Health Assessment of Loktak Lake Using Diatoms as Biological Indicators

Rachna Nautiyal and Prakash Nautiyal

1 Introduction

Wetlands are precious freshwater resources. They are fragile ecosystems. A small change in the abiotic factors or composition of biotic can render them susceptible to damage. The large freshwater Loktak Lake is one such wetland, characterized by phumdis, the floating islands, which are the unique habitat of the endangered mammal, the brow-antlered deer popularly known as Sangai. Phumdis occur in sizes ranging from a few centimeters to about 2.5 m. This wetland is a Ramsar Site since 1990. The Keibul Lamjao National Park occupying an area of 40 sq km offers protection to the Sangai. The lake is shrinking due to soil erosion resulting from deforestation and shifting cultivation in the catchment [1]. The present study therefore proposes to determine the water quality vis-à-vis health of the Loktak Lake ecosystem. This will be useful in restoration efforts in order to maintain the benefits provided by this wetland. The results of this study will also provide a baseline data on the diatom flora and community, useful for comparing ecology of the lake in future. Diatom communities respond quickly and predictably to changes in water quality and are therefore employed as bio-indicators in aquatic monitoring programs in Europe, the USA, Canada, South America, and Australia [2–11].

R. Nautiyal (✉)
Zoology Department, Government P.G. College, Dakpathar,
Vikasnagar, Dehradun 248125, Uttarakhand, India
e-mail: rachnanautiyal@ymail.com

R. Nautiyal
RUSA Directorate, Uttarakhand Government, Dehradun 248001, Uttarakhand, India

P. Nautiyal
Department of Zoology and Biotechnology, H. N. B. Garhwal University
(A Central University), Srinagar, Uttarakhand, India
e-mail: lotic.biodiversity@gmail.com

N. A. Siddiqui et al. (eds.), *Advances in Health and Environment Safety*,
Springer Transactions in Civil and Environmental Engineering,
https://doi.org/10.1007/978-981-10-7122-5_1

2 Methodology

Study Area: Diatom samples were collected from the Loktak Lake at 24°30′37″ N to 93°47′08″ E and elevation of 772 masl. Substrate comprising small boulders, pebbles and cobbles, free-floating water hyacinth, partly decomposed roots and rhizomes, small twigs and grasses were sampled to record all possible species in the ecosystem. Epilithic diatoms were obtained from hard substrate by scraping 3 × 3 cm surfaces with the help of sharp razor and brush. The epiphytic diatoms were obtained by collecting sizeable portions of root, stem and leaves. Two replicates were obtained for each substrate and mixed to form one sample. The sample was preserved in 4% formalin. Diatoms were cleaned with the acid and H_2O_2. Permanent mount was prepared in Naphrax. Diatom species were identified at ×1500 under bright field using NIKON 80i Trinocular Research Microscope and documented with DS-5M-LI digital camera. Diatom flora was recorded by identifying species, varieties, and forms using standard literature [12–17]. Species counts of 500 valves were made to determine relative abundance, species diversity, and evenness using Species Diversity and Richness software. The Van Dam, Hoffmann, Lange-Bertalot ecological values, and Leclercq Index were computed by OMNIDIA software.

3 Results and Discussion

The Loktak Lake is known as the lifeline of Manipur, owing to its socioeconomic and cultural values. A large number of fishermen depend directly on the lake resources for sustenance. Lake water is also used for generation of hydroelectric power by NHPC. A recent Union Planning Commission study stated that the habitat of the brow-antlered deer (*Cervus eldieldi,* locally called Sangai) has shrunk from 40 sq kms to only 6 sq kms today due to the Ithai Barrage commissioned in 1983. The bio-assessment of the water quality through diatom community to indicate the recent health of the Loktak Lake ecosystem thus becomes very important.

Diatom flora: The flora consisted of 115 species from 2 centrale and 39 pennale genera represented by 2 and 113 taxa, respectively (Appendix 1). Relatively more species of centric diatoms are known from lakes of Jammu & Kashmir [18, 19] and lentic waters from Gujarat [20]. Among the pennales, biraphid taxa constitute the bulk of the flora (86 taxa; 77%) while the araphid, monoraphid, and raphid species are few (26 taxa; 23%) as also evident from the other studies in India [13, 20–22] and also from outside of the Indian subcontinent [23–26]. The biraphid *Cymbella* and *Navicula* are the species-rich genera in the flora as observed not only in the above-said mountain waters but also from various parts of India [22, 27–29]. *Anomoeoneis styriaca* (Grun) Hustedt and *Brachysira vitrea* Ross are notable species in the flora that occur in Central Highland but not in the Himalayan waters [30].

Diatom community: The Loktak Lake shows remarkable variations in diatom community. In any community, usually some taxa attain >10% abundance but in this study no taxa attained 10% abundance attributed to high evenness in the community. Highest abundance was recorded for *Gomphonema parvulum* Kütz. (8.0%) which is an indicator of organically enriched waters and eutrophic state, as is good count of *Nitzschia palea* (Kütz) W. Smith also [31]. Other taxa figuring >5% category are *Gomphonema neonasutum* L-B & Reichardt, *Brachysira vitrea* (Grunow) Ross, and *Cocconeis placentula* Ehrenberg which are alkaliphilous and sensitive to very sensitive for pollution [31]. *B. vitrea* has rarely been recorded to gain more than 1% abundance in the natural waters and thus is notable for >5% abundance in this wetland. *Amphora veneta* Kütz and *Navicula cryptotenella* Lange-Bertalot are also indicators of the eutrophic state. The diatom taxa *Ulnaria ulna* (Nitzsch.) Compère indicate the presence of zinc and mercury hydragyrum in water. Also, diatoms such as *Navicula capitatoradiata* Germain, *Navicula cryptocephala* Kütz., *Navicula cryptotenella,* and *Nitzschia gracillis* Hantzsch are moderately tolerant forms [31]. The community appears to be highly diverse (H = 5.63) and even (E = 0.82) which could happen when a wide variety of nutrients are present in limiting amounts.

Ecological values: The examination of ecologic values shows considerable variations in the pH conditions. While majority of the community is represented by alkaliphilous and circumneutral forms, the alkalibiontic, acidobiontic, and acidophilus forms are notable because the last two categories have not been reported even from the organically enriched waters, e.g., Khanda Gad [32]. With respect to salinity conditions, 62.6% forms in the community belong to fresh-brackish state, a condition marked by presence of <500 mg/l chloride and salinity by <0.9%. Only 6.2% are freshwater diatoms (<100 mg/l chloride and <0.2% salinity). The presence of higher ecologic values even though meagerly indicates vicious conditions due to increasing salinity in the lake; 5.6% fresh-brackish diatoms (representing 500–1000 mg/l chloride and 0.9–1.8% salinity) and 3.3% brackish water diatom forms (1000–5000 mg/l chloride with 1.8–9.0% salinity).

For N_2 uptake metabolism, the lake was dominated by 28.8% N_2 autotrophic diatom taxa that tolerate elevated concentration of organically bound N_2. But then all other forms are also present in low numbers which support the above view that the ecosystem has degraded from the natural or semi-natural conditions. This statement receives support from fairly even distribution of diatom community in O_2 requirement categories (Table 1).

Like the above parameters, the saprobity values show presence of forms that prefer higher BOD and low O_2 saturation; 28.6% β-mesosaprobous (2–4 mg/l BOD and 70–85% O_2 saturation), 13.6% oligosaprobous (<2 mg/l BOD and >85% O_2 saturated), 11.9% α-mesosaprobous, and 10.6% α-mesopolysaprobous representing 4–13 and 13–22 mg/l BOD and 25–70% and 10–25% O_2 saturation, respectively, and 3.0% polysaprobous diatoms (>22 mg/l BOD and <10% O_2 saturation). All these categories are reflected in Hoffmann and Lange-Bertalot values. The trophic

Table 1 Ecological characteristics of Loktak Lake based on analysis using OMNIDIA software

N° PREP	Date		Basin	Imphal				
1	02/28/2008		River/Site	Loktak/KLNP				
Van Dam 1994								
	1	2	3	4	5	6	7	Dominant	
pH	0.3	1.4	26.5	46.1	6.0	0		4	Alkaliphilous
Salinity	6.2	62.6	5.6	3.3				2	Fresh brackish
N_2 uptake	21.4	28.8	9.4	3.5				2	N_2 autotrophic taxa tolerating elevated concentrations of organically bound nitrogen
O_2 requirements	14.9	24.0	14.1	11.3	1.4			2	Fairly high
Saprobity	13.6	28.5	11.9	10.6	3.0			2	β-mésosaprobic
Trophic state	3.0	12.3	3.1	6.8	39.1	3.1	3.9	5	Eutraphentic
Moisture	5.0	31.2	27.8	2.6	0			2	Mainly occurring in water sometimes on wet places
Lange-Bertalot 1979									
	11.8	6.6	8.0	0.3	8.0	3.7		1	Most pollution tolerant

Hofmann 1994												
	0	1	2	3	4	5	6	7	8	9	Dominant	
Trophic state	34.3	1.6	9.2	0.3	5.7	12.1	32.3	0.9	3.5		6	Tolerant
Saprobity	35.0	7.2	9.1	22.8	1.6	6.5	0	6.0	0.11	11.7	3	Mesosaprobe

status clearly indicates high share of eutraphentic forms (39.1% nearly double of natural waters). There is a reasonable presence of oligo-mesotraphentic forms. Other categories though low in share were consistent in presence; oligo-eutraphentic, mesotraphentic, and hyper-eutraphentic and oligotraphentic as observed in Hoffmann values. Moisture preferences showed that 31.2% taxa were mainly occurring in water bodies, sometimes on wet place, 27.8% taxa were occurring in water bodies, also rather regularly on wet and moist places, 5.0% taxa were never or very rarely occurring outside water bodies, and 2.6% taxa were occurring on wet and moist or temporarily dry places. Leclercq Index shows very high degradation in the lake. Probably the barrage prevents flushing of nutrients accumulated from decaying phumdis causing perturbations in the bio-geochemical cycles. There were 16.5% diatom taxa that indicated organic pollution while 15.33% indicated anthropogenic eutrophication, indicating low levels as indicated by green color (Fig. 1).

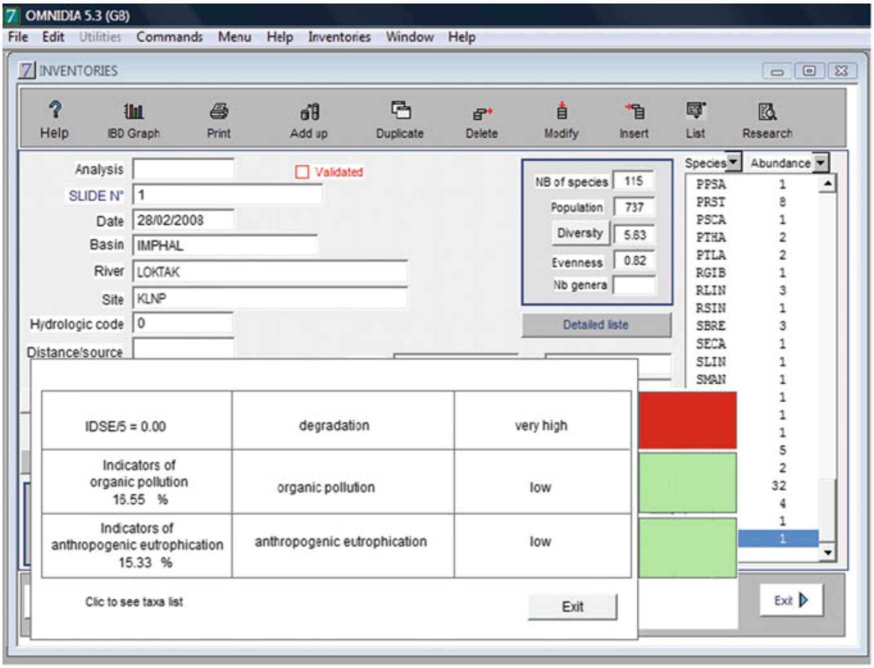

Fig. 1 OMNIDIA software showing levels of degradation, organic pollution, and anthropogenic eutrophication in Loktak Lake

4 Conclusion

The freshwater Loktak Lake ecosystem exhibits perturbations in the nutrient regimes and hence the water chemistry. This is reflected in the flora (presence of salinity loving forms *A. styriaca* and *B. vitrea*) and the community (higher abundance of *G. parvulum* that prefers organically enriched waters). The Van Dam ecologic values also support this observation, as evident by the higher share of nitrogen autotrophic diatom taxa that tolerate elevated concentration of organically bound N_2, forms that prefer higher BOD, low O_2 and eutraphentic conditions. The Leclercq index shows low organic pollution, anthropogenic eutrophication and very high degradation. Lake restoration is the only solution to current state of the Loktak Lake ecosystem.

Acknowledgements The first author acknowledges academic institutional support from the Principal, Government P.G. College, Dakpathar, and the co-author is thankful to the Head, Department of Zoology & Biotechnology, H.N.B. Garhwal University, Srinagar, for extending all facilities during the present study.

Appendix 1

Diatom flora of Loktak Lake

Pennales	**C**
Diatoma vulgaris Bory morpho *producta* Gr. in VH	4
Fragilaria rumpens (Kützing) G.W.F. Carlson	26
Tabellaria fenestrate (Lyngbye) Kützing	5
Ulnaria ulna (Nitzsch) Compère	1
U. u. var. *aequalis* (Kützing) Aboal	4
U. u. var. *acus* (Kützing) Abol	32
U. amphirhynchus (Ehrenberg) Compere et Bukhtiyarova	1
U. danica (Kützing) Compere et Bukhtiyarova	2
Achnanthes brevipes Agardh	1
Achnanthidium catenatum (Bily& Mar.) Lange-Bertalot	14
A. exigum (Grunow) var. *heterovalvum* (Krasske) Czarnecki	2
Achnanthes microcephala (Kützing) Grunow	1
A. minutissimum (Kutzing) Czarnecki	1
Cocconeis euglypta Ehrenberg	31
C. pediculus Ehrenberg	7
C. placentula Ehrenberg	40
Lemnicola hungarica (Gr) Round & Basson	1
Planothidium hauckianum (Gr) Round & Bukhtiyarova	2
P.lanceolatum (Brebisson ex Kutzing) Lange-Bertalot	2
P. rostratum (Öestrup) Round & Bukhtiyarova	8

(continued)

(continued)

Pennales	**C**
Rossithidium linearis (W. Smith) Round & Bukhtiyarova	3
Actinella guianensoides Metzeltin & Lange-Bertalot	1
Eunotia alpina (Naegeli) Hustedt	1
E. flexuosa (Brebisson) Kützing	1
E. pectinalis (Dyllwyn) Rabenhorst	1
E. monodon Ehrenberg	4
E. m. var. *bidens* (Gregory) Hustedt	1
Amphora libyca Ehrenberg	1
A. montana Krasske	2
A. pediculus (Kützing) Grunow	3
A. veneta Kützing	2
Amphipleura pellucida Kützing	1
Anomoeoneis styriaca (Grunow) Hustedt	1
Brachysira vitrea (Grunow) Ross in Hartley	40
Caloneis bacillum (Grunow) Cleve	1
Craticula accomoda (Hustedt) D.G. Mann	2
Craticula cuspidata (Kützing) D.G. Mann	1
Cymbella aspera (Ehrenberg) H. Peragallo	1
C. austriaca Grunow	1
C. excisa Kützing	10
C. gracilis (Ehrenberg) Kützing	1
C. hantzschiana Krammer	5
C. hustedtii Krasske	13
C. h. var. *crassipunctata* Lange-Bertalot & Krammer	7
C. mesiana Cholnoky	7
C. orientalis Lee in Lee Gotoh & Chung	1
C. perparva Krammer	1
C. parva (W. Smith) Kirchner in Cohn	1
C. pervarians Krammer	1
C. subleptoceros Krammer	11
C. subhelvetica Krammer	4
C. stigmaphora Østrup	5
C. tumida (Brébisson) Van Heurck	6
C. turgidula Grunnow	1
C. t. var. *venezolana* Krammer	1
Diadesmis confervacea Kützing	1
Diploneis elliptica (Kützing) Cleve	1
D. modica Hustedt	1
Encyonema minutum (Hilse in Rabenhorst) D.G. Mann	27
Epithemia sorex Kützing	3

(continued)

(continued)

Pennales	**C**
E. zebra (Ehrenberg) Kützing	10
Frustulia vulgaris (Thwaite) De Toni	2
Gomphonema affine Kützing	4
G. acuminatum Ehrenberg	18
G. neonasutum Lange-Bertalot & Reichardt	51
G. angustum Agardh	1
G. augur Ehrenberg	6
G. clevei Fricke	7
G. gracile Ehrenberg	2
G. olivaceum (Hornemann) Brébisson	1
G. parvulum Kützing	59
G. subtile Ehrenberg	1
G. truncatum Ehrenberg	1
Gyrosigma obtusatum (Sullivan & Wormley) Boyer	29
Hantzschia amphioxys (Ehrenberg) Grunow	5
Luticola goeppertiana (Bleish in Rbenhorst) D.G. Mann	2
Navicula capitatoradiata Germain	1
N. cryptocephala Kützing	10
N. cryptotenella Lange-Bertalot	9
N. krammerae Lange-Bertalot	1
N. upsaliensis (Grunow) Peragallo	1
N. phyllepta Kützing	20
N. radiosa Kützing	16
N. schroeteri Meister	16
N. rostellata Kützing	3
N. veneta Kützing	1
N. v. var. *viridula* (Kützing) Ehrenberg	4
N. v. var. *v.* forma *linearis* (Hustedt) Kobayasi	1
Neidium affine (Ehrenberg) Piftzer	1
N. ampliatum (Ehrenberg) Krammer	1
N. binodeforme Krammer	1
Nitzschia clausii Hantzsch	23
N. dissipata (Kützing) Grunow	1
N. dravellensis Coste & Ricard	1
N. frustulum (Kützing) Grunow	4
N. gracillis Hantzsch	2
N. hantzschiana Rabenhorst	12
N. obtusa var.*scalpelliformis* Grunow	1
N. palea (Kützing) W. Smith	20
Placoneis elliptica (Hustedt) Ohtsuka	1

(continued)

(continued)

Pennales	C
Pinnularia acrospheria W. Smith	1
P. braunii (Grunow) Cleve	1
P. subcapitata Gregory	1
Pleurosigma angulatum (Quekett) W. Smith	4
Reimeria sinuata (Gregory) Kociolek & Stoermer	1
Rhopalodia gibba (Ehrenberg) O. Müller	1
Sellaphora mantasoana Metzeltin et Lange-Bertalot	1
S. parapupula Lange-Bertalot	1
S. pupula (Kützing) Mereschkowsky	1
Stauroneis anceps Ehrenberg	1
S. phoenicenteron (Nitzsch) Ehrenberg	1
urirella capronii Brebisson in Kitton	3
S. linearis W. Smith	1
Centrales	
Cyclotella meneghiniana Kützing	8
Discostella stelligera (Cleve at Grunow) Houk & Klee	1

Acronym: C = Count

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