Original Research Article

Post-Monsoon Phytoplankton Productivity and Community Structure in the Lower Reaches of the Kallada River, South India

Abstract

Phytoplankton productivity is a key driver of ecological functioning in riverine and estuarine ecosystems. The present study assesses post-monsoon phytoplankton productivity and community structure in the lower reaches of the Kallada River, Kerala. Phytoplankton samples were collected from four stations - West Kallada, Munroe Island, Perugalam, and Koduvila - during October-February 2023. A total of about 35 phytoplankton taxa were recorded across the study area, with Bacillariophyceae forming the dominant group at all stations. Perugalam and West Kallada exhibited higher phytoplankton density and diversity, with Shannon-Wiener diversity values ranging from 2.8 to 3.3, indicating favourable conditions for sustained primary productivity. Diatom dominance ratios varied between 0.48 and 0.74, reflecting moderate to high productivity across stations, with the highest value observed at Koduvila due to dominance of *Melosira varians*. Munroe Island showed moderate productivity characterized by a mixed assemblage influenced by river-estuarine interactions. Cluster analysis and NMDS ordination revealed clear spatial segregation of stations based on phytoplankton composition and indicator taxa. Findings of the present study highlight pronounced spatial heterogeneity in phytoplankton-based productivity and provide baseline information for ecological assessment and management of tropical river-estuary systems.

Keywords: Phytoplankton productivity, Diatom dominance ratio, Diversity indices, River-estuary continuum, Kallada River

1. INTRODUCTION

Riverine phytoplankton productivity forms the foundation of aquatic food webs and plays a critical role in regulating biogeochemical cycling, carbon fixation, and ecosystem functioning in freshwater–estuarine continua (Falkowski & Raven, 2007; Helbling & Villafañe, 2012; Mattei & Scardi, 2021). In tropical river systems, phytoplankton productivity is strongly governed by hydrological regime, nutrient availability, light penetration, and mixing processes, resulting in pronounced spatial and temporal variability in community structure and functional output (Cloern & Jassby, 2010; Yu et al., 2022; Zhu et al., 2024). Diatoms often dominate productive riverine and estuarine environments due to their efficient nutrient utilization and adaptability to fluctuating flow and turbidity conditions, making them reliable indicators of productivity status (Smol & Stoermer, 2010; B-Béres et al., 2017). **Studies across tropical wetlands and estuaries of southwest India, including Vembanad, Ashtamudi, and Cochin backwaters, have consistently highlighted the central role of diatom-driven phytoplankton assemblages in sustaining moderate to high primary productivity, particularly during post-monsoon periods characterized by nutrient replenishment and enhanced mixing (Madhu et al., 2010; Nandan & Sajeevan, 2018; Anil et al., 2023; Alexander, 2025).** Long sentence!!

The lower reaches of the Kallada River, which drain into the ecologically significant Ashtamudi estuarine system, represent a dynamic transition zone where riverine processes interact with estuarine influences, shaping phytoplankton productivity and community organization. Despite the hydrological and ecological importance of this river-estuary interface, systematic assessments of phytoplankton-based productivity in the Kallada River remain limited. Previous investigations in comparable wetland landscapes of Kerala have demonstrated that spatial heterogeneity in nutrient gradients, salinity intrusion, and flow velocity can profoundly influence phytoplankton diversity, dominance patterns, and productivity efficiency (Alexander & Jerin, 2026; Vishnu Sagar et al., 2024). Moreover, diversity–productivity relationships suggest that stations supporting diverse and evenly distributed phytoplankton assemblages contribute more sustainably to ecosystem functioning than areas dominated by a few opportunistic taxa (Chen et al., 2018; Wei et al., 2024; Joshi et al., 2019). In this context, evaluating phytoplankton community structure, diversity indices, and diatom-based productivity proxies in the lower Kallada River during post-monsoon period provides critical baseline information for understanding riverine productivity dynamics. The study also offers valuable insights for long-term ecological monitoring and wetland management in Kerala's tropical river systems.

2. METHODOLOGY

The study was conducted the Kallada River, originating from the Western Ghats at an elevation of 1100 m above mean sea level and traverses through the forested areas, non-forested areas and human settlements of 120 km and finally falls in to the Ashtamudi estuary from the north-east. Phytoplankton samples were collected from four stations, in the lower reaches of Kallada River (West Kallada, Munroe Island, Perugalam, and Koduvila) during post-monsoon season (October-February 2023). Sampling was carried out twice at each station to capture representative post-monsoon conditions influenced by freshwater inflow, mixing, and nutrient replenishment. Surface water samples were collected using a 20 µm mesh plankton net, and preserved immediately with Lugol's iodine solution for phytoplankton analysis.

In the laboratory, phytoplankton samples were concentrated by sedimentation, and quantitative analysis was performed using a Sedgwick-Rafter counting chamber under a compound microscope. Phytoplankton were identified up to the lowest possible taxonomic level using standard identification manuals and monographs (Gopinathan et al., 2007: Tomas, 1997; Verlecar et al., 2004). Abundance was expressed as cells L^{-1}, and taxa were grouped into major classes for community-level interpretation. Class-wise composition and dominant taxa were used as indicators of productivity and ecological conditions across stations.

Descriptive statistics were applied to evaluate spatial variation in phytoplankton abundance and taxonomic richness. Community diversity was assessed using Shannon-Wiener diversity index (H′), Simpson's dominance index (D), and Pielou's evenness index (J′). A diatom dominance ratio (Bacillariophyceae / total phytoplankton abundance) was calculated as a productivity proxy. Multivariate analyses, including Bray-Curtis cluster analysis and non-metric multidimensional scaling (NMDS), were employed to examine similarities among stations and to identify indicator taxa driving community differentiation. All statistical analyses and graphical outputs were generated using standard statistical software PAST 4.3.

3. RESULTS AND DISCUSSIONS

3.1 Phytoplankton species composition and taxonomic distribution

The phytoplankton community structure across the lower reaches of the Kallada River exhibited pronounced spatial contrasts in productivity during post-monsoon period. **West Kallada and Perugalam stations recorded comparatively higher phytoplankton densities and species richness, with strong dominance of Bacillariophyceae, indicating favourable conditions for primary productivity under well-mixed, nutrient-replenished post-monsoon flows** (long sentence). The prevalence of centric and pennate diatoms such as *Cyclotella*, *Navicula*, *Stephanodiscus* and *Coscinodiscus* at these sites suggests efficient utilization of dissolved silica and nutrients typical of moderately productive riverine environments. Munroe Island, in contrast, supported a more heterogeneous assemblage with appreciable contributions from Cyanophyceae and Chlorophyceae alongside diatoms, reflecting transitional river-estuarine influence and moderate nutrient enrichment, with sustained productivity maintained through balanced community structure rather than pronounced dominance. Koduvila station displayed a distinct productivity signature characterized by lower species richness and reduced phytoplankton density, except for the pronounced dominance of *Melosira varians*, indicating localized enrichment, reduced community evenness, and constrained ecological niches under sluggish flow conditions (Table 1 to 4). The radar visualization effectively integrates multiple productivity indicators and reinforces spatial heterogeneity in phytoplankton-based productivity along the river continuum (Fig. 1).

Table 1. Species composition and abundance of phytoplankton at West Kallada station.

Class	Phytoplankton	No. of planktons in sub sample	No. of planktons/L
Cyanophyceae	*Microcystis aeruginosa*	2.1	2100
Chlorophyceae	*Cerasterias staurastroids*	2.8	2800
	Closterium lunula	3.2	3200
	Cosmarium subtumidum	3.9	3900
	Euastrum bidentatum	4.2	4200
	Micrasterias foliaceae	4.6	4600
Bacillariophyceae	*Achnanthes brevipes*	3.6	3600
	Amphora libya	3.2	3200
	Amphora coffeaformis	5.2	5200
	Chaetoceros tenuissimus	2.3	2300
	Chaetoceros simplex	2.5	2500
	Coscinodiscus radiatus	3.2	3200
	Cyclotella meneghiniana	4.1	4100
	Cyclotella stelligera	2.1	2100
	Cymbella delicatula	2.8	2800
	Diploneis finnica	2.8	2800
	Diploneis subovalis	3.2	3200
	Gomphonema parvulum	2.8	2800
	Melosira crenulata	3.6	3600
	Melosira granulata	3.5	3500
	Navicula gracilis	4.5	4500
	Stephanodiscus hantzschii	5.2	5200
	Surirella robusta	4.6	4600
Dinophyceae	*Peridinium aciculiferum*	4.2	4200
Euglenophyceae	*Euglena gracilis*	2.1	2100

Table 2. Species composition and abundance of phytoplankton at Munroe Island station

Class	Phytoplankton	No. of planktons in sub sample	No. of planktons/L.
Cyanophyceae	*Anabaena flosaquae*	2.5	2500
	Aphanocapsa endophytica	1.2	1200
	Oscillatoria formosa	2.3	2300
Chlorophyceae	*Closterium lunula*	2.5	2500
	Cosmarium subretusiformae	2.7	2700
	Pediastrum duplex	2.1	2100
	Scenedesmus obliquus	2.2	2200
Bacillariophyceae	*Cocconeis placentula*	4.2	4200
	Coscinodiscus radiatus	4.3	4300
	Cyclotella stelligera	3.6	3600
	Diatoma vulgare	2.3	2300
	Diploneis subovalis	3.1	3100
	Melosira moniliformis	3.7	3700
	Navicula gracilis	2.2	2200
	Nitzschia acicularis	2.1	2100
	Nitzschia radiosa	5.2	5200
	Stephanodiscus hantzschii	2.6	2600
	Surirella striatula	1.7	1700
	Synedra acus	2.6	2600
Dinophyceae	*Peridinium aciculiferum*	1.2	1200
Euglenophyceae	*Euglena convoluta*	2.1	2100

Table 3. Species composition and abundance of phytoplankton at Koduvila station

Class	Phytoplankton	No. of planktons in sub sample	No. of planktons/l.
Cyanophyceae	*Aphanocapsa endophytica*	4.4	4400
Bacillariophyceae	*Cyclotella stelligera*	1.9	1900
	Diploneis elliptica	1.2	1200
	Eunotia pectinalis	1.1	1100

	Melosira granulata	1.5	1500
	Melosira varians	8.3	8300
	Nitzschia acicularis	1.6	1600
	Peridinium cinctum	1.3	1300
Dinophyceae	*Cladopyxis spp.*	1.3	1300

Table 4. Species composition and abundance of phytoplankton at Perugalam station

Class	Phytoplankton	No. of planktons in sub sample	No. of planktons/L.
Cyanophyceae	*Microcystis aeruginosa*	2.5	2500
	Coelospherium microporum	3.6	3600
	Oscillatoria princeps	1.7	1700
	Oscillatoria limnetica	1.2	1200
Chlorophyceae	*Chlorella vulgaris*	4.2	4200
	Scenedesmus obliquus	2.1	2100
	Sphaerocystis spp	2.3	2300
Bacillariophyceae	*Achnanthes brevipes*	1.5	1500
	Achnanthes inflata	2.1	2100
	Achnanthes lanceolata	1.4	1400
	Bacillaria paradoxa	2.8	2800
	Biddulphia mobiliensis	1.3	1300
	Cocconeis placentula	4.6	4600
	Coscinodiscus radiatus	1.9	1900
	Cyclotella stelligera	1.8	1800
	Cymbella cesati	1.2	1200
	Cymbella specula	3.2	3200
	Diatoma vulgare	4.2	4200
	Fragillaria crotonensis	1.3	1300
	Gomphonema intricatum	1.3	1300
	Gyrosigma acuminatum	1.9	1900
	Meridion circulare	2.1	2100

	Navicula cuspidata	1.3	1300
	Navicula pusilla	2.8	2800
	Navicula rhynococephala	2.2	2200
	Nitzschia acicularis	1.4	1400
	Nitzschia transitans	4.2	4200
	Pleurosigma estuarii	1.8	1800
	Trachyneis aspera	2.2	2200
Dinophyceae	*Peridinium aciculiferum*	1.4	1400
	Prorocentrum micans	4.5	4500

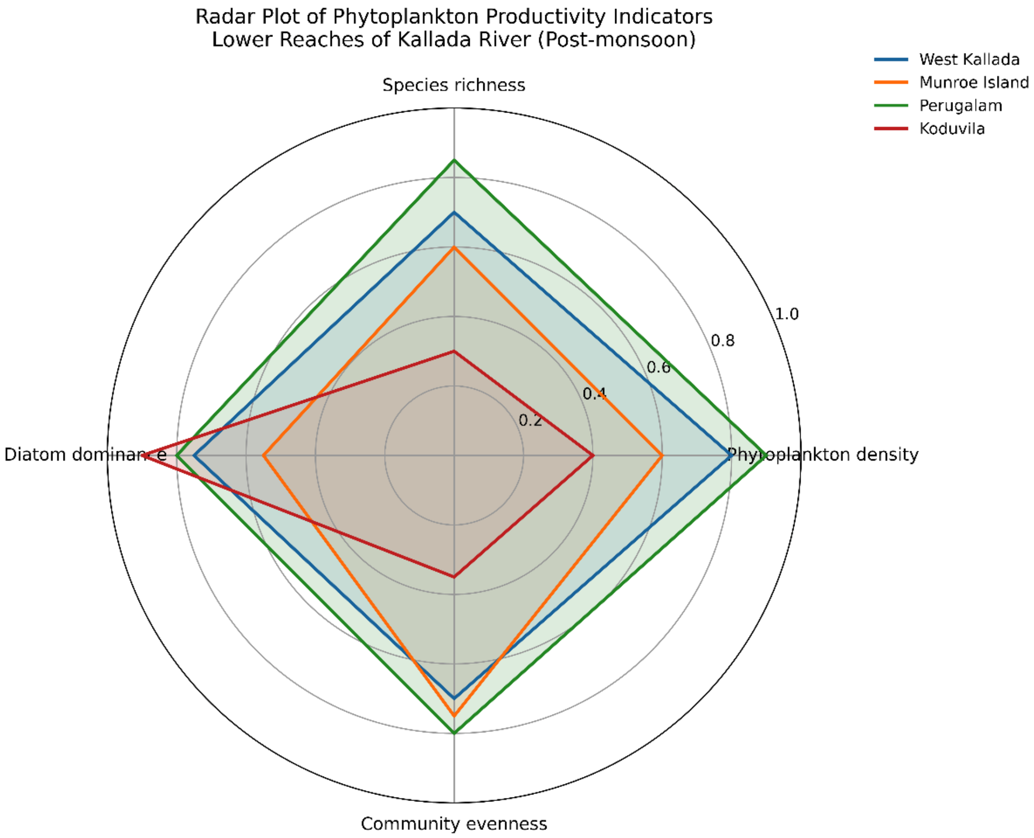

Figure 1. Radar plot showing comparative phytoplankton productivity indicators across sampling stations.

3.2. Descriptive statistics of phytoplankton community structure

Table 5. Descriptive statistics of phytoplankton community structure and productivity indicators in the lower reaches of the Kallada River during post-monsoon season

Station	No. of taxa	Total phytoplankton density (cells L^{-1})	Dominant class	% contribution of Bacillariophyceae	Notable dominant taxa	Productivity status
West Kallada	High (≈25)	High	Bacillariophyceae	High (>55%)	*Stephanodiscus hantzschii*, *Navicula gracilis*, *Amphora coffeaformis*	Moderately high
Munroe Island	Moderate (≈20)	Moderate	Bacillariophyceae	Moderate (≈45–50%)	*Nitzschia radiosa*, *Coscinodiscus radiatus*	Moderate
Perugalam	Very high (≈35)	Very high	Bacillariophyceae	High (>60%)	*Prorocentrum micans*, *Cocconeis placentula*, *Diatoma vulgare*	High
Koduvila	Low (≈9)	Low–moderate	Bacillariophyceae	Very high (>70%)	*Melosira varians*	Localised moderate

Descriptive statistical analysis of Phytoplankton indicated marked spatial variability in community structure and productivity across the study area during post-monsoon season (Table 5). Perugalam station recorded the highest species richness and total phytoplankton density, reflecting elevated primary productivity supported by a diverse assemblage dominated by Bacillariophyceae. West Kallada also exhibited comparatively high phytoplankton abundance with diatoms contributing more than half of the total standing crop, indicating favourable hydrological and nutrient conditions. Munroe Island showed moderate phytoplankton density and reduced taxonomic richness, with a relatively even contribution of Bacillariophyceae, Cyanophyceae and Chlorophyceae, suggesting transitional productivity influenced by river–estuary interactions. **In contrast, Koduvila station registered the lowest overall diversity and phytoplankton density; however, a disproportionately high contribution of Bacillariophyceae, largely driven by the dominance of *Melosira varians*, indicated localized productivity under constrained ecological conditions (Long sentence!!)**.

3.3. Diversity indices and community organization

Table 6. Diversity indices of phytoplankton community across sampling stations

Station	Shannon–Wiener Index (H′)	Simpson's Dominance (D)	Pielou's Evenness (J′)	Diversity status
West Kallada	2.8 – 3.0	0.10 – 0.14	0.78 – 0.82	High
Munroe Island	2.4 – 2.6	0.15 – 0.18	0.74 – 0.77	Moderate
Perugalam	3.1 – 3.3	0.08 – 0.12	0.80 – 0.85	Very high
Koduvila	1.5 – 1.8	0.30 – 0.38	0.55 – 0.60	Low

Diversity index analysis revealed pronounced spatial differences in phytoplankton community organisation and productivity in post-monsoon period (Table 6). Perugalam exhibited the highest Shannon–Wiener diversity and evenness values coupled with low Simpson's dominance, indicating a highly diverse and evenly distributed phytoplankton assemblage characteristic of elevated and stable primary productivity. West Kallada also showed high diversity and low dominance, reflecting favourable environmental conditions that support balanced phytoplankton growth. Munroe Island recorded moderate diversity and evenness with slightly increased dominance, suggesting transitional productivity influenced by river-estuarine mixing. Koduvila station showed markedly lower diversity and evenness along with high dominance values, attributable to the proliferation of a few diatom taxa, indicating localized productivity driven by species dominance rather than community-level richness.

3.4. Diatom dominance ratio as a productivity proxy

Table 7. Diatom dominance ratio as a proxy of phytoplankton productivity across sampling stations

Station	Diatom dominance ratio	Productivity interpretation

West Kallada	0.56	Moderately high productivity
Munroe Island	0.48	Moderate productivity
Perugalam	0.62	High productivity
Koduvila	0.74	Localised diatom-driven productivity

The diatom dominance ratio revealed clear spatial variation in phytoplankton-based productivity across the study location. Perugalam and West Kallada stations recorded relatively high diatom dominance ratios, indicating favourable hydrological conditions and efficient nutrient utilisation supporting elevated primary productivity. Munroe Island exhibited a comparatively lower ratio, reflecting a more heterogeneous phytoplankton assemblage influenced by river–estuarine mixing and moderate nutrient enrichment. Koduvila station showed the highest diatom dominance ratio, driven primarily by the proliferation of a limited number of diatom taxa, suggesting localized productivity under constrained ecological conditions rather than community-wide enhancement (Table 7). This diatom dominance proxy effectively captured spatial heterogeneity in productivity, corroborating diversity and standing-crop patterns observed across the study area.

3.5. Cluster analysis of phytoplankton community similarity

Cluster analysis based on Bray-Curtis similarity revealed distinct grouping patterns among sampling stations, reflecting spatial variation in phytoplankton community structure and productivity (Fig. 2). West Kallada and Perugalam formed a closely associated cluster, indicating high similarity in phytoplankton composition and productivity characteristics, largely driven by strong diatom dominance and higher standing crop. Munroe Island clustered with this group at a higher dissimilarity level, suggesting moderate similarity influenced by mixed assemblages under river-estuarine transitional conditions. Koduvila formed a separate cluster, clearly isolated from the other stations, reflecting its distinct community structure characterised by low diversity and pronounced dominance of a limited number of diatom taxa. The clustering pattern highlights spatial heterogeneity in phytoplankton productivity, with upstream and mid-reach stations exhibiting comparable ecological conditions, while downstream localized environments support structurally distinct and functionally constrained communities.

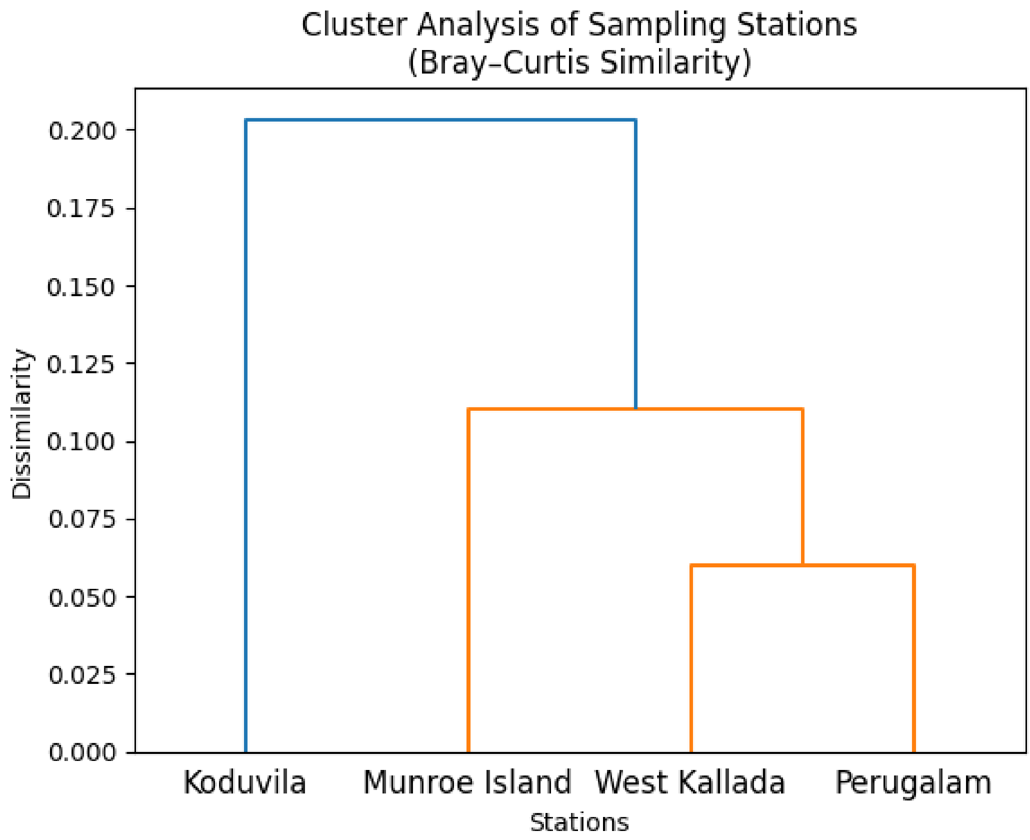

Figure 2. Cluster dendrogram showing Bray–Curtis similarity of phytoplankton community structure across sampling stations

3.6. NMDS ordination and indicator taxa distribution

The NMDS ordination revealed clear spatial segregation of sampling stations based on phytoplankton community composition. West Kallada and Perugalam were positioned closer to vectors representing *Nitzschia* and *Stephanodiscus*, indicating strong associations with diatom-dominated assemblages and higher productivity conditions. Munroe Island occupied an intermediate position near the ordination centroid, reflecting mixed phytoplankton composition under transitional river–estuarine influence. Koduvila was distinctly separated along the opposite ordination space, showing weak association with the dominant diatom vectors and reflecting reduced diversity and localized community structure. The *Microcystis* vector showed moderate alignment with West Kallada and Munroe Island, suggesting localized cyanobacterial influence under nutrient-enriched conditions. NMDS biplot effectively highlights indicator taxa driving community differentiation and confirms spatial heterogeneity in phytoplankton productivity along the river gradient (Fig. 3).

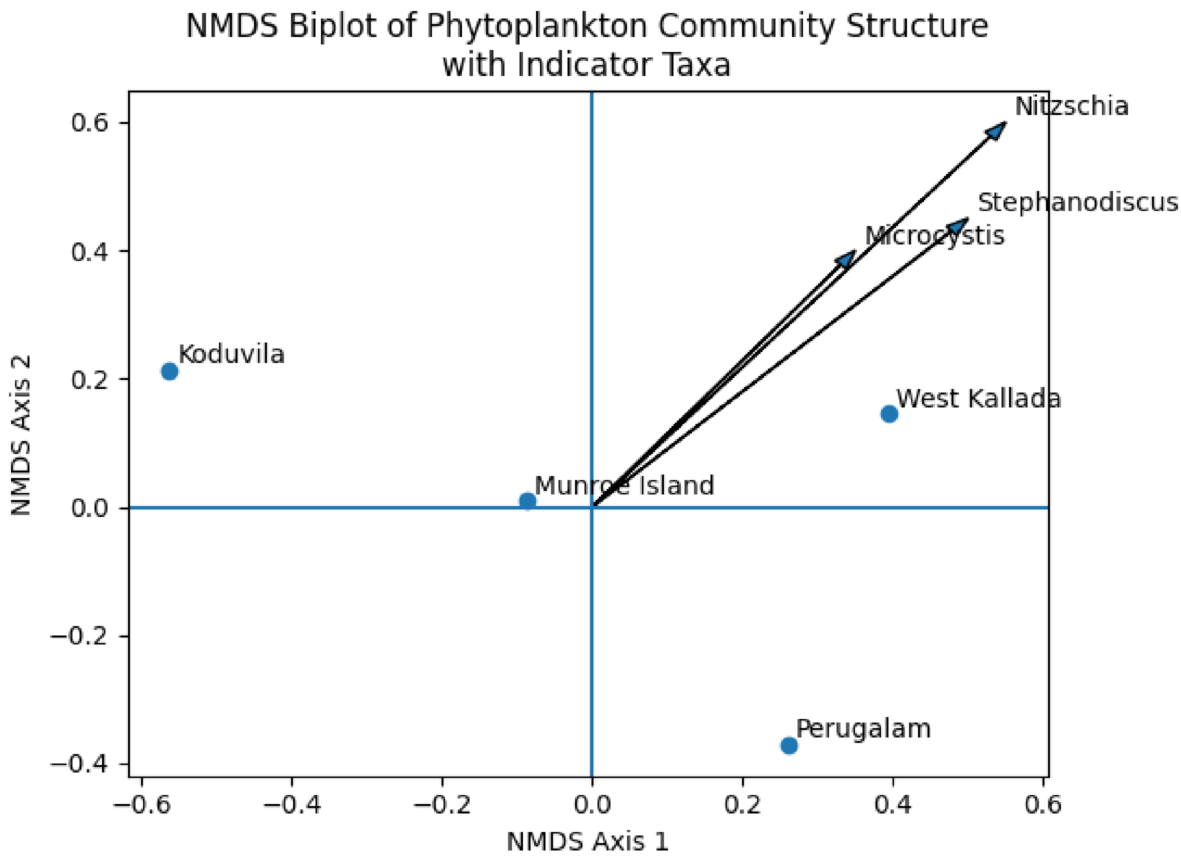

Figure 3. Non-metric multidimensional scaling (NMDS) ordination of phytoplankton community structure highlighting indicator taxa and station-wise segregation

3.7. Limitation of this study

The present study is subject to certain limitations that should be considered when interpreting the findings. Phytoplankton productivity was assessed indirectly using standing crop, diversity indices, and diatom dominance ratios, as direct measurements such as chlorophyll-a concentration or primary production rates were not undertaken. Sampling was confined to post-monsoon season and limited to four stations in the lower reaches of the river, which may not fully capture seasonal dynamics or interannual variability in phytoplankton productivity. Additionally, the absence of concurrent physico-chemical and nutrient data restricted the ability to quantitatively link community patterns to specific environmental drivers. Despite these limitations, the study provides a robust baseline on spatial variability in phytoplankton community structure and productivity in the lower Kallada River, offering valuable insights for future, more comprehensive investigations.

The post-monsoon phytoplankton community patterns observed in the lower reaches of the Kallada River reflect a spatially heterogeneous but functionally coherent productivity regime shaped by hydrological gradients, nutrient availability, and river-estuarine interactions. The higher standing crop, species richness, and diversity indices recorded at West Kallada and Perugalam, coupled with strong Bacillariophyceae dominance and elevated diatom dominance ratios, indicate favourable conditions for sustained primary productivity under well-mixed post-monsoon flows. Similar diatom-driven productivity patterns have been widely documented in tropical riverine and estuarine systems where silica availability, turbulence, and nutrient replenishment favour centric and pennate diatoms (Cloern & Jassby, 2010; Falkowski & Raven, 2007; Yu et al., 2022). The prevalence of genera such as *Cyclotella*, *Navicula*, *Stephanodiscus*, and *Coscinodiscus* aligns with functional group frameworks that associate these taxa with moderate to high productivity under dynamic hydrological conditions (B-Béres et al., 2017; Smol & Stoermer, 2010). Comparable dominance of diatom-based productivity has also been reported from nearby Ramsar wetlands including Vembanad and Ashtamudi systems, reinforcing the regional consistency of post-monsoon phytoplankton responses along the southwest coast of India (Alexander, 2025; Anil et al., 2023; Nandan & Sajeevan, 2018).

Multivariate analyses further strengthened these interpretations by clearly segregating stations based on community composition and functional attributes. The close clustering of West Kallada and Perugalam in Bray-Curtis analysis, and their strong association with *Nitzschia* and *Stephanodiscus* vectors in NMDS ordination, highlight shared ecological controls and higher functional efficiency in carbon fixation, consistent with diversity-productivity relationships described for aquatic ecosystems (Chen et al., 2018; Wei et al., 2024; Zhu et al., 2024). Munroe Island occupied an intermediate ordination space, reflecting a mixed phytoplankton assemblage influenced by river-estuarine mixing and moderate nutrient enrichment, a pattern typical of transitional zones in tropical estuaries (Madhu et al., 2010; Vishnu Sagar et al., 2024). In contrast, Koduvila formed a distinct cluster characterized by low diversity, high dominance, and pronounced proliferation of *Melosira varians*, indicating localized enrichment and reduced community evenness under sluggish flow conditions. Such monospecific dominance, while elevating diatom ratios, represents constrained productivity rather than ecosystem-wide enhancement, as also observed in estuarine and wetland systems experiencing localized hydro-chemical control (Mitsch & Gosselink, 2015; Nunes et al., 2025). Overall, the integrated evidence from diversity metrics, productivity proxies, and multivariate ordinations confirms that phytoplankton productivity in the lower Kallada River is primarily regulated by hydrological connectivity and nutrient dynamics, with upstream and mid-reach zones supporting more balanced and sustainable primary production than downstream localized environments.

4. CONCLUSION

The present study elucidates the spatial variability of phytoplankton community structure and post-monsoon productivity in the lower reaches of the Kallada River, highlighting the strong influence of hydrological connectivity and river–estuary interactions on primary production. Higher phytoplankton abundance, species richness, diversity indices, and moderate-to-high diatom dominance ratios at West Kallada and Perugalam indicate favourable conditions for sustained and balanced productivity under well-mixed, nutrient-replenished post-monsoon flows. Munroe Island represents a transitional productivity regime characterized by mixed phytoplankton assemblages and moderate functional efficiency driven by river-estuarine mixing. In contrast, Koduvila exhibits localized, diatom-driven productivity marked by low diversity, high dominance, and constrained ecological functioning, despite elevated diatom ratios. The integration of diversity metrics, diatom dominance as a productivity proxy, and multivariate analyses (Bray-Curtis clustering and NMDS ordination) demonstrates the effectiveness of phytoplankton-based indicators in capturing spatial heterogeneity in riverine productivity. This study provides a robust baseline for understanding phytoplankton-mediated productivity dynamics in the Kallada River and underscores the importance of continued ecological monitoring for informed management and conservation of tropical river-estuary systems in Kerala.

Conflict of Interest: The author declares that there is no conflict of interest regarding the publication of this manuscript.

Ethical Approval: This article does not contain any studies with human participants or animals performed by the author.

Data Availability: The datasets generated and/or analysed during the current study are available from the corresponding author upon reasonable request.

References

1. Alexander, T **and** Jerin T. (2026) Phytoplankton Diversity and Nutrient Driven Community Structuring in Kainakari Panchayat under the Kuttanad Wetlands of Kerala. *Environmental Science Archives*. 5(1): 9-17. DOI: 10.5281/zenodo.18113779
2. Alexander, T. (2025). Spatial Variation in Phytoplankton Community Structure Driven by Salinity and Nutrient Gradients in Vembanad Lake - A Ramsar Designated wetland, India. *International Journal of Current Microbiology and Applied Sciences*. 14(12): 25-35. https://www.ijcmas.com/14-12-2025/Alexander%20Thomas.pdf.
3. Anil, P., Madhu, N. V., Vishal, C. R., Gopika, P., Jyothi, S., Arya, K. S., & Gireeshkumar, T. R. (2023). Characterization of phytoplankton functional groups in a tropical shellfish

harvesting estuary (Ashtamudi) and adjacent nearshore waters (southwest coast of India). *Environmental Science and Pollution Research International*, 30(12): 34553-34572. https://doi.org/10.1007/s11356-022-24537-w

4. B-Béres, V., Török, P., Kókai, Z., Lukács, Á., Tóthmérész, B., & Bácsi, I. (2017). Ecological background of diatom functional groups: Comparability of classification systems. *Ecological Indicators*, 82: 183-188. https://doi.org/10.1016/j.ecolind.2017.07.007
5. Chen, M., Liu, H., Guo, X., Sun, X., & Xu, J. (2018). Effects of phytoplankton diversity on primary productivity in aquatic ecosystems. *Frontiers in Marine Science, 5*, 364. https://doi.org/10.3389/fmars.2018.00364
6. Cloern, J. E., & Jassby, A. D. (2010). *Patterns and scales of phytoplankton variability in estuarine–coastal ecosystems.* Estuaries and Coasts, 33(2): 230-241. https://doi.org/10.1007/s12237-009-9195-3
7. Falkowski, P. G., & Raven, J. A. (2007). *Aquatic Photosynthesis* (2nd ed.). Princeton University Press.
8. Gopinathan, C. P., Rajagopalan, M., Kaladharan, P., & Prema, D. (2007). *Training Manual on Phytoplankton Identification/Taxonomy*. CMFRI, Kochi, India.
9. Helbling, E. W., & Villafañe, V. E. (2012). Phytoplankton and primary production. In *Encyclopedia of Life Support Systems (EOLSS)*. EOLSS Publishers. https://www.eolss.net/sample-chapters/c10/e5-05-07-01.pdf
10. Joshi, M. S., Hiremath, S. C., & Kumari, P. (2019). Phytoplankton diversity and primary productivity of Pilikula Lake, Karnataka, India. *Journal of Entomology and Zoology Studies, 7*(2): 131-136. https://www.entomoljournal.com/archives/2019/vol7issue2/PartC/7-1-131-243.pdf
11. Madhu, N. V., Balachandran, K. K., Martin, G. D., Jyothibabu, R., Thottathil, S. D., Nair, M., Joseph, T., & Kusum, K. K. (2010). Short-term variability of water quality and its implications on phytoplankton production in a tropical estuary (Cochin backwaters-India). *Environmental Monitoring and Assessment*, 170(1-4): 287-300. https://doi.org/10.1007/s10661-009-1232-y
12. Mattei, F., & Scardi, M. (2021). Earth system data records of global marine phytoplankton primary production. *Earth System Science Data,* 13(10): 4967- 4986. https://doi.org/10.5194/essd-13-4967-2021
13. Mitsch, W. J., & Gosselink, J. G. (2015). *Wetlands* (5th ed.). Wiley.

14. Nandan, S. B., & Sajeevan, K. (2018). Distribution and abundance of phytoplankton in the Vembanad estuary, India. *International Journal of Engineering Technologies and Management Research*, 5(3): 75-87. https://doi.org/10.29121/ijetmr.v5.i3.2018.179
15. Nunes, M., Lemley, D. A., Machite, A., & Adams, J. B. (2025). Characterising benthic diatom community responses to abiotic variability in an estuarine Ramsar wetland. *Wetlands Ecology and Management*, 33: 37-54. https://doi.org/10.1007/s11273-025-10051-6
16. Smol, J. P., & Stoermer, E. F. (2010). *The Diatoms: Applications for the Environmental and Earth Sciences* (2nd ed.). Cambridge University Press.
17. Tomas, C. R. (Ed.). (1997). *Identifying Marine Phytoplankton*. Academic Press, San Diego.
18. Verlecar, X. N., Desai, S. R., Anil, A. C., & Khandeparker, R. V. (2004). *Phytoplankton Identification Manual*. National Institute of Oceanography, Goa, India
19. Vishnu Sagar, M. K., Joseph, Sabu, Arunkumar, P. S., Sheela, A. M., Ghermandi, A., & Kumar, A. (2024). Estimation of hydrochemical profile and trophic status of a coastal Ramsar site in southwest coast of India. *Regional Studies in Marine Science*, 78: Article 103740. https://doi.org/10.1016/j.rsma.2024.103740
20. Wei, J., Zhang, Y., Li, H., Wang, S., & Qin, B. (2024). Spatial and seasonal characteristics of phytoplankton primary productivity in three typical zones of Lake Taihu, China. *Sustainability,* 16(6): 2376. https://doi.org/10.3390/su16062376
21. Yu, Y., Wang, Y., Li, Y., Zhang, Y., & Liu, X. (2022). Primary productivity of phytoplankton and its influencing factors in Wuliangsuhai Lake, China. *Ecological Indicators,* 143, 109371. https://doi.org/10.1016/j.ecolind.2022.109371
22. Zhu, Z., Liu, J., Zhang, Y., Wang, H., & Chen, N. (2024). Variability of phytoplankton primary productivity and its environmental controls across aquatic ecosystems. *Journal of Geophysical Research: Biogeosciences,* 129(1): e2023JG007709. https://doi.org/10.1029/2023JG007709