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"Effect of seasonal variation on the diversity of zooplankton in Pulicat Lake, Thiruvallur District, Tamil Nadu, India, and the possible future consequences of climate change"

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Abstract

This investigation was conducted in Pulicat Lake located off the coast of Chennai, Tamil Nadu, India at Latitude 10°59′N and Longitude 76°57′E. It averaged 23 species of zooplankton; three were Copepoda and four Ostracoda; eight were Rotifera and eight Cladocera. Zooplankton is used as an ecological biomarker because it integrates the effects of the aquatic environment within a short time. The current observation shows that as a whole the Ostracoda constituted 7%, Copepoda 29%, Cladocera 29% and Rotifera constituted 35% of the total. It was discovered that the population density was at its peak in the summer and at its lowest in the early monsoon. The greater population density of zooplankton in summer can be attributed to the accelerated rise in lake temperature. However, the zooplankton productivity increased in the summer when the temperature of the lake was increased which proved that temperature affects it. Hence, the quantity of zooplankton that can be generated could be affected by heat that results from climate change. An evaluation of the zooplankton's diversity would be useful in tracking the health status of the lake.

1. Introduction

The diversity of zooplankton species is currently regarded as a crucial indicator for assessing the condition of the aquatic environment. Zooplankton is very important in the ecosystem because of the many roles it carries out, such as nutrient cycling, as a food for other living beings and in increasing the fertility of the soil. It has been identified that some species may even have a keystone species characteristic that guarantees the general wellness and productivity of the environment (Jeelani et al., 2008). Zooplankton inhabits a significant position in the food web of the freshwater lake ecosystems because they are considered the base of the trophic pyramid, and many fish species rely on them to feed during specific life stages(Lampert et al., 1997).
Moreover, the studies on the zooplankton communities might help to forecast the long-term changes of the lakes' ecosystems in response to the variations of the environmental conditions since the zooplankton seems to be sensitive to every alteration (Ferrara et al., 2002). Communities are susceptible to human impacts, and therefore, their conservation requires carefully planned human interventions. Several writers have discussed the potential use of zooplankton as a reliable indicator for assessing the ecological and trophic condition of lakes that are affected by climate and nutrient variations. The data on species, community, and zooplankton can aid as indicators of environmental variations in lakes and seas. The filtration component of the zooplankton is crucial in determining the degree of eutrophication in a lake.In short, human activities that change lakes and their surrounding areas, together with the inherent chemical and physical properties of the lake, can impact

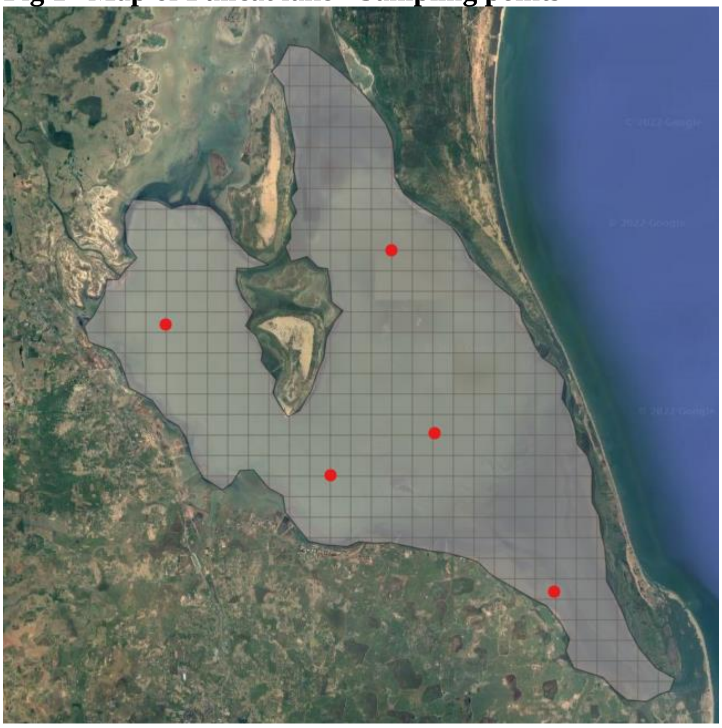
both the total number and types of zooplankton present in the ecosystem (Allen). Zooplankton are recognised as significant organisms in ecosystems and can be used for evaluationof the environment. The conformity and richness of zooplankton in water are inclined by variations in the chemical and physical properties of aquatic environments (Jose et al., 2015). The disposal of waste water products in India is exacerbated by the increased industry resulting from the country's rising population. The influx of harmful substances into the lake via drainage systems diminishes the water quality of the lake. Water may be characterised as having quality based on its chemical, physical, and biological attributes (Lawson et al., 2011). Prior to the administration of water bodies, it is necessary to consider the attributes of water quality and the circumstances of creatures inhabiting the aquatic environment. The dispersion of plankton is considered the primary ecological component in both marine and freshwater environments. The species diversity within any community is determined by the presence of a variety of distinct taxonomic and morphological species. Normal communities, such as those found in tropical and sub-tropical climates, have more species diversity compared to artificial or physically changed ones. Species evenness and species richness are two key components that determine the level of species variety within an ecosystem. Species richness refers to the quantification and assessment of the total number of different species present in a certain geographical region. Essentially, this is referred to as the ratio of the number of specific species (S) to the overall number of species (N). Species evenness is a metric used to determine how evenly a species is distributed in relation to its population.

1. Materials and Methods

1.1. Study area

Pulicat Lake, situated north side of Chennai, Tamil Nadu, India, is the second biggest brackish ecosystem in the country. (Fig : 1). It is located between latitude 13.3 and 13.6North and longitudes 8.23 to 80.25East. The lake in issue spans around 360 square kilometres and has varying depths ranging from 1 to 6 metres. It provides an optimal environment for water birds and is well-suited for the cultivation of fish and crab populations. The lake has been classified by UNEP as a "Ramsar Site". The management of the environment has been inadequate, and the presence of industrial waste has also led to water contamination.

Fig 1 –Map of Pulicat lake - Sampling points



1.2 Data Collection and Evaluation

The data were obtained from five different locations and the sampling covered a one-year duration from September 2018 to August 2019. Sterilised wide-mouth glass vials were used to collect the water samples. Water samples were taken for examination using a Van Dorn sampler between 5at midnight and 6:00 in the morning. The samples were taken vertically and at a 5-meter interval between the sampler and both the lake bottom and top. The samples collected from the lake were sent to laboratory and analyzed on same day. Both the atmospheric and water surface temperatures were also taken. Surface temperatures of the water and the air were also measured. In order to evaluate "pH, salinity, total dissolved solids (TDS), electrical conductivity (EC) and dissolved oxygen (DO), the µP Based Water & Soil Analysis Kit (Model-1160) was used in this investigation".

1.3Zooplankton's Quantitative and Qualitative analysis

Water samples were collected using Towing-Henson's 150 µm plankton net, pulled in a zigzag fashion. The initial sample at 0 meter gave the following target species abundance. 50 to 1. 00m for about 5 to 10minutes, all the time the boat was moving at a constant pace. For the quantitative analysis of the identified zooplankton species, water filtered using the plankton net constructed from tightly woven silk with a mesh size of 150 µm with a volume of 100 liters was used. The plankton biomass was placed into designated bottles, which were originally sealed with 5% formalin. The samples were then seen using a stereo microscope. The identified zooplankton species included rotifers, copepods, ostracods, and cladocerans. Subsequently, the specimens were meticulously separated using a brush and a delicate needle. Following this, the specimens were examined using the binocular stereo zoom dissection microscope manufactured by Magnus Japan.

1.4 Identification of zooplankton

The identification of all the plankton was conducted using standardised operating techniques and textbooks, with the use of a compound microscope coupled to a camera (Edmondson, 1959;Sharma & Michael, 1987). A millilitre of the material was put into the counting cell of the Sedgewick Rafter using a wide-mouthed pipette. After a certain period of time, the number of organisms present was counted. Three counts were recorded for each sample. The equation (Santhanam et al., 1989) was used to determine the density of plankton in a water sample, measured in litres.

$N = n \times v/V$,

Where,

- n = "mean amount of plankton in 1 mL of filtered water"
- v ="concentration of plankton in millilitres"
- V ="total volume of filtered water"

1.5statistical analyses and Diversity indices

Using correlation and linear regression tests, the data on zooplankton and their physicochemical parameters were analyzed using IBM-SPSS (v20. 0) software. Weiner and Shannon came up with the species diversity index (H) formula in 1949. So, The equation

$$\mathbf{H1 = pi \sum log2pi}$$

Where,

- I = 1 s, "states that species diversity in bits per individual"
- H1 = "species diversity in bits per individual"
- pi =ni/N,
- ni="number of individuals in the sample"
- N ="fraction of the sample that belongs to the species"

The species richness (SR) is calculated formula published by Gleason (1922)

$$\mathbf{D=1-C}$$

Where,

- $C = \sum pi2$,
- Pi = ni/N,
- ni − N/S,
- N = "total number of individuals"
- S = "number of species in the collection"

Evenness index (J1)was calculated using the formula of Pielous (1966);

$$\mathbf{J1 = H1/\ log2s}$$

Where,

- H1 = "species diversity in bits of information per individual"
- *S* = "number of species"

The second version of the PAST (Paleontological Statistics) program was used in particular. For the purpose of analyzing the species richness (SR), species evenness (J), and Shannon and Weiner's species diversity (H′) indexes, 02 is used.

2. Outcomes

2.3 Physico-chemical characteristics

Surface water and atmospheric temperatures were measured throughout the study's four seasons. In contrast to the surface water temperature, which varied between “24. 64 ± 0. 58 and 28. 93 ± 0. 39 °C”, the observed air temperature ranged from 23. 77 ± 0. 77 ± 0. 03 to 26. 95 ± 1. Throughout the course of this research, researchers noted that both atmospheric and surface water temperatures dropped during the monsoon and rose throughout the summer. The lake's pH and salinity levels fluctuate between 7 and during the study period. In terms of range, the readings varied between 31 ± 0. 34 and 8.54 ± 0. 58 mg/l, and between 0.84 ± 0. 10 and 1.01 ± 0. 20 mg/l, respectively. Reported pH values were found to be lowest and greatest throughout the monsoon season, in contrast to summer. There was a wide variety of reported values for EC, DO, and TDS in the present study area.

The ranges of TDS, EC, and DO are as follows. All three of these metrics showed higher summer readings and lower monsoon readings, as previously observed.

- TDS = 0.77 ± 0.03 to 1.25 ± 0.08 mg/l
- DO = 0.75 ± 0.03 to 1.23 ± 0.07 mg/l
- EC = 0.69 ± 0.07 to 8.59 ± 0.61 mg/l

2.4 Diversity of zooplankton and Species composition

A total of twenty-four distinct species of zooplankton were documented in Pulicat Lake. The specimens seen consist of 8 Rotifers, (2 families and 3 genera). Additionally, there are 8 Cladocerans, (3 families and 5 genera). Furthermore, there are 4 Copepods, (2 families and 3 genera). Lastly, there are Ostracods, (1 family and 4 genera) (Table 1). The current investigation on percentage composition reveals that Rotifers have the biggest proportion (35%), followed by Copepods (29%), Cladocerans (29%), and Ostracods (7%), as seen in Figure 3. The average population density of zoo-plankton in the study region ranged from 72,179 to 109,870 individuals per cubic meter (Fig. 4). It was lowest during the monsoon season and greatest during the summer season.

Consequently, the population density exhibited a significant increase during the summer and a very low level during the monsoon season. Among the many categories of zooplankton examined, rotifer, for example, exhibited considerably larger densities in all seasons ($p < 0.001$) as seen in Table 2. The findings also demonstrated that the abundance of Cladocerans and Copepods was much higher ($p < 0.001$) during the pre and post monsoon seasons.

It is necessary to highlight that the quantity of Ostracods was significantly lower than in the case of the other groups throughout the entire period of research. The species diversity of zooplanktons such as “Copepods, Ostracods, Cladocerans, and Rotifers varied from 2. 029 to 2. 085, 2. 063 to 2. 129, 1. 731 to 1. 756, and 1. 547 to 1. 581, respectively” (Table 3). The monsoon season was found to have the least species diversity while post monsoon identified to have the highest species diversity. The growth rates of the zooplankton species; Rotifera, Cladocera, Copepoda, and Ostracoda fluctuated in the productivity of the ranges 1. 149 to 1. 248, 1. 168 to 1. 317, 0. 745 to 0. 798, and 0. 716 to 0. 887, respectively (Table 3). Thus, in a broad sense, the period post-monsoon to summer received the least number of different species while the period pre-monsoon to monsoon was highest. The research period also showed that the observed Ostracods, Rotifers, Cladocerans, and Copepods species evenness was between 0. 938 to 0. 973, 0. 845 to 0. 895, 0. 873 to 0. 935, and 0. 947 to 0. 965, respectively (Table 3).

Table 1. List of freshwater zooplankton found in the pulicat lake between September 2018 to August 2019

Group	Family	Genus	Species
Rotifera	Brachionidae (Ehrenberg, 1838)	*Brachionus* Pallas, 1776	*Brachionus calyciflorus* Pallas, 1776
			Brachionus angularis Gosse, 1851
			Brachionus quadridentatus Hermann, 1783
			Brachionus caudatus personatus Ahlstrom,1940
			Brachionus rubens Ehrenberg, 1838
			Brachionus falcatus Zacharias, 1898
		Keratella Bory & Vincent, 1822	*Keratella tropica* Apstein, 1907
	Asplanchnidae (Harring & Myers, 1933)	*Asplanchna* Gosse, 1850	*Asplanchna intermedia* Hudson, 1886
Cladocera	Daphnidae (Straus, 1850)	*Daphnia* Muller, 1785	*Daphnia carinata* king, 1853
			Daphnia magna Straus, 1820
		Ceriodaphnia Dana, 1853	*Ceriodaphnia reticulate* Jurine, 1820
			Ceriodaphnia cornuta Sars, 1853
	Moinidae (Goulden, 1968)	*Moina* Baird, 1850	*Moina micrura* Kurz, 1874
			Moina brachiata Jurine, 1820
		Moinodaphnia Herrick, 1887	*Moinodaphnia macleayi* King, 1853
	Macrothricidae (Norman & Brady, 1867)	*Macrothrix* Baird, 1843	*Macrothrix goeldii* Richard, 1897
Copepoda (Calanoida) (Cyclopoida)	Diaptomidae (Baird, 1850)	*Heliodiaptomus* Kiefer, 1932	*Heliodiaptomus viduus* Gurney, 1916
	Cyclopoidae (Dana, 1853)	*Mesocyclops* Claus, 1893	*Mesocyclops hyalinus* Rehberg, 1880
			Mesocyclops leuckarti Claus, 1857
Ostracoda	Cyprididae (Baird, 1845)	*Cypris* Muller, 1776	*Cypris protubera* Muller, 1776
		Eucypris Vavra, 1891	*Eucypris bispinosa* Victor & Michael, 1975
		Cyprinotus Brady, 1886	*Cyprinotus nudus* Brady, 1885
		Hemicypris Sars, 1903	*Hemicypris anomala* Klie, 1938

3. Discussion

Understanding the hydrologic features of a lake is crucial for making maximum use of it. Therefore, the nutritional content and physico-chemical characteristics of the water have a significant impact on the distribution and species of plankton in a lake. Various studies have found diverse densities, species diversity, evenness, and richness of zooplankton in Pulicat Lake, in addition to different physical and chemical characteristics of the lake. Since the water's physico-chemical properties changed throughout the year, the diversity, quantity, and number of zooplankton species in the lake were also affected. Another critical and unstable aspect of the external environment is the temperature of the water at the surface as it determines the distribution of the flora and fauna which are characteristic of the lake environment(Singh et al., 1990). Besides, it is well understood that the surface water influences several limnological processes such as solubility of gases, stratification,conductivity &distribution of planktons. Many chemical and biological reactions move faster when there is an increase in the temperature. Organism growth and mortality have also been linked with the kinetics of BOD this is however influenced by the water temperature in a way (Khuhawaraet al., 1995). Feeding, reproduction, movement and dispersal in aquatic organisms are all profoundly affected by water temperature that is why research into this matter is so important (Manickam et al., 2012; 2013; 2015 and 2017; Bhavan et al., 2015). The solubility of gases falls and biochemical activities become faster with increase in temperature.The authors Harney et al. (2013) also state that the other environmental condition that has been considered is the temperature of the air whereby it is known that it is always higher than that of the water. The low depth of Pulicat Lake could be attributed to the fact that the maximum air and surface temperature recorded during summer in the present study while the minimum temperature recorded during monsoon. As this result confirms with Reid et al., (1976), Singhal et al., (1985), and Malhotra et al., (1986), it is evident that the surface water temperature has a relative link with the air temperature. This implied that while the length of days began to increase from April to August, water and especially air temperatures began to steadily rise due to increased amounts of solar radiation and hence evaporation. In the same manner, gradual decline in solar radiation could explain the decline in temperature from monsoon season October to February; post monsoon season, the temperature starts to rise in March(Hutchinson et al. 1957; Harney et al., 2013;).

Table 2. Density of zooplankton population in Pulicat Lake during September 2018 – August 2019.

Season	Rotifera	Cladocera	Copepoda	Ostracoda	F Value	P - value
Post monsoon	6499 ± 74^{a}	5001 ± 37^{c}	5107 ± 21^{b}	1188 ± 26^{d}	5891.37	0.000
Summer	9071 ± 63^{a}	5449 ± 49^{b}	5023 ± 45^{c}	2415 ± 21^{d}	8659.32	0.000
Pre-Monsoon	7052 ± 36^{a}	5890 ± 34^{b}	5589 ± 16^{c}	1463 ± 29^{d}	19,091.29	0.000
Monsoon	5123 ± 27^{a}	3683 ± 20^{c}	4661 ± 24^{b}	819 ± 15^{d}	16,981.31	0.000

The pH scale quantifies the acidity or alkalinity of water by evaluating the concentration of H+ ions present in it. Kataria et al. (1996) found that water bodies had a high rate of photosynthesis, resulting in elevated pH levels. This study was conducted in May, during the summer season. Additionally, the present research verifies that summertime had the highest pH levels and pre-monsoon times saw the lowest. Consequently, the research's results suggest that the hot summer temperatures caused significant water evaporation, resulting in higher salinity values. Additionally, the combination of low temperatures and increased freshwater from the monsoon season can account for the lower salinity levels observed during this period. In this way, salinity might have a more indirect impact on the zooplankton species since it attracts species that are able to live in areas with high salinity levels. Our findings have important implications for the study of climate change, as they point to the likelihood that temperate zone lakes' trophic structures would undergo alterations as a consequence of increased temperatures and, perhaps, salinity. This research found high summer dissolved oxygen (DO) levels, which may be linked to phytoplankton activity. Dissolved oxygen is lowest in monsoons. Decomposition and microbial respiration may consume dissolved organic matter (DO).

According to Manickam et al. (2015), the EC of the FWL environment peaked in May 2012 during summer and hit rock bottom in October 2012 during the monsoon season. In addition, the water intake and outflow rates changed during the summer, post-monsoon, and monsoon seasons, which caused the TDS levels to fluctuate, going up or down depending on the month.

Table 3. Seasonal fluctuations in the diversity of zooplankton species in pulicat lake from September 2018 to August 2019.

Zooplankton Groups		Zooplankton species Diversity indices											
		Post monsoon			Summer			Pre-Monsoon			Monsoon		
		Dec 2018	Jan 2019	Feb 2019	Mar 2019	Apr 2019	May 2019	Jun 2019	Jul 2019	Aug 2019	Sep 2018	Oct 2018	Nov 2018
Shannon (H)	Rotifera	2.029 ± 0.029			2.084 ± 0.014			2.089 ± 0.012			2.049 ± 0.019		
	Cladocera	2.063 ± 0.016			2.100 ± 0.007			2.133 ± 0.009			2.105 ± 0.021		
	Copepoda	1.752 ± 0.006			1.748 ± 0.005			1.761 ± 0.003			1.731 ± 0.012		
	Ostracoda	1.547 ± 0.027			1.577 ± 0.006			1.585 ± 0.011			1.558 ± 0.019		
Evenness	Rotifera	0.845 ± 0.029			0.886 ± 0.015			0.895 ± 0.012			0.851 ± 0.017		
	Cladocera	0.873 ± 0.023			0.907 ± 0.006			0.935 ± 0.008			0.911 ± 0.018		
	Copepoda	0.961 ± 0.006			0.965 ± 0.004			0.965 ± 0.003			0.947 ± 0.012		
	Ostracoda	0.938 ± 0.026			0.971 ± 0.006			0.973 ± 0.011			0.951 ± 0.021		
Richness	Rotifera	1.215 ± 0.025			1.149 ± 0.021			1.201 ± 0.022			1.248 ± 0.013		
	Cladocera	1.269 ± 0.043			1.168 ± 0.027			1.232 ± 0.031			1.317 ± 0.022		
	Copepoda	0.784 ± 0.013			0.745 ± 0.014			0.749 ± 0.076			0.798 ± 0.010		
	Ostracoda	0.828 ± 0.064			0.716 ± 0.021			0.779 ± 0.035			0.887 ± 0.039		

The presence of some dissolved solids in the water may be attributed to the build-up of human activities, which might impact the water quality. This is particularly evident in the pioneer report, which documents the highest average value of this parameter (Manickam et. al., 2012, 2014, 2015 and Bhavan et al., 2015). According to the latest research, the analysis of water samples obtained during periods of high temperature revealed elevated Total Dissolved Solids (TDS) levels. These results show that zooplankton production in the lake is much greater in the summer, which might be because of the increased nutrient concentrations. A grand number of twenty-four zooplankton species were documented during the most recent observation. Among them, eight species were classified under the groups of Rotifera and Cladocera, three species belonged to the Copepoda group, and another four species were classified under the Ostracoda group. Prior studies (Dhanasekaran et. al., 2017) have corroborated this discovery. Extreme heat was the major factor that researchers at Pulicat Lake looked at when analyzing zooplankton diversity. The magnitude of surface water temperature influences the metabolic rates and activity levels of zooplanktonic creatures. This relationship has been shown in studies by Goss et al. (1983). The current study clearly shown that the rise in temperature caused by the release of home and industrial waste might result in the occurrence of TDS. Thus, it is confirmed that elevated levels of Total Dissolved Solids (TDS) and water temperature might potentially enhance zooplankton density under certain circumstances. The statistical study indicated a favorable correlation between the number of zooplankton in Pulicat Lake and its water parameters. The current study determined that Rotifera had the highest proportion of zooplankton, followed by “Copepoda, Cladocera, and Ostracoda”. On the density and distribution of zooplankton, the cardinal physical and chemical characteristics of the environment play the key role. From the present investigation, it is understood that rotifers are more diverse in group where they act as eutrophication indicators(Manickam et al., 2012).

Thus, to minimize water pollution within the watershed area, people’s activity within the area should be regulated. The study did not show any swarming activity of the zooplankton particularly “Rotifera, Cladocera, Copepoda and Ostracoda” for the entire period of the study. The population rose to the highest during the summer, rose again during the winter and during monsoon season. The differences in the population of the given components did not impede or enhance anything in any way. This might be because of the availability of food in the lake environment or due to better environmental conditions such assummer might be the reason for observing high population of zooplankton(Manickam et al., 2014). Hence, the analysis of the current work reveals that the total zooplankton biomass in the aquatic ecosystem is relatively low during monsoon. Low light intensity, high degree of turbidity, cloudy atmosphere and heavy rain may have a role to play in this.

This lentic water system may have eliminated the physico-chemical environment that was required for zooplankton development, because the density of the zooplankton population significantly decreased during the monsoon season. Some animals in the higher trophic level living in the body of water consume large quantities of zooplanktons, which can lead to such effects; examples of such animals are the planktivorous fish, which control the zooplanktonic population in water masses (Poongodi et al., 2009). Rains reduce the concentration of zooplankton for the reason that the environments of the lakes during monsoon become weak while the population of the zooplankton becomes more during the winter season because of favorable factors like temperature, dissolved oxygen, and nutrient value in the form of bacteria, nano-plankton and suspended detritus.There have also been papers that indicated that with increase in environmental factors such as temperature, abundance of zooplankton increases during winter (Edmondson et al., 1965). Results showing higher species variety in this research indicated that the lake's species were doing well. Zooplankton often exhibits poor species diversity when exposed to stressful and contaminated environments. (Bass & Harrel, 1981). Based on the results of this study, the number of zooplankton species is highest between the monsoon and post-monsoon periods, as compared to the summer and pre-monsoon periods. It was observed that there was a decline in the numbers of plankton species during the rainy season with the species equitability or evenness slightly higher (Adesalu& Nwankwo, 2008).

2. Conclusion

The outcomes of this study showed that the high temperatures resulting in the enhanced rate of evaporation of water in the lake which means the improvement of nutrient concentrations and overall increase in the number of zooplanktons in summer. However, zooplankton declines at this time because of rain in the lake attributed to monsoon. The results of this research suggest that higher water temperatures might encourage zooplankton population diversity via the positive correlation between temperature, dissolved solutes, and plankton abundance. However, in order to identify vulnerable and sentinel species, as well as to construct effective conservation models, further research into the precise impacts of climate change on zooplankton distribution is required.

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