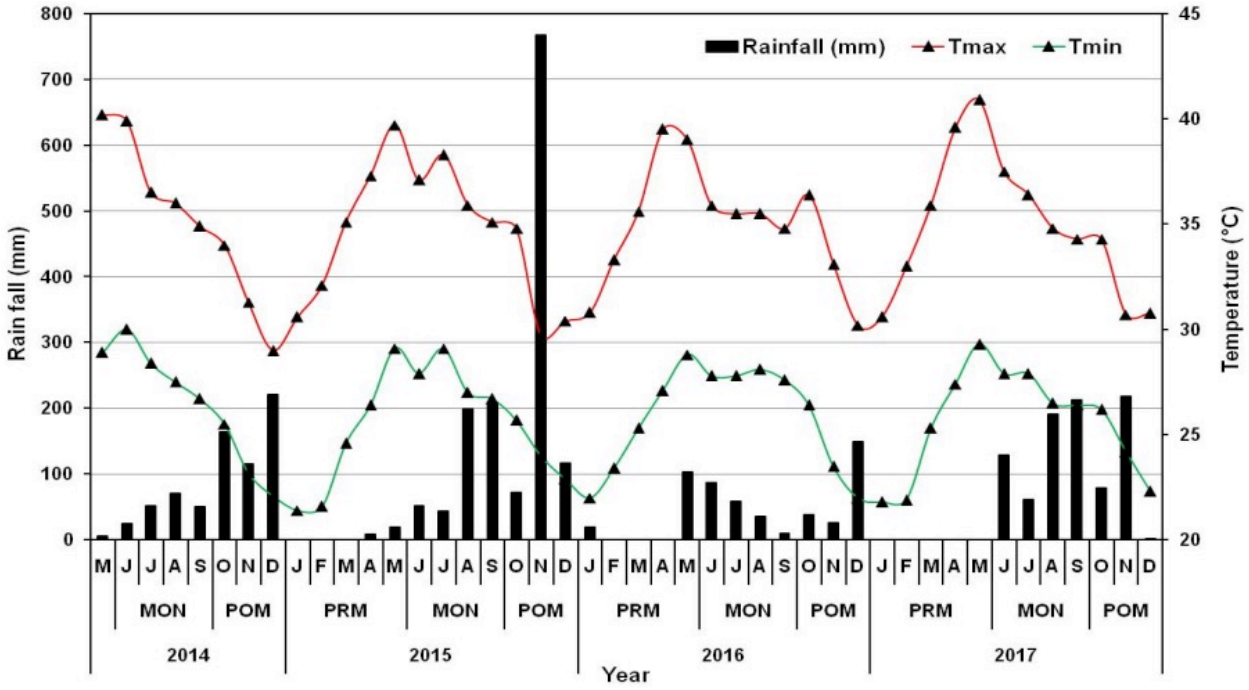

Figure 2. Temperature (°C) and rainfall (mm) data from 2014 to 2017 in Nellore (Tmax= maximum temperature, Tmin= minimum temperature).

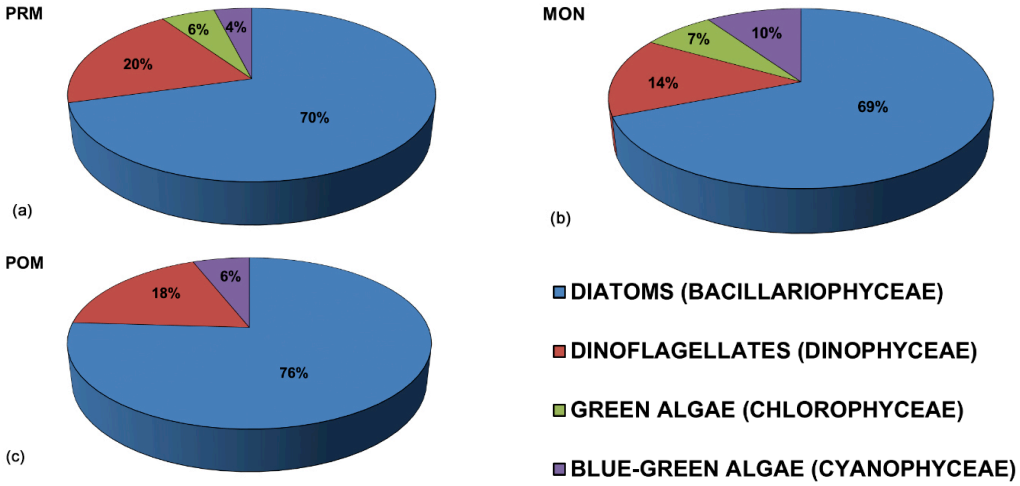

Figure 3. Seasonal variation (a) PRM, (b) MON, and (c) POM showing phytoplankton groups at Pamanji.

were relatively higher in the PRM and POM compared to the MON season. The relatively low value in MON can be attributed to the high species diversity during this season. In general, the high species dominance in PRM and POM can be related to the low species richness in these seasons. The maximum phytoplankton abundance and chl-*a* biomass were recorded during the PRM followed by MON season. The highest phytoplankton abundance and biomass was recorded during 2014 and 2015.

Zooplankton density and diversity

A total of 58 different species of zooplankton conforming to nine different phyla, i.e., Sarcomastigophora, Ciliophora, Ctenophora, Cnidaria, Chordata, Chaetognatha, and Arthropoda were recorded. The increased diversity of zooplankton especially the copepods observed in the estuarine region was on par with previous reports from the east coast of India (Madhupratap et al. 1992; Thippeswamy & Malathi 2009). However, the number of copepod taxa

Table 1. Spatio-temporal univariate diversity indices for phytoplankton.

Season	Station	Total species (S)	Total Individuals (N)	Margalef's species richness (d)	Pielou's evenness (J')	Shannon Wiener Diversity index (H')	Simpson's dominance (D)
PRM	BC	36	23217	3.27	0.93	3.36	0.96
	SR2	35	22493	3.13	0.91	3.25	0.94
	SR1	36	18980	3.26	0.93	3.35	0.95
	SRM	35	21054	3.16	0.93	3.34	0.95
	OS	35	13647	3.28	0.91	3.25	0.95
MON	BC	45	22746	4.54	0.71	2.70	0.87
	SR2	40	22409	3.99	0.73	2.72	0.87
	SR1	41	18585	4.15	0.73	2.71	0.88
	SRM	42	20040	4.12	0.82	3.09	0.93
	OS	41	18906	3.90	0.78	2.90	0.91
POM	BC	30	14959	3.05	0.88	2.99	0.93
	SR2	27	16378	2.75	0.92	3.05	0.94
	SR1	29	10521	3.03	0.92	3.11	0.94
	SRM	29	16973	2.94	0.91	3.07	0.94
	OS	18	9492	1.87	0.91	2.64	0.90

Table 2. Spatio-temporal univariate diversity indices for zooplankton.

Season	Station	Total species (S)	Total Individuals (N)	Margalef's species richness (d)	Pielou's evenness (J')	Shannon Wiener Diversity index (H')	Simpson's dominance (D)
PRM	BC	19	27100	1.759	0.7223	2.13	0.8415
	SR2	19	27793	1.828	0.7863	2.32	0.8749
	SR1	19	26655	1.874	0.7829	2.31	0.8615
	SRM	19	29114	1.827	0.7811	2.30	0.8694
	OS	19	20090	1.873	0.7468	2.20	0.8447
MON	BC	23	24006	2.306	0.7836	2.46	0.8493
	SR2	21	16390	2.057	0.7903	2.41	0.8460
	SR1	19	24330	1.932	0.7172	2.11	0.7880
	SRM	22	21521	2.019	0.6835	2.11	0.8170
	OS	19	16691	1.793	0.5965	1.76	0.6701
POM	BC	16	16576	1.463	0.5105	1.42	0.5485
	SR2	9	22426	0.714	0.2415	0.53	0.2313
	SR1	8	14828	0.783	0.6151	1.28	0.6249
	SRM	14	19619	1.184	0.4009	1.06	0.4726
	OS	13	13286	1.045	0.3664	0.94	0.3983

reported during the present survey was comparatively less than previous reports in the Andhra coast (Rakhesh et al. 2006).

In BC, density varied 2,722–82,540 ind./m^3. In SR1, it varied 2,871–84,230 ind./m^3. In SR2, the density of zooplankton varied 1,645–105,558 ind./m^3. In SRM, it varied 7,551–131,579 ind./m^3. Similarly, in OS, it varied 1,523–96,872 ind./m^3. It was observed that zooplankton density was maximum at SRM (131,579 ind./m^3) (Figure 5a). Zooplankton density in PRM, MON, and POM ranged 20,090–29,114 ind./m^3, 16,390–24,330 ind./m^3, and 13,286–22,426 ind./m^3, respectively. Maximum

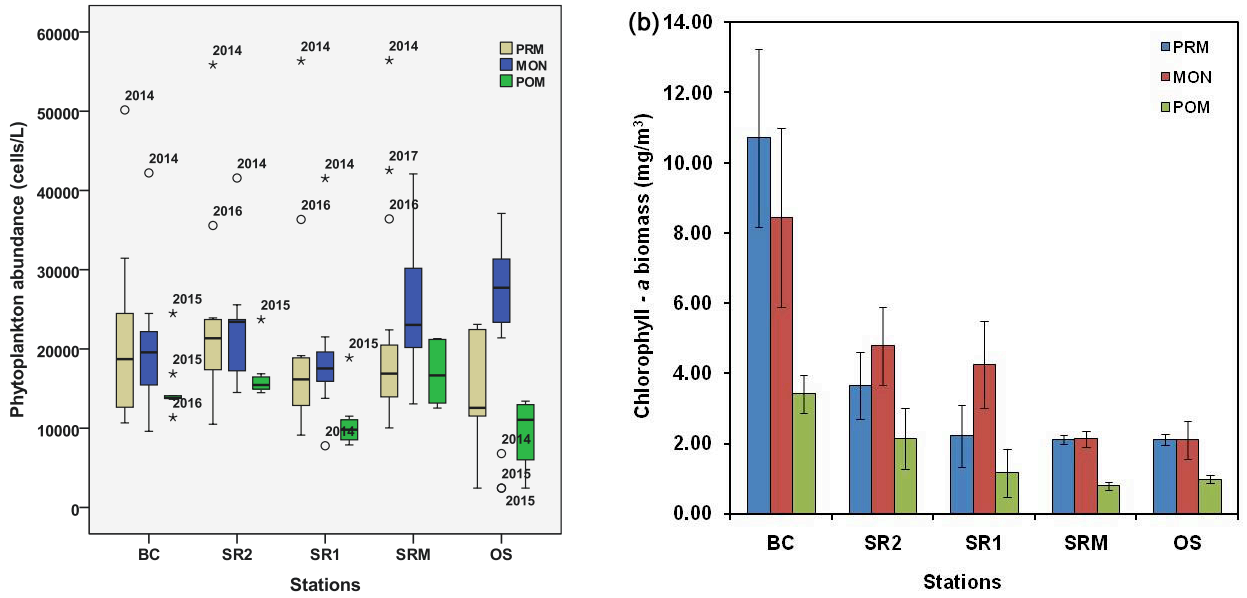

Figure 4. Box-plot representing the seasonal variation in: a—phytoplankton abundance observed at Pamanji. Each box plot with the central point represents the median, the box gives the interval between the 25% and 75% percentiles, the whisker indicates the range, mild outliers are marked with a circle (o) and extreme outliers are marked with an asterisk (*) | b—chlorophyll-a, is expressed in mg/m³.

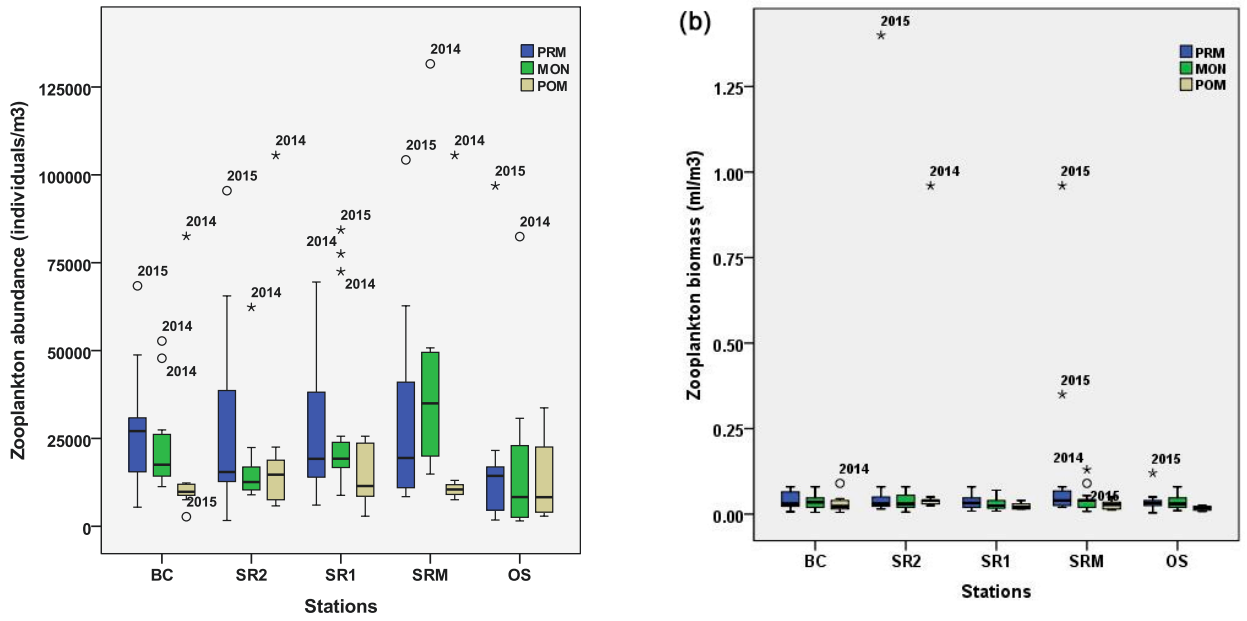

Figure 5. Box-plot representing the seasonal variation in: a—zooplankton abundance | b—biomass observed at Pamanji during 2014–2017. Each box plot with the central point represents the median, the box gives the interval between the 25% and 75% percentiles, the whisker indicates the range, mild outliers are marked with a circle (o) and extreme outliers are marked with an asterisk (*).

zooplankton abundance was observed during PRM followed by MON and POM during the study period. The OS recorded the least abundance throughout the seasons (PRM: 20,091 ind./m³, MON: 16,390 ind./m³ & POM: 13,286 ind./m³, respectively). Maximum zooplankton biomass was observed in SR2 ranging from 0.04 to 0.13 ml/m³ throughout the study period (Figure 5b). OS recorded the least biomass (0.02 to 0.04 ml/m³) throughout the sampling period. Overall PRM followed by MON season exhibited favourable conditions for zooplankton growth in the SRE region.

Zooplankton exhibited a typical season-specific

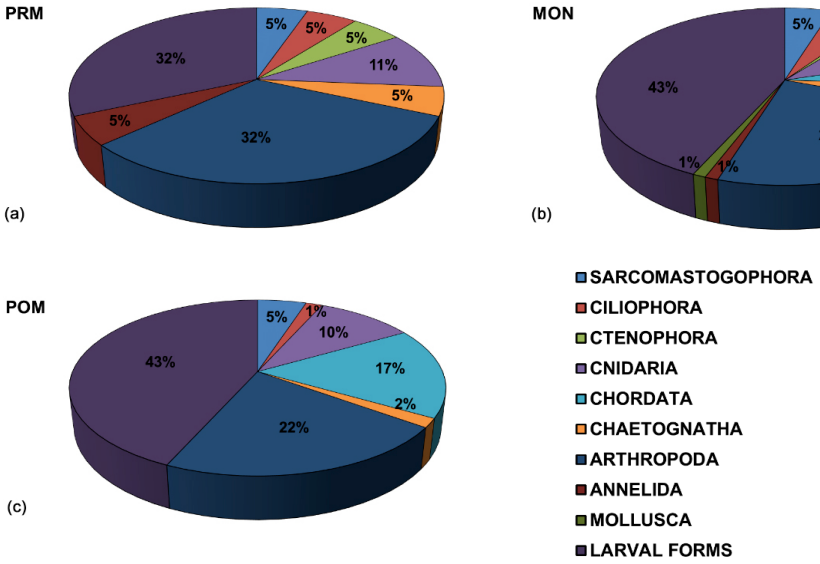

Figure 6. Seasonal variation (a) pre-monsoon, (b) monsoon, and (c) post-monsoon in percentage composition of zooplankton groups at Pamanji.

and site-specific variation. Copepods followed by invertebrate larval forms dominated the zooplankton community during all three seasons. A total of 37 species of copepods were recorded during the survey, with the major species being *Acartia danae*, *A. spinicauda*, *A. clausii*, *Paracalanus parvus*, *Acrocalanus gibber*, *A. longicornis*, *Corycaeus danae*, *C. catus*, *Oithona rigida,* and *Euterpina acutifrons* were recorded throughout the year irrespective of seasons. Copepods followed by larval forms dominate the entire zooplankton community irrespective of seasons (Figure 6). The least contributing groups (less than 10%) include organisms belonging to phyla/group Sarcomastigophora, Ciliophora, Ctenophora, Cnidaria, Chordata, Chaetognatha, and Annelida. Copepods species such as *Eucalanus* sp., *Subeucalanus* sp., *Onacaea* sp., *Centropages* sp., and *Copilia* sp. were present only during POM season in higher numbers in all stations which correlates with the lowering salinity in all stations due to the north-east monsoon. Apart from the copepods, some other larval forms exhibited seasonality such as bivalve (PRM and MON) and gastropod veligers (MON and POM). Larval forms belonging to phylum Mollusca, e.g., *Creisis* sp. and the Ophiothrix larva were exclusively present only in monsoon. Copepod nauplius, crustacean nauplius, and polychaete larvae were present throughout the year in all the stations.

Univariate diversity indices have shown variations between the three seasons (Table 2). Marglef's species richness (d) was the highest in MON, followed by PRM and POM. Among the five stations, a significant difference in the diversity indices was observed during the POM. BC region was more diverse and recorded maximum zooplankton species (19–23). This could be attributed to anthropogenic activities in the surrounding environment (Pandey et al. 2021).

The zooplankton community exhibited significant differences between the seasons (F= 191.1, p <0.001) as well as the stations (F= 224.5, p <0.001). The present investigation has shown the presence of discrete assemblages of zooplankton communities observed in the SRE and coastal region indicating a strong seasonal fluctuation with lower abundances in POM and higher during the PRM and MON season. A similar study conducted elsewhere suggested that phytoplankton abundance plays a very important role in regulating zooplankton population in estuaries (Jagadeesan et al. 2013; Nandy & Mandal 2020).

The coast is prone to heavy rainfall, the likely discharges from the nearby aquaculture activities in the inner stations (BC, SR2, and SR1) of the SRE region which was supported with previous studies (Sreenivasulu et al. 2018). The results of this study are in agreement with Jha et al. (2019) and Pandey et al. (2021) in the same region.

CONCLUSION

The present long-term study reveals the spatial and temporal variations of phytoplankton and zooplankton in the SRE and the adjoining coast. The study also

highlights that the SRE region receives very little rainfall during the MON period and most of the rainfall occurred only during the POM period, i.e., during the north-east monsoon (NEM) period. The SRE region is known to have a good cover of mangroves swamps and is usually impacted by anthropogenic activities, such as, aquaculture farms, agriculture activities, and discharge areas from nearby vicinity. The increased nutrient concentration significantly affected the plankton community in the SRE region. Our study indicates that the phytoplankton community exhibited significant variations between seasons. The zooplankton density also showed significant variation and revealed the anthropogenic impact in the study. The present study suggests that phytoplankton and zooplankton are important indicators of a healthy ecosystem which was evident in the present study. Moreover, the study also suggests that a long-term monitoring could help in understanding the ecosystem and planning the mitigation management strategy for the tropical coastal environment.

REFERENCES

Achary, M.S., S. Panigrahi, K.K. Satpathy, G. Sahu, A.K. Mohanty, M. Selvanayagam & R.C. Panigrahy (2014). Nutrient dynamics and seasonal variation of phytoplankton assemblages in the coastal waters of southwest Bay of Bengal. *Environmental Monitoring and Assessment* 186: 5681–5695.

Baliarsingh, S.K., S. Srichandan, A. A. Lotliker, K. C. Sahu & T. Srinivasa Kumar (2016). Phytoplankton community structure in local water types at a coastal site in north-western Bay of Bengal. *Environmental Monitoring and Assessment* 188: 427. https://doi.org/10.1007/s10661-016-5424-y

Berdalet, E., C. Marrase, M. Estrada, L. Arin, & M. Maclean (1996). Microbial community responses to nitrogen and phosphorus deficient nutrient inputs: Microplankton dynamics and biochemical characterization. *Journal of Plankton Research* 18(9): 1627–1641.

Calbet, A. (2008). The trophic roles of microzooplankton in marine systems. *ICES Journal of Marine Science* 65: 325–331.

Clarke, K & R.N. Gorley (2006). Primer v6: User Manual/Tutorial.

Dash, S., S. Padhan, G. Rajhans, P. Mohapatra, R. Sarangi, D. Raut, B. Mohanty, S. Nayak & L. Patnaik (2019). Abundance and Diversity of Plankton in the Coastal Waters of Chandipur, Bay of Bengal. *Russian Journal of Marine Biology* 45: 252–261.

D'Silva, M.S., A.C. Anil, R.K. Naik & P.M. D'Costa (2012). Algal blooms: a perspective from the coasts of India. Natural Hazards 63: 1225–1253.

Hasle, G.R. (1978). The inverted-microscope method, pp. 88–96. In: Sournia, A. (eds.). *Phytoplankton Manual 6.* UNESCO Monographs on Oceanographic Methodology.

Hays, G.C., A.J. Richardson & C. Robinson (2005). Climate change and marine plankton. *Trends in Ecology and Evolution* 20: 337–344.

Jagadeesan, L., R. Jyothibabu, A. Anjusha, P.M. Arya, K.R. Muraleedharan & K. Sudheesh (2013). Ocean currents structuring the mesozooplankton in the Gulf of Mannar and Palk Bay, southeast coast of India. *Progress in Oceanography* 110: 27–48.

Jeong, K.S., D.K. Kim, & G.J. Joo (2007). Delayed influence of dam storage and discharge on the determination of seasonal proliferations of Microcystis aeruginosa and Stephanodiscus hantzschii in a regulated river system of the lower Nakdong River (South Korea). *Water Research* 41: 1269–1279.

Jha, D.K., K. Ratnam, S. Rajaguru, G. Dharani, M.P. Devi & R. Kirubagaran (2019). Evaluation of trace metals in seawater, sediments, and bivalves of Nellore, southeast coast of India, by using multivariate and ecological tool. *Marine Pollution Bulletin* 146: 1–10.

Jutla, A., S. Akanda & S. Islam (2009). *Relationship between Phytoplankton, Sea Surface Temperature and River Discharge in Bay of Bengal.* Geophysical Research Abstracts 11, EGU2009-1091-2, 2009, EGU General Assembly 2009.

Kannan, R., M.V. Ramanamurthy & A. Kanungo (2016). Shoreline Change Monitoring in Nellore Coast at East Coast Andhra Pradesh District Using Remote Sensing and GIS. *Journal of Fisheries & Livestock Production* 4: 161. https://doi.org/10.4172/2332-2608.1000161

Kasturirangan, L.R. (1963*).* *A key for the identification of the more common planktonic Copepoda of Indian coastal waters*. Publication no.2, Indian National Committee on Oceanic Research. CSIR, New Delhi.

Lalli, C & T. Parsons (1993). *Biological Oceanography: An Introduction. Butterworth-Heinemann*.

Longhurst, A.R. (2007). *Ecological geography of the sea*. Amsterdam: Elsevier, 542pp.

Madhupratap, M., P. Haridas, N. Ramaiah & C.T. Achuthankutty (1992). *Zooplankton of the southwest coast of India: Abundance, composition, temporal and spatial variability in 1987.* In B.N. Desai (eds.). *Oceanography of the Indian Ocean*. Oxford and IBH, New Delhi, 99pp.

Mckee, L.J., B.D. Eyre & S. Hossain (2000). Transport and retention of nitrogen and phosphorus in the sub-tropical Richmond River estuary, Australia - A budget approach. *Biogeochemistry* 50: 241–278.

Nandy, T & S. Mandal (2020). Unravelling the spatio-temporal variation of zooplankton community from the river Matla in the Sundarbans Estuarine System, India. *Oceanologia* 62 (3): 326–346.

Nybakken, J.W. & M.D. Bertness (2005). Estuaries and salt marshes. In J.W. Nybakken & M. D. Bertness (eds.). *Marine biology: an ecological approach*. Pearson/Benjamin Cummings, San Francisco, 579pp.

Pandey, V., S. Venkatnarayanan, P.S. Kumar, R. Krupa, D.K. Jha, S. Rajaguru & G. Dharani (2021). Assessment of ecological health of Swarnamukhi river estuary, southeast coast of India, through AMBI indices and multivariate tools. *Marine Pollution Bulletin* 164: 112031. https://doi.org/10.1016/j.marpolbul.2021.112031

Parsons, T.R., Y. Maita & C.M. Lalli (1984). *A Manual of Chemical and Biological Methods for Seawater Analysis.* Pergamon Press, Oxford, 173 pp.

Rakhesh, M., A. Raman & D. Sudarsan (2006). Discriminating zooplankton assemblages in neritic and oceanic waters: A case for the northeast coast of India, Bay of Bengal. *Marine Environmental Research* 61(1): 93-109.

Reddi, K.R., N. Jayaraju, I. Suriyakumar & K. Sreenivas (1968). Tidal fluctuation in relation to certain physio-chemical parameters in Swarnamukhi river estuary, East coast of India. *Indian Journal of Geo-Marine Sciences* 22: 232–234.

Reddy, S.R., B.C., N. Jayaraju, G. Sreenivasulu, U. Suresh & A.N. Reddy (2016). Heavy metal pollution monitoring with foraminifera in the estuaries of Nellore coast, East coast of India. *Marine Pollution Bulletin* 113(1-2): 542–551. https://doi.org/10.1016/j.marpolbul.2016.08.051

Roberts, A.D. & S.D. Prince (2010). Effects of urban and non-urban land cover on nitrogen and phosphorus runoff to Chesapeake Bay. *Ecological indicators* 10 (2): 459-474.

Santhanam, R., N. Ramanathan, K.V. Venkataramanuja, & G. Jegathee-san (1987). *Phytoplankton of the Indian Seas: An Aspect of marine Botany*. Daya Publishing House, Delhi, 127 pp.

Santhanam, R. & A. Srinivasan (1994). *A manual of marine zooplankton*. Oxford & IBH Publishing Company, 160pp.

Shenai-Tirodkar, P.S., M.U. Gauns & Z.A. Ansari (2016). Evaluation of surface water and sediment quality in Chicalim Bay, Nerul Creek, and Chapora Bay from Goa coast, India– a statistical approach. *Environmental Monitoring and Assessment* 188(8): 472. https://doi.org/10.1007/s10661- 016-5445-6

Sreenivasulu, G., N. Jayaraju, B.C.S.R. Reddy & T.L. Prasad (2015). Physico-chemical parameters of coastal water from Tupilipalem coast, Southeast coast of India. *Journal of coastal sciences* 2(2): 34–39.

Sreenivasulu, G., N. Jayaraju, B.C.S.R. Reddy, T.L. Prasad, B. Lakshmanna, K. Nagalakshmi & M. Prashanth, (2016). River mouth dynamics of Swarnamukhi estuary, Nellore coast, southeast coast of India. *Geodesy and Geodynamics* 7(6): 387 - 395. https://doi.org/10.1016/j.geog.2016.09.003

Sreenivasulu, G., N. Jayaraju, B.C.S.R. Reddy, B. Lakshmanna & T.L. Prasad (2018). Influence of coastal morphology on the distribution of heavy metals in the coastal waters of Tupilipalem coast, Southeast coast of India. *Remote Sensing Applications: Society and Environment* 10: 190–197. https://doi.org/10.1016/j.rsase.2018.04.003

Subrahmanyan, R., (1946). *A systematic account of the marine plankton diatoms of the Madras coast*. Proceedings of the Indian Academy of Sciences-Section B, 24(4): pp 85–197.

Subrahmanyan, R., (1959). *Studies on the phytoplankton of the west coast of India*. parts I and II. Proceedings of the Indian Academy of Sciences, 50B: pp 113–187.

Thippeswamy, S. & S. Malathi (2009). *Plankton Diversity in Indian Estuaries – A review*. In: Plankton dynamics of Indian waters, pp. 306-333, edited by B. B. Hosetti, Daya Publishing House, Jaipur, India

Tomas, C.R., (1997). *Identifying Marine Phytoplankton: San Diego*. Academic Press, California.

Unanam, A.E. & A.W. Akpan (2006). *Analysis of physico-chemical characteristics of some freshwater bodies in Essien Udim Local Government area of Akwa Ibom State, Nigeria*, In: Proceeding of the 21st Annual Conference of the Fisheries Society of Nigeria.

Utermöhl, von H. (1931). Neue Wege in der quantitativen Erfassung des Planktons. (Mit besondere Beriicksichtigung des Ultraplanktons) Mit 4 Abbildungen im Text. *Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen* 5(2): 567–596.

Zhou, G., X. Zhao, Y. Bi & Z. Hu (2012). Effects of rainfall on spring phytoplankton community structure in Xiangxi Bay of the Three-Gorges Reservoir, China. *Fresenius Environmental Bulletin* 21: 3533-3541.

Author details: Krupa Ratnam is working as a Scientist in the National Institute of Ocean Technology, Ministry of Earth Sciences, Govt. of India, Chennai, India, involved in (ship) ballast water management, environmental impact studies, marine biofouling, etc. He has more than 23 years of research experience in coastal and estuarine systems. Presently, he is involved in the establishment of a land-based ballast water treatment test facility at Nellore, India. Limna Mol V.P. is working as Assistant Professor in Kerala University of Fisheries and Ocean Studies, Kochi, India. She is a marine biologist with a focus on marine ecological studies and biotechnological interventions towards conservation of the marine environment and sustainable utilization of marine resources. Srinivas Venkatnarayanan worked in National Institute of Ocean Technology, Ministry of Earth Sciences, Govt. of India, Chennai, India, as a Scientist. He expertises in marine biotechnology, marine microbiology, zooplankton ecology, algae culture, larval rearing, biocides, antifouling, marine biofouling. He has more than 10 years of research experience. Dilip Kumar Jha is working as a Scientist in National Institute of Ocean Technology, Ministry of Earth Sciences, Govt. of India, Chennai, India. He has expertise in coastal and marine ecology, pollution, geospatial modeling, the underwater study of biological resources, and conservation measures. He has about 24 years of research experience in coastal and marine modeling and management. Presently focussing on site suitability, cage development, and societal benefits through fish farming in open sea conditions along the Indian coasts. G. Dharani is working as Scientist and Head of Marine Biotechnology group in National Institute of Ocean Technology, Ministry of Earth Sciences, Govt. of India, Chennai, India. He has about 28 years of research experience in the field of marine biotechnology and plankton biology. He has published many research articles in peer-reviewed international journals. Prashanthi Devi Marimuthu is working as Associate Professor in Bharathidasan University, Tiruchirappalli, India. She has expertise in remote sensing, geographical information system (GIS), spatial analysis, environment, Wetlands, Cluster Analysis, Biodiversity, water quality for the coastal environment. She has successfully guided many Ph.D. scholars and published many research articles in peer-reviewed international journals. She has about 25 years of research experience in the field of coastal area management.

Author contributions: KR—Participation in sampling, analysis, writing the original draft; VPLM—Participation in sample analysis; SV—Participation in sample analysis; DKJ—Participation in sampling, critical review, commentary or revision – including pre-or post-publication stages; GD—Coordination of the study and leadership responsibility for the research activity planning and execution; MPD—Statistical analysis of the data, guidance and mentorship.

Journal of Threatened Taxa is indexed/abstracted in Bibliography of Systematic Mycology, Biological Abstracts, BIOSIS Previews, CAB Abstracts, EBSCO, Google Scholar, Index Copernicus, Index Fungorum, JournalSeek, National Academy of Agricultural Sciences, NewJour, OCLC WorldCat, SCOPUS, Stanford University Libraries, Virtual Library of Biology, Zoological Records.

NAAS rating (India) 5.64

Print copies of the Journal are available at cost. Write to:
The Managing Editor, JoTT,
c/o Wildlife Information Liaison Development Society,
No. 12, Thiruvannamalai Nagar, Saravanampatti - Kalapatti Road,
Saravanampatti, Coimbatore, Tamil Nadu 641035, India
ravi@threatenedtaxa.org

Journal of Threatened Taxa

www.threatenedtaxa.org

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

February 2022 | Vol. 14 | No. 2 | Pages: 20539–20702
Date of Publication: 26 February 2022 (Online & Print)
DOI: 10.11609/jott.2022.14.2.20539-20702

Publisher & Host

WILD ZOOREACH
Threatened Taxa