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RESEARCH ARTICLE

Seasonal variation in the macrophyte species of Loktak Lake, a Ramsar Site in the North East India

Thingujam Manithoi Singh[1], Bijay Thakur[1], Prajnyan Sarma[1], Mutum Sanjoy Singh[2], Ashalata Devi[1*]

[1]School of Sciences, Department of Environmental Science, Tezpur University, Napaam, Assam, India.

[2]North Eastern Regional Institute of Science and Technology, Nirjuli, Arunachal Pradesh.

*Corresponding author email: ashalatadevi12@gmail.com
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Abstract

An investigation on distribution of macrophyte species was carried out in the Loktak lake, a Ramsar Site in Manipur, India which is the largest freshwater lake in the North East India. The lake is located between the geographical coordinates 93˚46′-93˚55′ E and 24˚25′-24˚41′ N, altitude 768 m asl and spans 246.72 km². The study aimed to determine the species diversity, distribution, and density of macrophytes in the lake that is experiencing degradation problems. A total of 26 sites located across the lake were examined over a period of four seasons as per the Indian Meteorological Department during 2020-2021. Phytosociological method was followed using opportunistic sampling, where 5 quadrats measuring 1x1 m² were placed in each site. Quantitative parameters of the community, such as density, frequency, abundance, IVI, and A/F ratio, were computed. A total of 47 macrophyte species under 40 genera and 19 families were recorded across the lake. Highest number of macrophyte species (47) were recorded during the monsoon season, while the least number of species (27) were recorded during pre-monsoon season. The highest species diversity was recorded for Poaceae (12). The dominant species which were consistently found throughout the year were *Alternanthera philoxeroides, Azolla filliculoides, Brachiaria mutica, Leersia hexandra, Zizania latifolia, Hydrilla verticillata, Limnophila aquatica,* and *Rotala rotundifolia.* Various economically significant plants, such as *Hedychium flavum, Ipomoea aquatica, Nelumbo nucifera, Nymphaea nouchali, Nymphaea pubescens, Nymphoides indica,* and *Oenanthe javanica* were observed during different seasons. The lake was found to be infested with abundant growth of invasive species such as *Hydrilla verticillata, Limnophila aquatica,* and *Pontederia crassipes* indicated eutrophication. Earlier study also found *Alpinia nigra, Polygonum barbatum*, and *Trapa natans*, but not recorded during the study. Immediate and effective conservation efforts are needed to restore the diversity of macrophyte plant species in Loktak Lake to safeguard the endangered species Sangai (*Rucervus eldii eldii*) from becoming extinct.

Keywords: Loktak Lake; Macrophytes; Community Parameters; Ramsar Site; Bioresources; Sangai

1. Introduction

Freshwater macrophytes, also known as aquatic plants or hydrobionts, encompass various plant species found abundantly in tropical and subtropical regions. They comprise of spermatophytes, pteridophytes, and bryophytes capable of thriving in or near water bodies. These macrophytes are categorized into four groups based on their habitat within the water body: surface floating (e.g., *Azolla spp.*), submerged (e.g., *Hydrilla spp.*), emergent (e.g., *Potamogeton spp.*), and marginal (e.g., *Ipomoea spp.*). This classification encompasses a range of plants, including those free-floating, rooted but floating, submerged, and amphibious. Among the spermatophytes, pteridophytes, and bryophytes, vascular plants constitute less than 2% of aquatic vegetation (Bornette and Puijalon, 2009; Soloviy and Malovanyy, 2019). Macrophytes include any plants visible to the naked eye and easily identifiable which flourish in nutrient-rich aquatic environments (Holmes and Whitton, 1977). They serve as primary producers, providing habitat for periphytons, invertebrates (such as zooplankton), and vertebrates (including fish and frogs). Crucially, these plants play a vital role in freshwater ecosystems by regulating biogeochemical cycles, hydrology, and sediment dynamics. For instances, they contribute to organic carbon production by extracting carbon dioxide from the air and water, fixing it through photosynthesis. Additionally, macrophytes aid in nutrient mobilization, absorbing excess nutrients like nitrogen and phosphorous from the water and mitigating issues like eutrophication. Moreover, due to their ability to modify water flows, freshwater macrophytes are capable of modifying hydrology and sediment dynamic, with some other factors. Consequently, they are indispensable components of freshwater ecosystems (Bornette and Puijalon, 2009). Changes in the abundance of

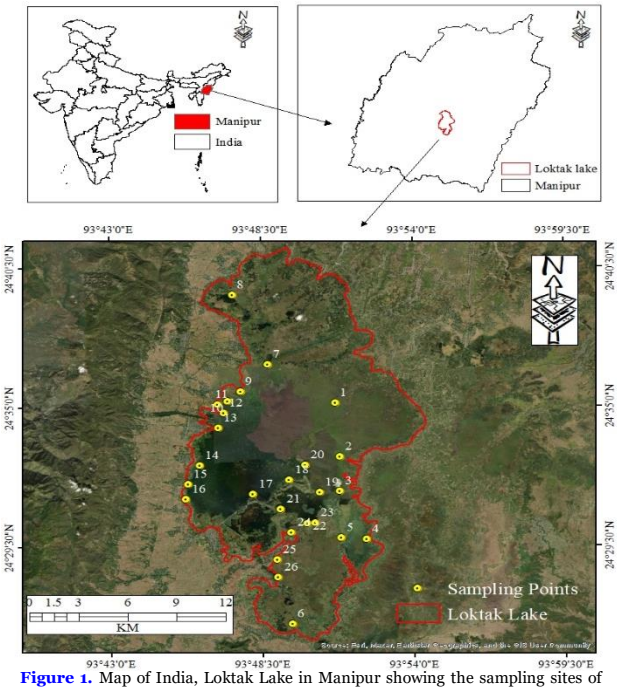

Figure 1. Map of India, Loktak Lake in Manipur showing the sampling sites of macrophytes viz. *Mayang Imphal, Phoubakchao Komlakhong, Laphupat Tera, Khordak, Ithai Wapokpi, Yangoi, Keinou, Khoijuman, Nachou, Kha-Potsangbam, Upokpi Khunou, Ningthoukhong ITI, Thinungei, Phubala, Naranshena, Ithing, Thanga chingkha, Thanga Salam, Karang, Thanga Moirangthem, Nashik Houbi, Ngakra Kom, Sagram, Keibul Mayai Leikai and KLNP 2nd IB post.*

individual species and community composition of macrophyte species provide valuable insights into ecosystem dynamics. These plants also serve as indicators of water quality, with shifts in species composition often signalling environmental changes like eutrophication-induced loss of species diversity. Furthermore, macrophytes interact with and are influenced by factors such as lake morphology, water chemistry, and biological characteristics, contributing to the overall physical, chemical, and biological characteristics of the aquatic environment (Lacoul and Freedman, 2006). This study was conducted to examine the spatial and temporal changes in the diversity and distribution of macrophyte species in Loktak Lake. The primary objective of the study was to assess the quantitative attributes, such as frequency, density, abundance, and ecological importance, of the aquatic macrophytes. This study provides a crucial repository for evaluating the distribution of aquatic macrophytes in the lake. The comprehensive results for the entire study period are presented here, along with a discussion that considers the previous research conducted in wetlands both in India and abroad.

2. Study site

The selected study site - Loktak Lake of Manipur is a Ramsar site and recognized as a largest freshwater lake in the North East India. The lake is situated at an altitude of approximately 768m above mean sea level. It covers an area of 246.72 km², located between longitudes 93˚46′ to 93˚55′ E and latitudes 24˚25′ to 24˚41′ N, as reported by the National Wetland Atlas in 2011. The lake was added to the Montreux Record in 1993 due to its deterioration and environmental issues (Ramsar Convention, 2016).

The lake is distinguished by the presence of floating rings of aquatic vegetation along with thick associated debris, known locally as "*phumdi*". At the southern part of lake lies the only floating national park in the world, the Keibul Lamjao National Park, above a substantial aggregation of aquatic vegetation. The Park is situated above a significant amount of aquatic vegetation. The park serves as the habitat for the endangered species of deer known as "Sangai" (*Rucervus eldii eldii*) as well as other types of wildlife. Several species of flora, which serves as sustenance for both wildlife and local communities residing near the lake, is consistently accessible throughout all seasons.

3. Methodology

The macrophytes of Loktak Lake were studied using the phytosociological method, as described by Curtis and McIntosh (1950) and Misra (1968). The sampling was conducted using 1 x 1 m² quadrats over a one-year period from June 2020 to May 2021, encompassing four distinct seasons: Monsoon (June-September), Post-monsoon (October-December), Winter (January-February), and Pre-monsoon (March-May), as classified by the Indian Meteorological Department (IMD) (Attri and Tyagi, 2010). A total of 26 sampling sites were surveyed across the lake. An opportunistic sampling method was employed, where 5 quadrats measuring 1 x 1 m² were placed in each site. The number of individuals belonging to each species was then documented (Phillips, 1959). The community's quantitative parameters, such as density, frequency, abundance, Importance Value Index (IVI), and abundance to frequency (A/F) ratio, were calculated using methods described by Curtis (1959), Misra (1968), and Mueller-Dombois and Ellenberg (1974). The Species Richness Index (Margalef, 1958), Species Diversity Index (Shannon and Weiner, 1964) was calculated using the IVI values derived from Magurran (1988). The concentration of dominance of the community (Simpson, 1949), Evenness Index (Pielou, 1966), and Similarity Index (Sørensen, 1948) were also calculated.

Margalef's Index = (S – 1) / In N
Where, S is the total number of species and N is the number of individuals

Shannon - Weiner Diversity Index (H′)

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

Where, H′ – Shannon -Weiner Diversity Index
pi is the proportion of individuals of *i*th species i.e *(ni/N)*,

Figure 2. Macrophytes from across Loktak lake, Manipur. **A**. *Hedychium flavum* Roxb., **B**. *Salvinia cucullata* Bory, **C**. *Pontederia crassipes* Mart. and **D**. *Rotala rotundifolia* (Buch.-Ham. ex Roxb.) Koehne

(ni/*N*) is the total number of individuals of all the species, *ni* is Importance Value Index of the species and *N* is Importance Value Index of the community

Simpson's Index

$$Cd = \sum_{i=1}^{s} (pi)^2$$

Where, pi is the same for the Shannon - Weiner Diversity Index (Shannon and Weiner, 1964)

Pielou's evenness index (*e*)
$e = H'/\log S$

Where, *H′* is the number derived from the Shannon-Diversity Index and *S* is the total number of species.

$$\text{Sørensen Similarity Index} = \frac{2C}{A+B} \times 100$$

Where C is the number of species common to two seasons, A is the total number of species in season A, and B is the total number of species in season B.

4. Results

The bioresources of Loktak Lake play a crucial role in the livelihood of both the local population and the entire people of the whole Impal valley. The majority of the villagers derive their livelihoods from the varied bioresources of the lake, which offer a wide range of seasonal vegetables, fruits, and fish. The seasonal abundance of macrophytes were measured during the study period in four different time periods: pre-monsoon, monsoon, post-monsoon, and winter. A total of 47 species of macrophyte belonging to 40 different genera and 19 different plant families were recorded during four different seasons of the year (Table 1 and Figure 3). Family, genera and species of macrophytes enumerated from the Loktak Lake are provided in Table 2. The analysis of seasonal variation of macrophyte showed highest species diversity during monsoon season, with a total of 47 species, 40 genera, and 19 families. In contrast, the Pre-monsoon season was recorded with the lowest number of species, which comprises of 27 species belonging to 26 genera, and 16 plant families.

Diversity indices were calculated for each season during the study period. The results revealed that the Shannon Diversity ndex exhibited its highest value during the Monsoon season (3.44) and its lowest value during the Pre-monsoon season (2.96). The Margalef Richness Index has demonstrated a consistent decrease, reaching its highest value during the Monsoon season and a lower value during the Pre-monsoon season. In contrast, the evenness

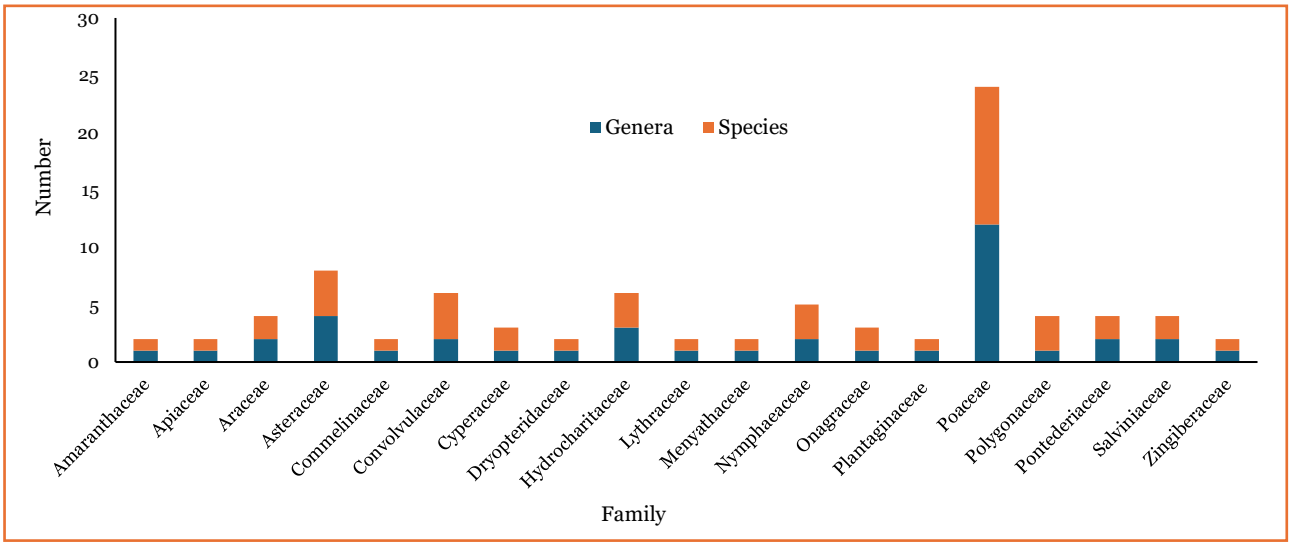

Figure 3. Family, genera and species of macrophytes enumerated from Loktak lake of Manipur, India.

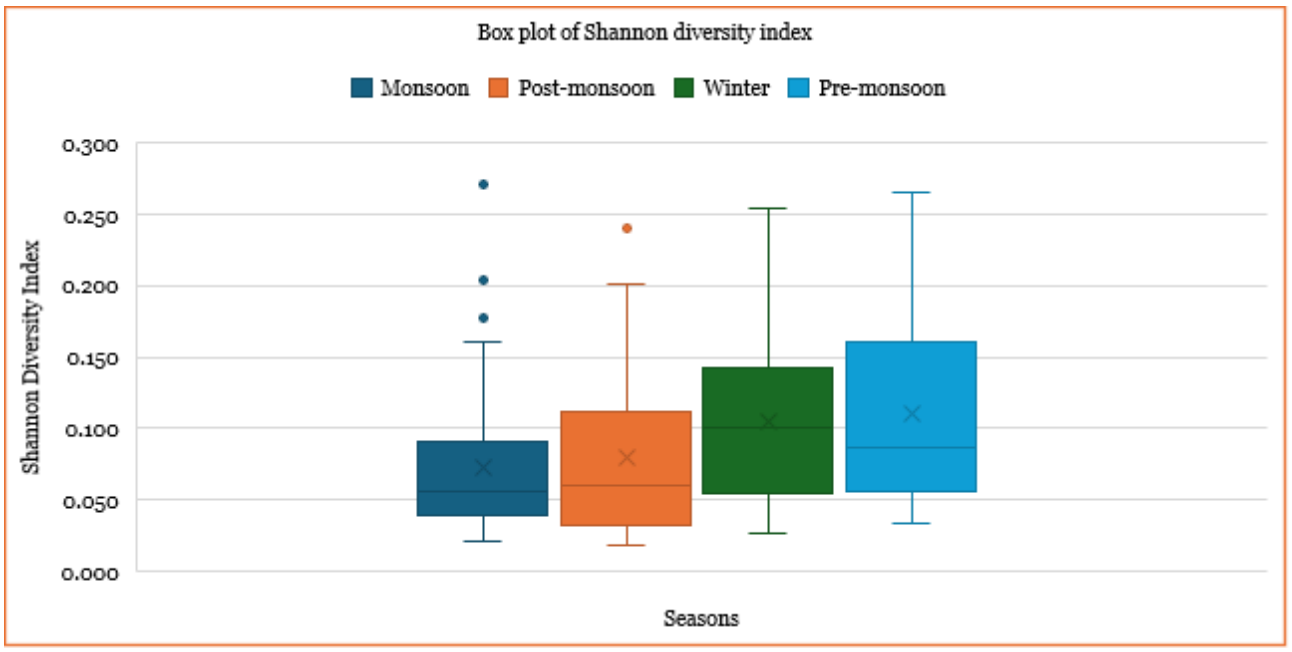

Figure 4. Seasonal variation in diversity index of macrophytes of Loktak lake in Manipur, India.

index showed a consistent range of 0.89 to 0.9 throughout all the four seasons.

Table 3 demonstrated comprehensive community parameters of macrophytes, such as species richness and diversity indices. The species similarity index was found highest during the Monsoon and Pre-monsoon seasons, with a value of 94.38%. This was followed by the Winter and Pre-monsoon seasons (78.87%). The lowest similarity index was observed between the Monsoon and Post-monsoon seasons (72.97%). The results of similarity index are summarized in Table 4. Throughout the four seasons, certain plant species, including *Alternanthera philoxeroides, Azolla filliculoides, Brachiaria mutica, Leersia hexandra, Zizania latifolia, Hydrilla verticillata, Limnophila aquatica, Rotala rotundifolia, and Pontederia crassipes*, were observed to be dominant species, maintaining their presence throughout the year. During monsoon the species diversity was found lesser as compared to other seasons while pre-monsoon season demonstrated the highest species diversity (Figure 4). Less dominance signifies higher diversity of species and higher dominance signifies less diversity of species.

5. Discussion and conclusion

The current investigation documented a total of 47 species of macrophytes, belonging to 40 different genera and 19 distinct plant families. Previous studies in Manipur have found similar number of species in Kharungpat Lake (Singh et al., 2013) and Oinampat Lake (Nivanonee, 2020), while Poiroupat Lake (Singh et al., 2018) was reported with low species diversity. These lakes share similar climatic and geographic conditions with Loktak Lake. Devi and Singh (2016) observed higher abundance of species in Keibul Lamjao National Park during their study conducted from 2010 to 2012 which can be attributed to the protected status of Kebul Lamjao. These differences indicating significant decline in species diversity between the years 2010 and 2020, which can be attributed to the encroachment and excessive exploitation of plant resources from the lake.

The community quantitative parameters, such as frequency, abundance density, and Importance Value Index (IVI), of the macrophytes examined in various locations of Loktak Lake were found to be highest during the monsoon season and lowest during the winter season. Previous study of Hogeweg et al (1969) and Verma et al (1982) also documented the most favourable growth of macrophytes in tropical regions during the rainy season. Therefore, the highest values observed during the monsoon season can be attributed to the favourable climatic conditions, such as warm temperatures and rainfall, which are ideal for the optimal growth of macrophytes like *Alternanthera philoxeroides, Azolla filliculoides, Brachiaria mutica, Cyperus sp., Pontederia crassipes, Leersia hexandra, Zizania latifolia*, and *Hydrilla verticillata*. The lowest values observed during winter could be mainly attributed by factors such as low temperatures, minimal rainfall, and dry weather conditions. These factors contributed to

Table 1. Importance Value Index of macrophyte species diversity and occurrence in Loktak Lake of Manipur with respect to Seasonal variation

Species	Vernacular Name	Family	Monsoon		Post monsoon		Winter		Pre monsoon	
			IVI	A/F	IVI	A/F	IVI	A/F	IVI	A/F
Ageratum conyzoides	Khongjai Napi	Asteraceae	4.27	0.144	4.85	0.116	–	–	2.65	0.325
Alternanthera philoxeroides	Kabaw napi	Amaranthaceae	24.29	0.178	23.71	0.101	34.66	0.076	20	0.116
Azolla filliculoides	Kang macha	Salviniaceae/Azollaceae	16.67	1.069	15.78	1.414	10.43	3.380	9.74	0.447
Brachiaria mutica	Wana Manbi/Para Grass	Poaceae	12.02	0.188	13.11	0.080	17.68	0.094	12.11	0.189
Colocasia sp.	Pan	Araceae	2.42	0.114	4.22	0.079	5.82	0.094	2.05	0.195
Commelina sp.	Wangden Khoibi	Commelinaceae	2.91	0.179	1.97	0.260	2.96	0.780	2.65	0.325
Cuscuta reflexa	Uri Hangam Mapal	Convolvulaceae	2.18	1.300	–	–	–	–	5.73	0.520
Cyperus sp. 1	Sedge	Cyperaceae	8.98	0.371	8.91	0.715	10.67	0.455	–	–
Cyperus sp. 2	–	Cyperaceae	6.02	1.690	9.3	1.184	11.22	0.488	–	–
Dryopteris marginalis	Fern	Dryopteridaceae	5.49	0.077	5.29	0.179	4.45	0.164	–	–
Echinochloa colona	Urikchak	Poaceae	4.7	0.146	3.64	0.520	–	–	4.67	0.191
Eclipta alba	Uchi Sumban	Asteraceae	3.45	0.205	1.38	0.164	–	–	–	–
Pontederia crassipes	Kabaw Kang	Pontederiaceae	8.58	0.536	11.06	1.300	18.81	1.300	10.43	0.096
Enydra fluctuans	Komprek Tujombi	Asteraceae	5.61	0.080	6.09	0.090	–	–	16.64	0.211
Hedychium flavum	Loklei	Zingiberaceae	3.98	0.455	2.48	0.374	–	–	5.26	0.433
Hydrilla verticillata	Charang	Hydrocharitaceae	11.33	0.406	17.05	0.186	24.46	0.549	32.71	0.339
Hygroryza aristata	Tebo	Poaceae	2.19	0.163	5.55	0.260	8.43	0.281	5.06	0.585
Hymenachne amplexicaulis	Tebo	Poaceae	6.13	0.130	7.41	0.585	10.26	1.300	10.21	0.372
Ipomoea aquatica	Kolamni	Convolvulaceae	2.79	0.104	0.92	0.520	–	–	3.86	0.390
Ipomoea cairica	Singaa	Convolvulaceae	2.54	1.235	3.26	0.184	4.45	0.125	–	–
Ipomoea sp.	–	Convolvulaceae	3.02	0.357	1.38	0.260	–	–	–	–
Isachne globosa	–	Poaceae	4.61	0.202	–	–	–	–	–	–
Leersia hexandra	Hoop	Poaceae	40.85	0.260	32.45	0.096	20.63	0.260	25.08	0.780
Limnophila aquatica	Charang matu chombi	Plantaginaceae	11.88	0.062	19.81	0.260	36.13	0.085	39.18	0.229
Ludwigia adscendens	Ishing Kundo	Onagraceae	5.05	1.300	3.14	0.347	5.13	0.260	2.95	0.343
Ludwigia sp.	–	Onagraceae	1.58	0.390	–	–	8.41	0.520	–	–
Mikania micrantha	Uri	Asteraceae	5.71	0.347	5.41	0.520	–	–	–	–
Najas graminea	Charang asaangba	Hydrocharitaceae	1.99	0.520	4.1	0.195	3.71	0.520	6.22	1.300
Nelumbo nucifera	Thambal	Nymphaeaceae	2.59	0.146	3.72	1.820	–	–	–	–
Nymphaea nouchali	Thariktha	Nymphaeaceae	2.06	1.820	1.97	0.260	3.81	0.195	–	–
Nymphaea pubescens	Tharo	Nymphaeaceae	1.38	0.094	1.71	0.578	2.74	0.260	–	–
Nymphoides indica	Tharo Macha	Menyathaceae	2.18	0.154	0.92	0.238	1.47	1.300	2.18	0.896
Oenanthe javanica	Komprek	Apiaceae	4.51	0.309	3.72	0.520	4.91	0.238	6.38	0.387
Oryza rufipugon	Wainu Chara	Poaceae	2.96	0.520	1.38	0.341	2.21	3.120	–	–
Ottelia alismoides	Touthra	Hydrochataceae	1.11	0.196	1.71	0.285	2.74	0.195	–	–
Persicaria hydropiper	Moroksabi	Polygonaceae	3.45	0.323	3.64	0.195	–	–	–	–
Persicaria perfoliata	Lilhar Mana	Polygonaceae	2.9	0.195	0.92	0.183	–	–	–	–
Persicaria sp.	–	Polygonaceae	3.59	0.255	5.26	0.229	1.47	0.164	–	–
Phragmites karka	Tou	Poaceae	7.31	0.223	7.01	0.404	4.45	0.179	8.14	0.124
Pistia stratoites	Kangjao	Araceae	3.89	0.390	–	–	11.78	1.040	3.26	0.148
Pontederia vaginalis	Kakla	Pontederiaceae	2.39	0.173	1.38	0.260	–	–	–	–
Rotala rotundifolia	Loubuk leiri	Lythraceae	14.72	0.520	14.97	0.780	16.41	0.144	24.77	0.218
Salvinia cucullata	Kang	Salviniaceae	8.35	0.318	13.07	0.211	9.68	5.460	8.63	0.406
Tripidium bengalense	Khoimom	Poaceae	1.99	0.390	–	–	–	–	6.88	11.700
Unidentified species	Luwang Tou	Poaceae	1.11	10.400	1.83	8.320	–	–	–	–
Erianthus procerus	Shingnang	Poaceae	2.81	0.198	3.95	0.390	–	–	–	–
Zizania latifolia	Ishing Kambong	Poaceae	19.48	0.585	20.57	0.347	–	–	22.54	0.156

the dead of a majority of plant species. Similar results were also

Table 2. Family, genera and species of macrophytes enumerated from Loktak Lake of Manipur, India.

Family	Genera	Species	Family	Genera	Species
Amaranthaceae	1	1	Menyathaceae	1	1
Apiaceae	1	1	Nymphaeaceae	3	2
Araceae	2	2	Onagraceae	2	1
Asteraceae	4	4	Plantaginaceae	1	1
Commelinaceae	1	1	Poaceae	12	12
Convolvulaceae	4	2	Polygonaceae	3	1
Cyperaceae	2	1	Pontederiaceae	2	2
Dryopteridaceae	1	1	Salviniaceae	2	2
Hydrocharitaceae	3	3	Zingiberaceae	1	1
Lythraceae	1	1			

Table 3. Quantitative summary of macrophyte species present in Loktak Lake, Manipur, India.

Parameters	Seasons			
	Monsoon	Post-monsoon	Winter	Pre-monsoon
No. of species (47 species)	47	42	29	27
No. of genera (40 species)	40	36	25	26
No. of family (20 species)	20	19	17	16
Total density (individuals ha-1)	863461	621153	315769	585384
Margalef Species Richness Index	5.96	5.55	4.17	3.55
Simpson Index	0.05	0.05	0.06	006
Shannon Weiner Diversity Index	3.44	3.33	3.04	2.96
Pielou's Index	0.89	0.89	0.90	0.89

Table 4. Similarity [based on Sørensen Similarity Index (%)] of macrophytes occurring in the four seasons.

Seasons	Post-monsoon	Winter	Pre-monsoon
Monsoon	72.97	76.32	94.38
Post-monsoon	100	75	75.36
Winter	-	100	78.87

found in various studies conducted in identical Lakes in Manipur (Devi, 2007; Devi, 2008; Usha et al., 2010; Singh et al., 2013).

It was noted that the species diversity tends to decrease as the depth increased throughout the lake. A greater number of macrophyte species were found occurring in the peripheral and shallow regions of the lake, while fewer macrophyte species were found in the middle and deeper zone which is in agreement with previous reports of Moss (1989), and Singh et al (2013). Whitford (1949) and Curtis and Cottam (1956) established a method for determining the distribution pattern of plant species based on the abundance to frequency (A/F) ratio. This ratio can be interpreted as indicating regular (0.025), random (0.025–0.05), or contagious (>0.05) dispersions. In the current study, the A/F values were observed to be greater than 0.05, suggesting a widespread distribution of macrophyte species across different seasons and sampling sites. *Hedychium flavum, Ipomoea aquatica, Nelumbo nucifera, Nymphaea nouchali, Nymphaea pubescens, Nymphoides indica*, and *Oenanthe javanica* have been reported with significant economic value due to their potential use as food and as raw materials for various utility products. The stem and rhizome of *Hedychium flavum* was found to be consumed for their flavour and fragrance. The young shoots and leaves of this plant species was reported to serve as a primary source of food for the endangered deer species known as "*Sangai*". The flower of *Nelumbo nucifera* was found to be used in the production of tea, perfume, and other fragrant items. The leaf was employed for wrapping food items, while the root consumed as vegetable. Additionally, the stalk's fiber was found to be utilized in the creation of high-end textiles. The stems of *Nymphaea nouchali, Nymphaea pubescens*, and *Nymphoides indica* were found to be utilized as both food and decorative flowers. During the study, other economically significant plants species such as *Polygonum barbatum* and *Alpinia nigra*, which were reported in earlier studies (Devi and Singh, 2016), were not observed in present study sites. *Trapa natans*, also known as Heikrak, was earlier reported as most prevalent aquatic plant that served as a local food source. However, this study did not observe the presence of *T. natans* in their natural habitat, except occasional presence in privately-owned ponds.

The present study revealed that certain macrophyte species, which were once abundant in their natural habitat a decade ago, are now found absence in their native habitat. This demonstrates the progressive deterioration of the natural ecosystem due to the various anthropogenic activities and proliferation of invasive species such as *Ageratum conyzoides, Alternanthera philoxeroides, Pontederia crassipes, Mikania micrantha, Pistia stratoites*, and *Hydrilla verticillata*. Such invasive species usually outcompete native macrophyte species and disrupt normal ecosystem functions. Efforts to control and manage invasive species through manual removal, biological control methods, and community participation is urgently required. High concentrations of nutrients like nitrogen and phosphorous aids in the abundant proliferation of specific plant species such as *Hydrilla verticillata* and *Limnophila aquatica* throughout the majority of the lake which indicated eutrophication in nature. Implementing effective conservation strategies and regulating the excessive exploitation of endangered and rare macrophyte species in Loktak Lake, which serve as the primary food source for the endangered Sangai, is crucial for ensuring a sustainable livelihood and preserving the Sangai population. Conservation efforts should encompass all including avian and animal species, while conserving the diversity of aquatic flora present in the Loktak Lake of Manipur.

Loktak Lake, situated in the North Eastern State of Manipur, India, is renowned for its rich biodiversity, including abundant presence of various macrophyte species. These macrophytes, such as *Azolla, Hydrilla, Salvinia, Rotala*, *Pontederia* etc, play a crucial role in maintaining the ecological balance of the lake ecosystem. However, they have been found to facing habitat threats due to environmental degradation triggered by anthropogenic activities. To conserve the diversity of macrophyte species in Loktak Lake, several strategies may be implemented including regulation of human encroachment and bioresource exploitation, invasive species management, community engagement and awareness activities for wetland restoration. By implementing these conservation strategies, stakeholders should aim to ensure the long-term survival and health of the macrophyte species in Loktak Lake, thereby preserving the ecological integrity of this unique freshwater ecosystem recognized as Ramsar Sites of International Importance.

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Declaration of conflict of interest

The authors have no conflict of interest to disclose.

Author's contribution

All authors have equally contributed in the study conception and design. Material preparation and data collection were performed by [Thingujam Manithoi Singh and Mutum Sanjoy Singh] under the guidance of Prof. Ashalata Devi; data analyses were performed by [Thingujam Manithoi Singh, Bijay Thakur and Prajnyan Sarma]. The first draft of the manuscript was done by [Thingujam Manithoi Singh and Prof. Ashalata Devi] and all authors commented on previous versions of the manuscript. All authors read and approved the final version of the manuscript before communication.

References

Attri SD and Tyagi A. 2010. *Climate profile of India, India*. Environment Monitoring and Research Centre, Indian Meteorological Department (IMD), Lodi Road, New Delhi- 110003.

Bornette G and Puijalon S. 2009. Macrophytes: Ecology of Aquatic Plants. 10.1002/9780470015902.a0020475.

Curtis J. 1959. The vegetation of Wisconsin, an ordination of plant communities. University Wisconsin Press, Madison, Wisconsin.

Curtis JT and McIntosh RP. 1950. The interrelations of certain analytic and synthetic phytosociological characters. Ecology 31 (3): 434–455.

Curtis JT and Cottam G. 1956. *Plant Ecology Workbook: Laboratory Field Reference Manual*. Bergers Publishing Co., Minnesota. Pp.193.

Devi LG. 2007. *Studies on the Vegetational Dynamics and Primary Productivity of Awangsoipat Lake, Bishnupur (Manipur)*. A Ph.D. Thesis submitted to Manipur University, Manipur, India.

Devi MH and Singh PK. 2016. Diversity pattern of habitats of Macrophytes in Keibul Lamjao National Park (KLNP), a floating mat (Phumdi) environment of Loktak Lake, Manipur, India. IRA-International Journal of Applied Sciences 03 (2): 157-179. https://dx.doi.org/10.21013/jas.v3.n2.p7.

Devi SU. 2008. *Ecological analysis of the macrophytes in Oksoipat lake (Bishnupur) Manipur*. A Ph.D. Thesis submitted to Manipur University, Manipur, India.

Hogeweg P and Brenkert AL. 1969. Structure of aquatic vegetation: A comparison of aquatic vegetation in India, Netherlands and Czechoslovakia. Tropical Ecology 10: 139-162.

Holmes NTH and Whitton BA. 1977. Macrophytic vegetation of the River Swale, Yorkshire. Freshwater Biology 7: 545-558. DOI: 10.1111/j.1365-2427.1977.tb01706.x.

Lacoul P and Freedman B. 2006. Environmental influences on aquatic plants in freshwater ecosystems. Environmental Review 14: 89–136. DOI: 10.1139/A06-001.

Magurran AE. 1988. *Ecological Diversity and its Measurement*. Princeton University Press, Princeton, New Jersey.

Margalef R. 1958. Information Theory in Ecology. General Systems 3: 36–71.

Misra R. 1968. *Ecology Work Book*. Oxford and IBH Publishing Co., New Delhi.

Moss B. 1989. *Ecology of Freshwaters*. Man and Medium. Blackwell Scientific Publication, Oxford.

Mueller-Dombois D and Ellenberg H. 1974. *Geographical Review*. Willy and Sons. DOI: 10.2307/213332.

National Wetland Atlas. 2011. SAC/EPSA/ABHG/NWIA/ATLAS/34/2011. Space Applications Centre (ISRO), Ahmedabad, India. P. 310. https://saconenvis.nic.in/publication/NWIA_National_atlas.pdf.

Nivanonee Ch. 2020. Ecological Analysis of the Macrophytes of Oinampat Lake, Manipur. International Journal of Science, Engineering and Management 5 (10): 203 – 208.

Phillips EA. 1959. *Methods of Vegetation Study*. A holt dryden book henry hold & Co., Inc., New York.

Pielou EC. 1966. The measurement of diversity in different types of biological collections. Journal of Theoretical Biology 13: 131–144.

Ramsar Convention. 2016. An Introduction to the Ramsar Convention on Wetlands. Ramsar Convention Secretariat, Gland, Switzerland, 2016. https://www.ramsar.org/sites/default/files/documents/library/handbook1_5ed_introductiontoconvention_e.pdf.

Shannon CE and Wiener W. 1964. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana.

Simpson E. H. 1949. Measurement of diversity. Nature 163: 688.

Singh KK, Sharma BM and Usha K. 2013. Inventory of the Aquatic Macrophytes in Lake Kharungpat, India. Journal of Energy Technologies and Policy 3 (11: 64 – 75.

Singh KK, Usha K and Sharma BM. 2018. A study on the biomass variation of the macrophytes in Poiroupat Lake, Manipur, northeast India. Science Vision 18 (1): 22—31. https://doi.org/10.33493/scivis.18.01.04.

Soloviy K and Malovanyy M. 2019. Freshwater ecosystem macrophytes and microphytes: development, environmental problems, usage as raw material. Review. Environmental Problems 4 (3): 115-124. https://doi.org/10.23939/ep2019.03.115.

Sørensen T. 1948. A Method of Establishing Groups of Equal Amplitude in Plant Sociology Based on Similarity of Species Content and its Application to Analyses of the Vegetation on Danish Commons. Biologiske Skrifter/Kongelige Danske Videnskabernes Selskab 5: 1-34.

Usha K, Sharma BM and Singh KK. 2010. Growth form analysis of the marcophytes of Poiroupat Lake, Manipur, India. The Ecoscan 4 (2&3): 217-220.

Verma KR, Pandey D and Ambasht RS. 1982. Productive status of marsh zone vegetation of Geyar lake (Khetasalai) Jaunpur, India. In: Gopal B, Turner RE, Wetzct RG and Wingham DF (Eds.) *Wetland Ecology and Management*. National Institute of Ecology and International Scientific Publications, India. Pp. 29-34.

Whitford PB. 1949. Distribution of Woodland Plants in Relation to Succession and Clonal Growth. Ecology 30 (2): 199-208.