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A study on influence of sediment properties on zooplankton abundance in Chilika Lake, Odisha, India

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Abstract
This study addresses the critical role of sediment properties in shaping zooplankton abundance in Chilika Lake, focusing on temporal and spatial variations across six sampling stations from 2019 to 2021. Key sediment characteristics, including organic carbon, nitrogen, phosphorus, pH, and conductivity, were analyzed alongside quantitative assessments of zooplankton groups such as Cladocera, Copepoda, and Rotifera. Findings reveal strong positive correlations between sediment organic carbon and nitrogen content and zooplankton abundance, particularly during pre-monsoon and post-monsoon seasons. Enhanced nutrient availability from organic-rich sediments promotes primary productivity, leading to increased zooplankton growth, with Cladocera and Copepoda showing the most significant responses. Principal Component Analysis (PCA) identified sediment pH and organic carbon as major determinants of zooplankton community structure. This research underscores the significance of sediment-water interactions in regulating the biodiversity and productivity of Chilika Lake, highlighting sediment properties as key drivers of zooplankton abundance.

Keywords: Sediment properties, zooplankton abundance, Chilika Lake, organic carbon, nutrient availability, community structure

1. Introduction

Chilika Lake, the largest brackish water lagoon in India, is renowned for its unique ecological dynamics and rich biodiversity. Spanning over 1,100 square kilometers along the eastern coast of India, it serves as a critical habitat for numerous aquatic species, including plankton, fish, migratory birds, and other wildlife. The lake's dynamic environment, which alternates between freshwater and saline conditions depending on seasonal and tidal influences, makes it an ecologically sensitive region [21]. Understanding the variations in physico-chemical parameters and their relationship with biodiversity is crucial for managing the lake's ecological balance, especially given increasing anthropogenic pressures and climate change [17]. Plankton communities, comprising both phytoplankton and zooplankton, form the foundation of aquatic food webs and are essential indicators of ecosystem health [31]. In Chilika Lake, plankton abundance and diversity are influenced by a variety of factors, including water temperature, salinity, dissolved oxygen, and nutrient availability [12]. These factors fluctuate significantly due to seasonal shifts, particularly the monsoon, which introduces high variability in the lake's physico-chemical parameters [18]. The seasonal dynamics of water quality directly affect the structure and function of plankton communities, thereby impacting the broader aquatic food web[19]. Moreover, sediment characteristics play a crucial role in determining the productivity and biodiversity of aquatic ecosystems. Sediment acts as a source and sink for nutrients, organic matter, and contaminants, influencing nutrient cycling and water quality [8]. In Chilika Lake, sediment parameters such as organic carbon content, nitrogen, phosphorus, and pH are critical determinants of nutrient availability, which in turn affect the primary productivity of phytoplankton [24]. Studies have shown that variations in sediment characteristics can significantly impact the spatial and temporal distribution of plankton [22]. In addition to affecting nutrient dynamics, seasonal fluctuations in sediment parameters also influence the ecological interactions between various components of the ecosystem. For instance, the nutrient-rich sediments deposited during the monsoon season can enhance primary productivity, while periods of low sediment nutrient levels may reduce plankton abundance.

Investigating the relationship between sediment properties and plankton communities is thus essential for understanding the drivers of ecosystem functioning in Chilika Lake [4]. This study aims to examine the temporal and spatial variations in sediment and plankton parameters in Chilika Lake over two years (2019-2021), focusing on how seasonal fluctuations influence these key environmental and biological factors. The study assesses the interrelationship between sediment characteristics - such as organic carbon, pH, nitrogen, phosphorus, and conductivity - and the abundance and diversity of zooplankton groups. The findings will provide valuable insights into the role of sediment parameters in shaping planktonic community structure and contribute to a better understanding of the factors driving ecological dynamics in Chilika Lake. Additionally, the study employs multivariate statistical tools such as Principal Component Analysis (PCA) to identify key factors influencing the lake's sediment and plankton dynamics [9]. By analyzing these relationships, the study seeks to contribute to the ongoing efforts to conserve Chilika Lake. It offers a deeper understanding of the natural processes that support its biodiversity, providing critical information for developing sustainable management strategies to protect this vital ecosystem from the threats posed by human activities and environmental changes [21].

2. Materials and Methods

Soil organic matter (SOM) comprises the non-mineral portion of soil, including a diverse range of materials such as decayed plant and animal tissues and amorphous brown to black substances, collectively referred to as 'soil humus.' It contains living and dead microbial tissues, microbially synthesized compounds, and derivatives produced from microbial decay. Most nitrogen (95-99%), phosphorus (33-67%), and sulfur in soils exist in organic forms that mineralize, releasing essential nutrients for plant uptake. SOM typically consists of 5% nitrogen and 0.5% each of phosphorus and sulfur, resulting in a N: P: S ratio of 10:1:1. The organic matter content is estimated based on carbon, which accounts for approximately 52-58% of SOM, with a carbon-to-nitrogen ratio ranging from 10 to 15. To assess the physico-chemical parameters of lagoon soil, including average organic carbon, pH, nitrate nitrogen (NO_3-N), available phosphorus, and conductivity, soil samples were collected from Chilika Lake between March 2019 and February 2021. A grid-based sampling strategy was employed to select locations based on pollution levels, encompassing both contaminated and uncontaminated areas. At each location, nine to ten samples were collected from various points, which were then combined into a composite sample to represent the entire area. After collection, the composite samples were transported to the laboratory, where they were air-dried to remove moisture for accurate analysis. The organic carbon content was measured using the titrimetric method, while sediment pH was determined with a calibrated electronic device. Available phosphorus was estimated using Olsen's Method, and sediment conductivity was assessed following the standardized procedures outlined by the American Public Health Association [3]. Quantitative analysis of zooplankton was conducted through a systematic process involving sample collection, preservation, sedimentation, concentration, microscopic examination, and data analysis. Surface water samples, each totaling 5 liters, were collected at six stations (S1, S2, S3, S4, S5, S6) using a plankton net (length: 48 cm; mouth diameter: 25 cm) towed horizontally for 5-10 minutes. The samples were preserved by adding Lugol's iodine solution (final concentration of 1%) and formalin (final concentration of 2%). After 48 hours of sedimentation, the supernatant water was carefully siphoned off, reducing the sample volume to 15-30 mL. A 1 mL aliquot from the concentrated sample was transferred to a Sedgwick-Rafter cell for microscopic examination. Using a light microscope (COSLAB), zooplankton were identified and counted, with results expressed as cells per liter. To ensure accuracy, three aliquots from each sample were analyzed, and the average value was used to determine the numerical abundance of zooplankton. Identification at the genus and species levels followed standard literature references, including [11, 15, 2, 1, 3, 10]. Additionally, the compilation of the zooplankton species checklist utilized updated scientific names and classification systems sourced from the World Register of Marine Species (WoRMS) (http://www.marinespecies.org/).

2.1 Statistical Analysis

Monthly mean, season wise mean, yearly mean, sampling station wise mean with standard deviation were calculated for comparisons of spatial and temporal study of plankton communities with physico-chemical parameters of sediment samples using SPSS software. One way ANOVA, principal component analysis was calculated using SPSS statistical software version 20.

3. Results and Discussion

The results from the analysis of sediment and plankton parameters across two years (2019-2020 and 2020-2021) highlight distinct seasonal variations in both abiotic and biotic factors in Chilika Lake.

3.1 Sediment Parameters

Organic carbon levels varied between seasons, with the highest values during the pre-monsoon season (Fig.1). In 2019-2020, organic carbon peaked at 1.64 mg/kg in pre-monsoon, while the lowest value was recorded during the monsoon (1.22 mg/kg). Similarly, in 2020-2021, pre-monsoon organic carbon concentrations were slightly higher at 1.65 mg/kg, while monsoon values rose compared to the previous year but remained lower than pre-monsoon (1.40 mg/kg). This seasonal pattern indicates increased organic carbon levels in pre-monsoon and post-monsoon seasons, likely due to reduced dilution and increased organic matter decomposition. Sediment pH showed a trend of alkalinity across both years, with peak pH values during the monsoon (8.63 in 2019-2020 and 8.46 in 2020-2021) and lower values in pre-monsoon (7.97 in 2019-2020 and 7.90 in 2020-2021) (Fig.2). This suggests increased basicity during the monsoon, likely influenced by freshwater influx and sediment-water interactions. Sediment nitrogen was highest in pre-monsoon, with 3.27 mg/kg in 2019-2020 and 3.63 mg/kg in 2020-2021, while the monsoon seasons had the lowest nitrogen levels (2.81 mg/kg and 3.17 mg/kg, respectively). Sediment phosphorus remained relatively consistent, with slightly higher levels in pre-monsoon (13.68 mg/kg in 2019-2020 and 14.11 mg/kg in 2020-2021) and lower concentrations during the monsoon (Fig.3). Sediment conductivity varied significantly, being lower during the monsoon and higher during post-monsoon (Fig.4). In 2019-2020, conductivity was highest in post-monsoon (3290.79 µS/cm) and lowest in monsoon (3156.72 µS/cm), with a similar pattern in 2020-

2021, where monsoon conductivity was slightly higher at 3296.93 µS/cm, reflecting the influence of freshwater influx and increased salinity post-monsoon.

3.2 Plankton Community Dynamics

The Copepoda community exhibited seasonal variation, with higher densities during pre- and post-monsoon seasons, peaking 5800.42 org. /m^3 in 2019-2020 and 5950.83 organisms/m^3 during the study period 2020-2021, while monsoon densities dropped to 3553.96 and 3700.17 organisms/m^3, (Fig.5) respectively. Chaetognatha and Mysida showed fluctuations, with Chaetognatha highest at 602.92 organisms/m^3 in the year 2019-2020, at the monsoon but decreasing in the following year. Mysida showed lower densities in both monsoon seasons (Fig.6). Siphonophora had low abundance across seasons (Fig.7), while Cladocera and crustacean larvae followed predictable patterns, with higher post- and pre-monsoon densities. Sergestida (Fig.8) also peaked in post-monsoon (232.83 organisms/m^3 in 2019-2020), with a slight decrease in 2020-2021. Seasonal variations in environmental factors like organic carbon, sediment conductivity, and pH strongly influenced zooplankton community structure. A Kruskal-Wallis ANOVA (Table-1) confirmed significant seasonal variation in most sediment and zooplankton parameters ($p < 0.001$), except sediment conductivity and Cladocera. Principal Component Analysis (PCA) (Table-2) identified five components explaining 79.3% of variance, with sediment characteristics dominating Component 1, and various zooplankton groups influencing the other components. Bartlett's test confirmed the suitability of PCA for this dataset, and the Kaiser-Meyer-Olkin (KMO) (Table-3) score indicated marginal sampling adequacy. Despite the factor extraction, some variables (e.g., Mysida, Cladocera) had low Measures of Sampling Adequacy (Table-4), suggesting limited contribution to the overall analysis.

Table 1: One-way ANOVA

	χ^2	df	p
Organic carbon (mg/kg)	91.27	2	< .001
Sed. pH	78.58	2	< .001
Sed. N (mg/kg)	50.89	2	< .001
Sed. P (mg/kg)	93.83	2	< .001
Sed. conductivity (microseimens/ohm/cm)	2.49	2	0.288
Copepoda (Organisma/cubic meter)	19.48	2	< .001
Chaetognatha (Organisms/cubic meter)	20.67	2	< .001
Mysida (Organisms/cubic meter)	10.71	2	0.005
Siphonophora (Organisms/cubic meter)	22.82	2	< .001
Cladocera (Organisms/cubic meter)	4.20	2	0.122
Crustacean larvae (Organisms/cubic meter)	15.27	2	< .001
Sergestida (Organisms/cubic meter)	29.89	2	< .001
Other zoopl. (Organisms/cubic meter)	58.17	2	< .001

Table 2: Principal component analysis of studied parameters

Component Loadings						
	Component					
	1	2	3	4	5	Uniqueness
Sed. P (mg/kg)	0.930					0.1066
Organic carbon (mg/kg)	0.890					0.2001
Sed. pH	-0.822					0.2963
Sed. N (mg/kg)	0.733					0.3628
Chaetognatha (Organisms/cubic meter)	-0.513			0.307	-0.438	0.4068
Other zoopl. (Organisms/cubic meter)	0.321	0.846				0.1769
Sergestida (Organisms/cubic meter)		-0.772			0.314	0.2470
Crustacean larvae (Organisms/cubic meter)		0.761		0.327		0.2474
Copepoda (Organisma/cubic meter)		-0.681		0.552		0.1353
Mysida (Organisms/cubic meter)			0.903			0.0786
Cladocera (Organisms/cubic meter)		0.322	0.835	-0.344		0.0406
Siphonophora (Organisms/cubic meter)				0.883		0.1595
Sed. conductivity (microseimens/ohm/cm)					0.869	0.2351
Note. 'varimax' rotation was used						

Table 3: Bartlett's test of sphericity

Bartlett's Test of Sphericity		
χ^2	df	p
1139	78	< .001

Table 4: Measure of sampling adequacy using PCA

KMO Measure of Sampling Adequacy	
	MSA
Overall	0.534
Organic carbon (mg/kg)	0.803
Sed. pH	0.854

Sed. N (mg/kg)	0.783
Sed. P (mg/kg)	0.733
Sed. conductivity (microseimens/ohm/cm)	0.440
Copepoda (Organisma/cubic meter)	0.648
Chaetognatha (Organisms/cubic meter)	0.284
Mysida (Organisms/cubic meter)	0.243
Siphonophora (Organisms/cubic meter)	0.429
Cladocera (Organisms/cubic meter)	0.323
Crustacean larvae (Organisms/cubic meter)	0.363
Sergestida (Organisms/cubic meter)	0.422
Other zoopl. (Organisms/cubic meter)	0.585

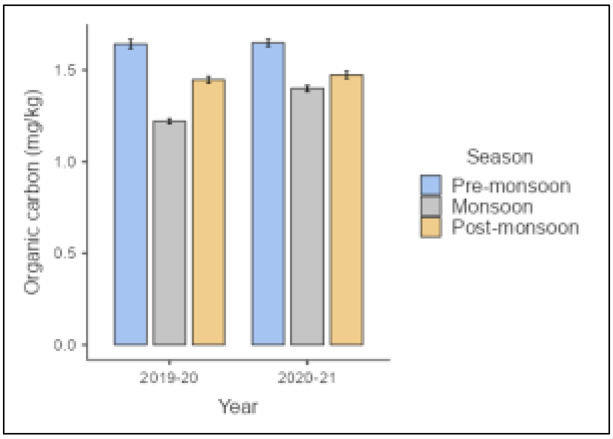

Fig 1: Seasonal variability of organic carbon of soil during the study period 2019-21

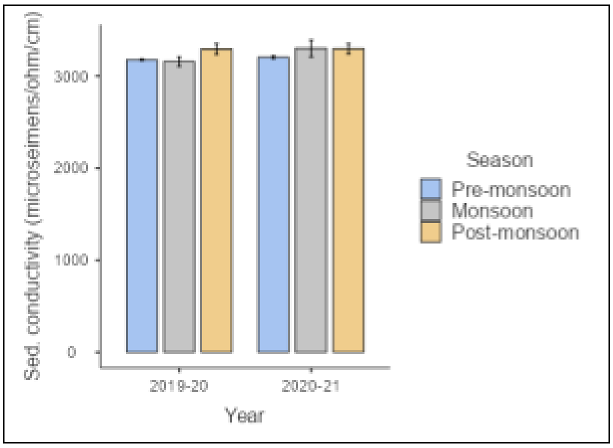

Fig 4: Seasonal variability of sediment conductivity during the study period 2019-21

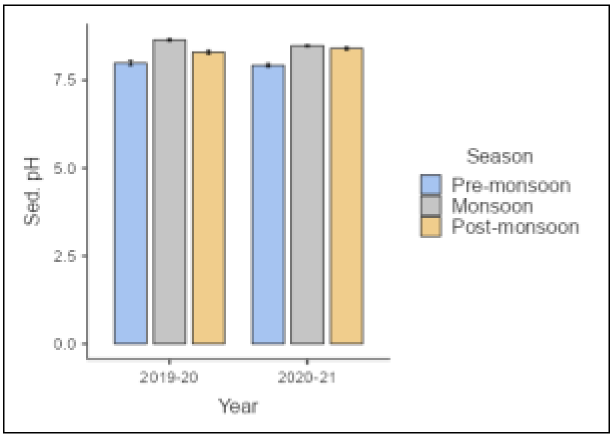

Fig 2: Seasonal variability of sediment pH during the study period 2019-21

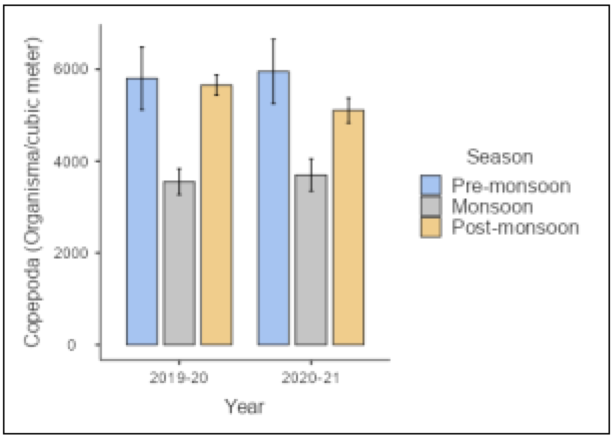

Fig 5: Seasonal variability of Copepoda group during the study period 2019-21

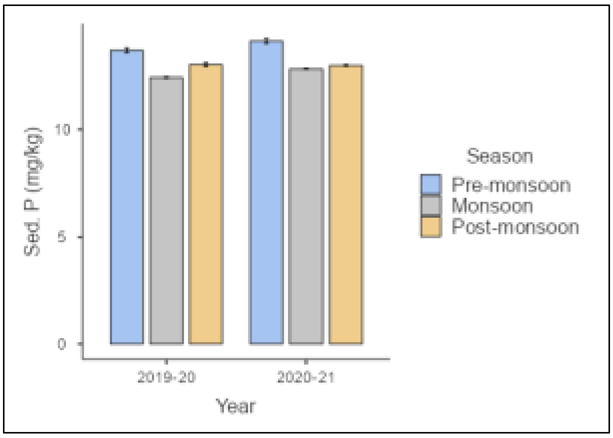

Fig 3: Seasonal variability of sed. P for the during the study period 2019-21

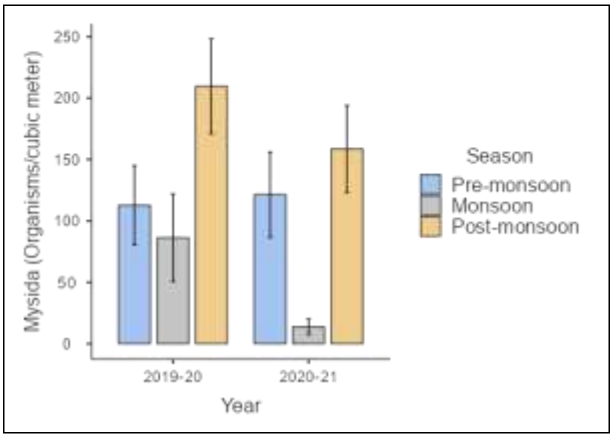

Fig 6: Seasonal variability of Mysida group during the study period 2019-21

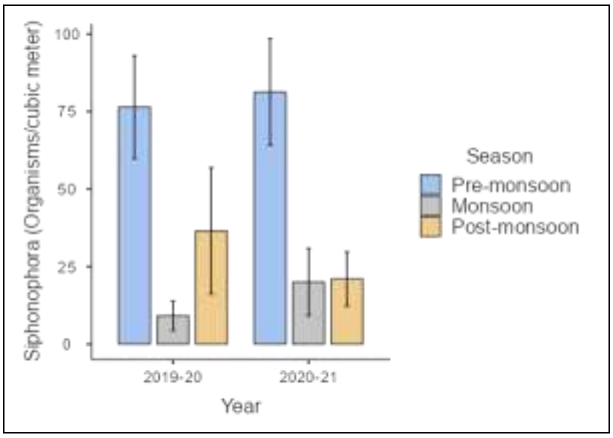

Fig 7: Seasonal variability of Siphonophora group during the study period 2019-21

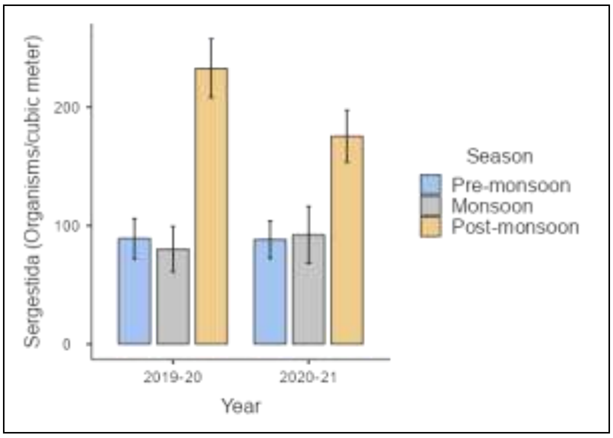

Fig 8: Seasonal variability of Sergestida group during the study period 2019-21

4. Discussion

The analysis of sediment parameters in Chilika Lake from 2019 to 2021 reveals significant seasonal fluctuations, particularly in organic carbon, pH, nitrogen, and phosphorus levels, while sediment conductivity remained relatively stable. Organic carbon peaked during pre-monsoon seasons, likely due to reduced water flow and enhanced organic matter deposition, aligning with similar findings in coastal ecosystems [14]. Sediment pH was highest during the monsoon, indicating increased alkalinity from freshwater influx [25]. Nitrogen and phosphorus levels also peaked in pre-monsoon periods, driven by nutrient cycling and mineralization processes [23]. Despite observable conductivity changes, statistical analysis showed no significant seasonal variation5, suggesting stable sediment conductivity across seasons.Plankton Community Dynamics.

The zooplankton community in Chilika Lake, particularly Copepoda, exhibits pronounced seasonal patterns, with higher densities observed during pre- and post-monsoon periods. Copepod abundance peaked in pre-monsoon (5800.42 organisms/m³ in 2019-2020, 5950.83 organisms/m³ in 2020-2021), while declining during the monsoon, likely due to the disruptive effects of freshwater influx [13]. The Kruskal-Wallis test confirmed significant seasonal variation in zooplankton, including Copepoda, Chaetognatha, and Mysida ($p< 0.001$), indicating sensitivity to changing water conditions [20]. Chaetognatha populations peaked during the monsoon, but a decline in 2020-2021 suggests a response to shifts in salinity and nutrients [5]. Mysida, sensitive to salinity fluctuations, followed a similar trend, highlighting environmental control over zooplankton dynamics. Cladocera and crustacean larvae showed higher densities during pre- and post-monsoon periods, but Cladocera exhibited no significant seasonal variation ($p = 0.122$), suggesting resilience to environmental changes, as noted [28].

4.1 Principal Component Analysis (PCA)

The PCA revealed five distinct components that explain nearly 80% of the variance in sediment and plankton data. Component 1, which explains 26.18% of the variance, is dominated by sediment parameters like phosphorus, organic carbon, and nitrogen, suggesting that nutrient cycling and sediment chemistry drive much of the variation in sediment characteristics. Component 2, contributing 19.33%, captures zooplankton dynamics, highlighting the influence of plankton abundance on ecosystem variability. Similar findings have been reported in coastal lagoon studies [16], where nutrient cycling and plankton dynamics were found to be crucial in shaping ecosystem structure. The independence of these components, as indicated by the lack of inter-component correlations, underscores the distinct roles of sediment characteristics and plankton abundance in driving the ecosystem's variability. This is consistent with previous PCA applications in tropical coastal systems, where sediment and plankton parameters were found to operate independently [29]. The results of Bartlett's Test of Sphericity ($\chi^2 = 1139$, $p< 0.001$) confirmed that the dataset is suitable for PCA. However, the KMO score (0.534) suggests only marginal adequacy, with some variables, such as Mysida and Siphonophora, having low Measures of Sampling Adequacy (MSA). These findings align with other ecological PCA studies where low KMO scores necessitated variable refinement for better component representation [30].

5. Conclusion

The dynamics of sediment and zooplankton in Chilika Lake are strongly shaped by seasonal variations, with pre-monsoon and post-monsoon periods emerging as key phases that support higher nutrient concentrations in sediments and elevated plankton abundance. Organic carbon, nitrogen and phosphorus levels in sediments peak during the pre-monsoon, reflecting intensified decomposition and nutrient mineralization, while monsoon periods witness a dilution effect due to freshwater influx. Similarly, sediment pH and conductivity exhibit seasonal fluctuations, with increased alkalinity and conductivity in the post-monsoon, likely due to altered sediment-water interactions and reduced freshwater input. Zooplankton communities, particularly Copepoda, Chaetognatha, and Mysida, follow these seasonal shifts, with higher densities recorded during the stable environmental conditions of pre and post-monsoon seasons, while monsoons disrupt these communities with changes in salinity and nutrient flow. The resilience of certain groups, such as Cladocera, indicates differential responses to environmental stressors, further adding complexity to the ecosystem's seasonal dynamics. The Principal Component Analysis (PCA) underscores the independent yet interconnected roles of sediment chemistry and zooplankton community structure in driving the lake's ecological balance. Sediment parameters, such as organic carbon, nitrogen, and pH, emerge as critical factors influencing nutrient availability, while zooplankton abundance and diversity act as bioindicators of ecosystem health. Together, these elements demonstrate how Chilika Lake's ecological processes are intricately linked to seasonal patterns, with each factor playing a distinct yet complementary role in sustaining the lake's biodiversity and productivity. This understanding is essential for the conservation and management of such dynamic coastal ecosystems, where both sediment and biological communities respond in tandem to environmental shifts.

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