Original Article
LIMNOLOGY FRESHWATER BIOLOGY

Diatom diversity and community structure of the littoral zone of Lake Ugii, Mongolia

Bukhchuluun Ts.[1]*, Barkhas L.[2], Erdenesukh E.[2]

[1] *Natural plant genbank, Botanic Garden and Research Institute of Mongolian Academy of Sciences, Bayanzurkh district, Ulaanbaatar, 13330 Mongolia*
[2] *Water recovery LLC, Sukhbaatar district, Ulaanbaatar, Mongolia*

ABSTRACT. Lake Ugii, one of the largest freshwater lakes in central Mongolia, has experienced increasing anthropogenic pressure and environmental change over recent decades. To evaluate the current ecological condition of the lake shoreline, diatom assemblages were investigated at multiple sampling sites around the lake and associated habitats. A total of 86 diatom taxa were identified in 2024, compared with 110 taxa reported in 2009, indicating a decline in species richness over the past fifteen years. Elevated phosphorus concentration indicators were recorded along the northern and northeastern shoreline, suggesting the influence of organic inputs from surrounding riparian areas. Additionally, there was low substrate stability at sites along the Hooloy River, Hoid Mergen Shanaa, and Saidiin Hoshuu. Multivariate analyses revealed significant spatial variation in diatom community composition among sampling sites (PERMANOVA; $R^2 = 0.554$; $p = 0.001$), while differences in within-site dispersion were not significant (PERMDISP; $p = 0.087$). Indicator Species Analysis identified five significant indicator taxa, including *Diatoma vulgaris* Bory, *Nitzschia palea* (Kützing) W.Smith, *Encyonema elginense* (Krammer) D.G.Mann, *Epithemia sorex* Kützing, and *Diatoma tenuis* C.Agardh. Although measured physicochemical variables (conductivity, temperature, total dissolved solids, salinity, and pH) did not show significant relationships with community composition, spatial differences among assemblages suggest the influence of local shoreline conditions and ongoing land-use changes within the watershed. Comparison with previous surveys indicates a significant decline in diatom diversity and a marked shift in shoreline community composition in Lake Ugii. These findings provide important baseline information for ecosystem monitoring, conservation planning, and sustainable management of the lake and its watershed.

Keywords: diatom, diversity, changes, Lake Ugii, Mongolia

For citation: Bukhchuluun Ts., Barkhas L., Erdenesukh E. Diatom diversity and community structure of the littoral zone of Lake Ugii, Mongolia // Limnology and Freshwater Biology. 2026. - № 4. - P. 621-631. DOI: 10.31951/2658-3518-2026-A-4-621

1. Introduction

Lake Ugii is situated in the northern part of the Khangai Mountains, covering an area of approximately 12 km^2 and reaching a maximum depth of 17 m. The Hogshin Orhon River flows into Lake Ugii, while the Hooloy River traverses the montane steppes before continuing northwest to join the Orhon River downstream of the lake (Wang et al., 2005).

The Ugii Lake basin is experiencing increasing anthropogenic pressure (Nomindari et al., 2024). Human impact assessments indicate substantial increases in road density, population concentration, land-use modification, and overall human influence between 2000 and 2020 (Fig. 1). Due to intensive livestock grazing, phosphorus (PO_4^{3-}) concentrations in the lake have increased (Amgalan et al., 2020a), while evaporation exceeds annual precipitation (Amgalan et al., 2020b). Human activities, including urbanization, mining, industrialization, livestock grazing, and forest exploitation, together with climate change, are affecting biodiversity and contributing to changes in species composition (Dagvadorj et al., 2014). These landscape-scale transformations may alter habitat heterogeneity and environmental conditions within shoreline ecosystems, potentially affecting the structure and distribution of aquatic communities.

*Corresponding author. E-mail address: bukhchuluunts@mas.ac.mn (Ts. Bukhchuluun)

Received: June 15, 2026;
Accepted after revised: August 21, 2026;
Available online: August 28, 2026

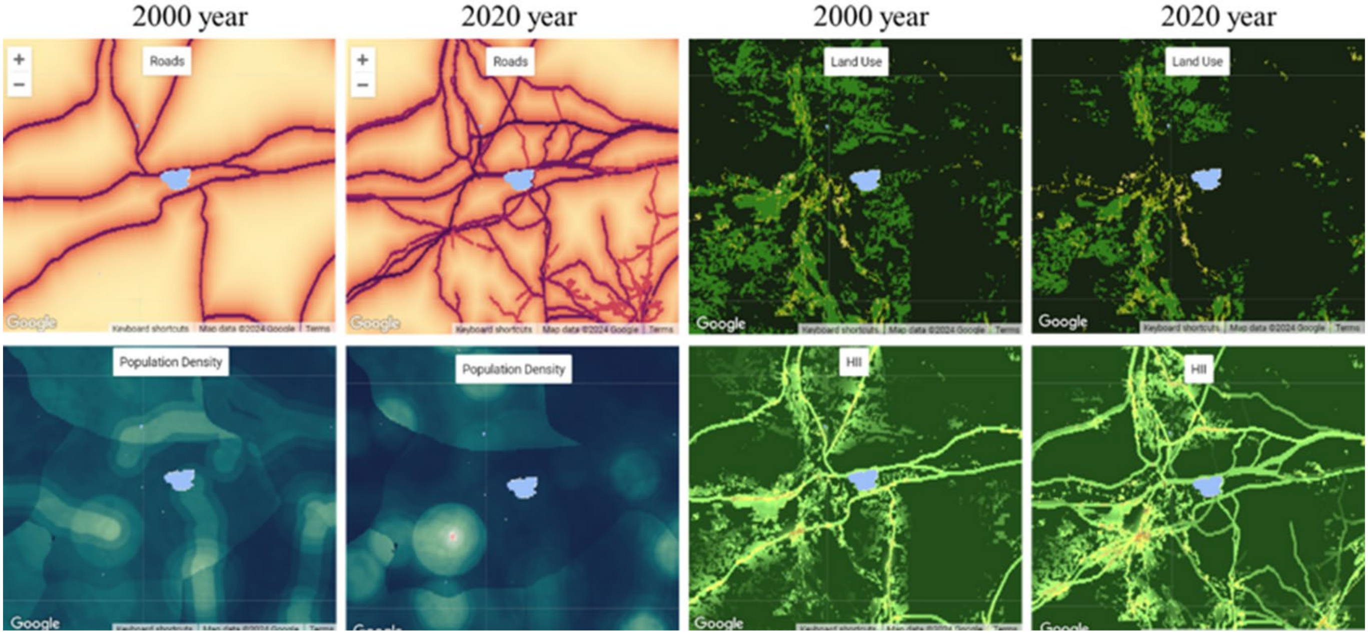

Fig.1. Changes in landscape characteristics within the Ugii Lake watershed between 2000 and 2020. Maps illustrate variations in road density, land-use patterns, population density, and human influence, indicating increasing anthropogenic pressure in the lake watershed over the past two decades.

Long-term climatic records derived from the Climate Research Unit (CRU) dataset indicate considerable interannual variability in air temperature within the Ugii Lake region during the last century (New et al., 2000; Fig. 2).

Additionally, temporal changes in lake extent indicate substantial fluctuations in water level and surface area during recent decades (https://earth.google.com/web/@47.77366175,102.74352177,1333.93828722a,15916.59223393d,35y,0h,0t,0r/data=ChY6EAgBEQAAAAAAABAGMEPIABCAggBSg0I________ARAA, Fig. 3).

However, the consequences of these environmental changes for aquatic biodiversity remain insufficiently investigated. The species composition and abundance of aquatic organisms are important indicators of water quality and ecosystem health (Moe et al., 2023; Prommi, 2023; Zakharenko et al., 2022). As human settlement and land-use intensity increase around freshwater resources, the condition of aquatic ecosystems and their ecosystem services deteriorates worldwide (Deeksha and Rama, 2023; Zou and Mao, 2022; Santos et al., 2023).

Diatoms are widely used in water-quality assessment because they occur in nearly all aquatic habitats, comprise numerous species, are readily identifiable, respond rapidly to environmental change, and serve as reliable indicators of ecological conditions (Chen et al., 2022; Pan et al., 2004). Water quality and land use are closely linked and often exhibit basin-specific relationships (Baker, 2003). Therefore, diatom assemblages are considered among the most sensitive biological

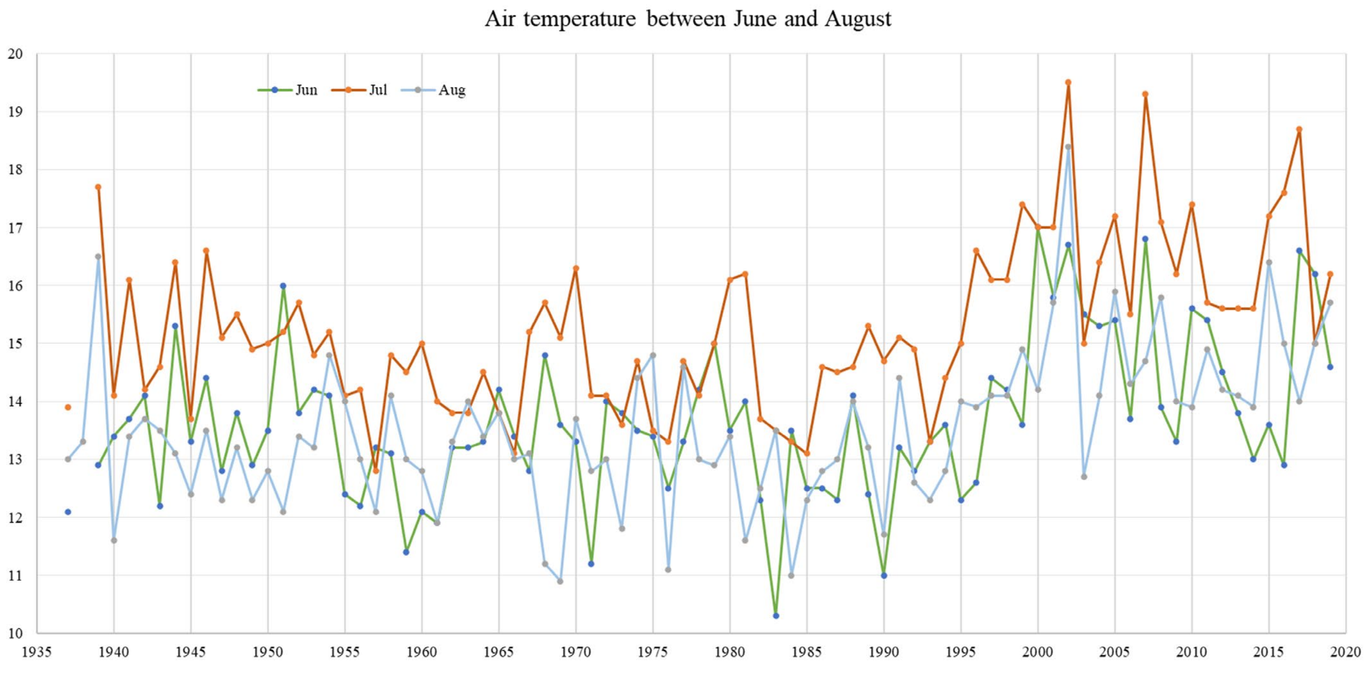

Fig.2. Air temperature of the surrounding area of Lake Ugii.

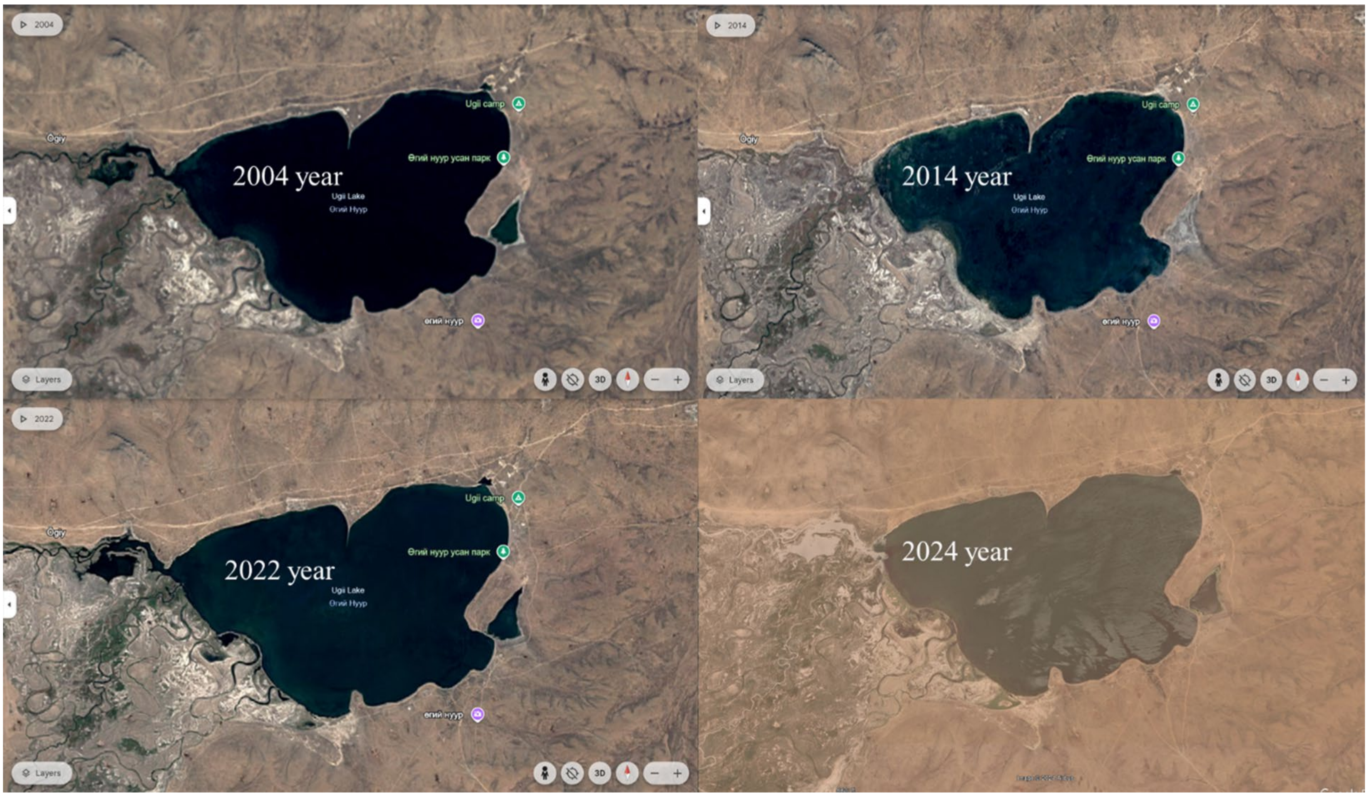

Fig.3. Changes in the surface area of Lake Ugii.

indicators for assessing the long-term effects of land-use change on aquatic ecosystems (Jüttner et al., 2021; Trábert et al., 2020; Mbao et al., 2020).

Accurate assessment of biodiversity and community structure is essential for understanding ecosystem condition, identifying environmental stressors, and supporting effective conservation and management strategies (Cazorla et al., 2020; Kapelkina and Teplyakova, 2021). Therefore, evaluating diatom assemblages and their relative abundance provides valuable information for assessing aquatic ecosystem status and identifying factors influencing ecological change.

The present study aimed to characterize the spatial variability of shoreline diatom assemblages in Lake Ugii, evaluate differences in community composition among sampling sites, identify indicator taxa associated with particular habitats, and examine relationships between community structure and selected environmental variables.

2. Material and methods

Benthic and planktonic algae samples were collected from 11 study sites along the shoreline of Lake Ugii in August 2024, each in a 100 mL container and fixed in 4% formalin (Bahls, 1993). Some bays, named after locals, are marked with blue circles in Fig. 4, starting from the source of Lake Ugii, such as the Hooloy River, and going eastward, such as Ugii–North 1. Dureing sampling, we measured water conductivity (µs/cm), temperature (C°), TDS (ppm), salinity (ppt), and pH.

For the identification of diatoms to the species level, a fixed preparation was prepared (Stoermer et al., 1995). This involved cutting a small amount of the collected sample to completely remove organic residues, dissolving it in 30 mL of 30% H_2O_2 in a sterile glass beaker, and gently heating it in a laboratory fume hood for about an hour. After cooling to room temperature, 30 mL of 70% HNO_3 was added; it was gently heated for another hour, and then deacidified by passing it through cooled distilled water. After the cleaned sample filled the area of the cover glass, dripping and evaporating, the permanent preparation was prepared by attaching the collection label to the glass slide with balsam and attaching it to the right-angled corner (Spaulding et al., 2021). The prepared fixed preparations were examined under a microscope at 1000× magnification with immersion oil and identified to the genus and species level using the basic identification guide (Metzeltin et al., 2009), (Krammer and Lange-Bertalot, 1991a; 1991b; 2000), and 400-600 plates or 200-300 individuals were counted per preparation (Taylor et al., 2007) to calculate the relative abundance of each species in the sample. Relative abundance was the number of individuals of a species counted in a given sample compared to the total number of individuals counted (Birks, 2010).

Species diversity was calculated based on the number of species in each group and the relative abundance of each species (Shannon, 1948). The Shannon-Wiener index of species evenness in a community was calculated based on the diversity value and species richness (Pielou, 1966).

Species composition recorded in 2024 was compared with historical data collected from the same sites in 2009 (Bukhchuluun and Soninkhishig, 2009).

Environmental indicator taxa, including indicators of nitrogen enrichment, phosphorus enrichment, salinization, ecological condition, and nitrogen-fixing taxa, were assigned following Stevenson (1997) and are summarized in Table 1.

Table 1. Ecological guild and indicator taxa of diatom

Ecological guild	Genera
Low-profile	*Amphora, Cocconeis, Diploneis, Encyonema, Fragilaria, Kolbesia, Lemnicola, Meridian, Planothidium, Reimeria, Rhoicosphenia*
High-profile	*Ctenophora, Cymbella, Cymbopleura, Diatoma, Gomphonema, Pseudostaurosira, Staurosira, Staurosirella,*
Motile	*Caloneis, Craticula, Cymatopleura, Epithemia, Fallacia, Geissleria, Gyrosigma, Hippodonta, Luticola, Navicula, Neidium, Nitzschia, Pinnularia, Rhopalodia, Sellaphora, Stauroneis, Surirella, Tryblionella*
Planktic	*Aulacoseira, Stephanocyclus, Cyclotella,*
High nitrogen concentrations	*Amphipleura pellucida, Cyclotella meneghiniana, Nitzschia frustulum,Nitzschia palea, Nitzschia sigmoidea*
High salinization process	*Amphipleura pellicuda, Amphora coffeaeformis, Caloneis silicula,Ctenophora pulchella Hantzschia amphioxys, Melosira varians, Nitzschia frustulum, Nitzschia palea, Rhopalodia gibberula*
Soil siltation index	Navicula, Nitzschia, and Surirella
High phosphorus concentrations	*Amphora pediculus, Cocconeis euglypta, Planothidium lanceolata, Reimeria sinuata, Rhoicosphenia abbreviata*

The genera identified in this study were assigned to ecological guilds following Passy (2007) and related literature. Representative genera associated with each guild are summarized in Table 1.

Ecological guild classification and environmental indicator classification were applied independently. Therefore, a species could simultaneously belong to an ecological guild (e.g., motile) and serve as an indicator of a particular environmental condition (e.g., nitrogen enrichment).

Species richness (S), relative abundance, diversity index (H'), and evenness index (J') were calculated using Microsoft Excel 2016. Analysis of variance (ANOVA) of taxonomic diversity was performed using JMP Pro 14. The original data were transformed into a multivariate analysis of variance (Legendre and Gallagher, 2001).

The soil erosion indicator was estimated using the soil siltation index and calculated as the summed relative abundance of taxa belonging to the genera Navicula, Nitzschia, and Surirella (Stevenson and Bahls, 1999). Diatom community data were analyzed using abundance matrices. Bray–Curtis dissimilarity was used to quantify differences in species composition among sampling sites. Patterns in community composition were visualized using non-metric multidimensional scaling (NMDS). Both two-dimensional and three-dimensional solutions were evaluated, and ordination quality was assessed using stress values. Differences in diatom assemblage composition among sampling sites were tested using permutational multivariate analysis of variance (PERMANOVA) based on Bray–Curtis dissimilarities with 999 permutations. To assess the assumption of homogeneity of multivariate

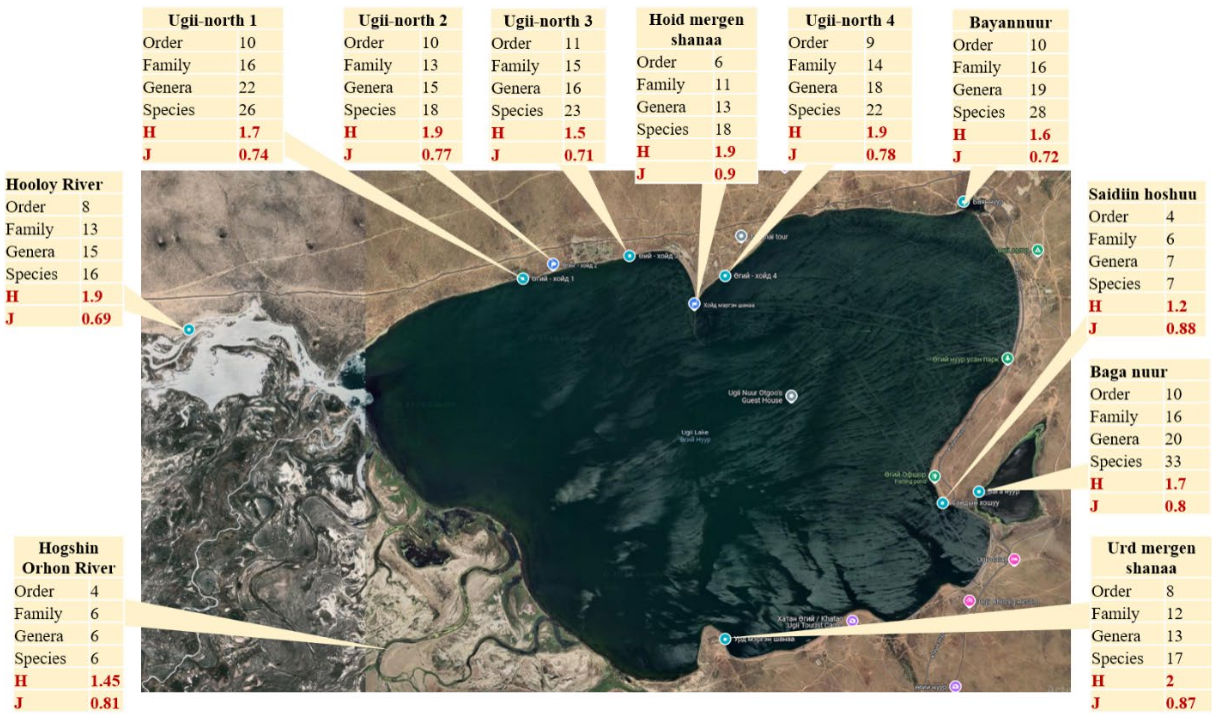

Fig.4. Study sites and diatom diversity.

dispersion, distances to group centroids were analyzed using PERMDISP (betadisper), and significance was evaluated using analysis of variance (ANOVA). Species contributing most strongly to differences among sites were identified using Similarity Percentage Analysis (SIMPER). Indicator Species Analysis (IndVal) was conducted to identify taxa significantly associated with particular sites. Statistical significance was evaluated using 999 permutations. All analyses were performed in R using the vegan and indicspecies packages.

3. Results

3.1. Species richness

Overall, 86 diatom species were identified from 26 samples, with *Gomphonema* and *Navicula* species being the richest in species composition. Low-profile species number was 11, high-profile–26, motile species–45, and plankton–4. The highest number of diatom species was recorded in Bayannuur and Baganuur, while the lowest number was recorded in Saidiin hoshuu and the Hogshin Orhon River. The mean value of the species richness of the diatom community in 26 samples was 10.6 ± 0.66, with a minimum value of 6 and a maximum of 33.

Among the species recorded in 2009, 78 were not observed in 2024, whereas 56 taxa were newly recorded. To identify the most ecologically important newly recorded taxa, species occurring in three or more samples of the 26 samples were selected, and their maximum relative abundance and occurrence frequency are presented in Fig. 5. Most newly recorded taxa were rare, with 40 taxa (71.4%) occurring in only one or two samples. In contrast, only 16 taxa were recorded in three or more samples. Among these, *Encyonema elginense* (Krammer) D.G.Mann was the most widespread species, occurring in 14 of the 26 samples, followed by *Pseudostaurosira brevistriata* (Grunow) D.M.Williams & Round (9 samples), *Craticula halophila* (Grunow) D.G.Mann (8 samples), *Cocconeis euglypta* Ehrenberg (8 samples), *Stephanocyclus meneghinianus* (Kützing) Kulikovskiy, Genkal & Kociolek (7 samples), and *Craticula ambigua* (Ehrenberg) D.G.Mann (7 samples).

Among the 78 taxa recorded in 2009 but not observed in 2024, 17 species belonged to the genus Navicula and 13 species–to the genus Nitzschia, indicating that species turnover was particularly pronounced within these two genera. In 2009, 59% of the species composition was motile, while in 2024, 51% was motile. Spatially, the species composition recorded in the Saidiin hoshuu on the eastern shore of Lake Ugii is in the same group as the results of 2009 and 2024.

Cluster analysis showed that most samples were grouped according to sampling year, indicating substantial temporal turnover in species composition between 2009 and 2024 (Fig. 6). Only 22% of taxa were shared between surveys.

3.2. Community structure

The species diversity index had a mean value of 1.8 ± 0.06, with a minimum of 1.11 and a maximum of 2.3. The evenness index had a mean value of 0.78 ± 0.01, with a minimum of 0.62 and a maximum of 1. The species richness index was 1.5–1.9 on the north and east shores of the lake, while the southern shore had 2. The evenness index was 0.69–0.88. There were no statistically significant differences in the species richness, species diversity, and evenness indices between the study sites.

Permutational multivariate analysis of variance (PERMANOVA) based on Bray–Curtis dissimilarities revealed significant differences in diatom community composition among the sampling sites ($F = 1.865$; $R^2 = 0.554$; $p = 0.001$). Site identity explained 55.4% of the total variation in community structure. Analysis of multivariate homogeneity of group dispersions (PERMDISP) indicated no significant differences in within-group dispersion among sites ($F = 2.154$; $p = 0.087$). Non-metric multidimensional scaling (NMDS) further

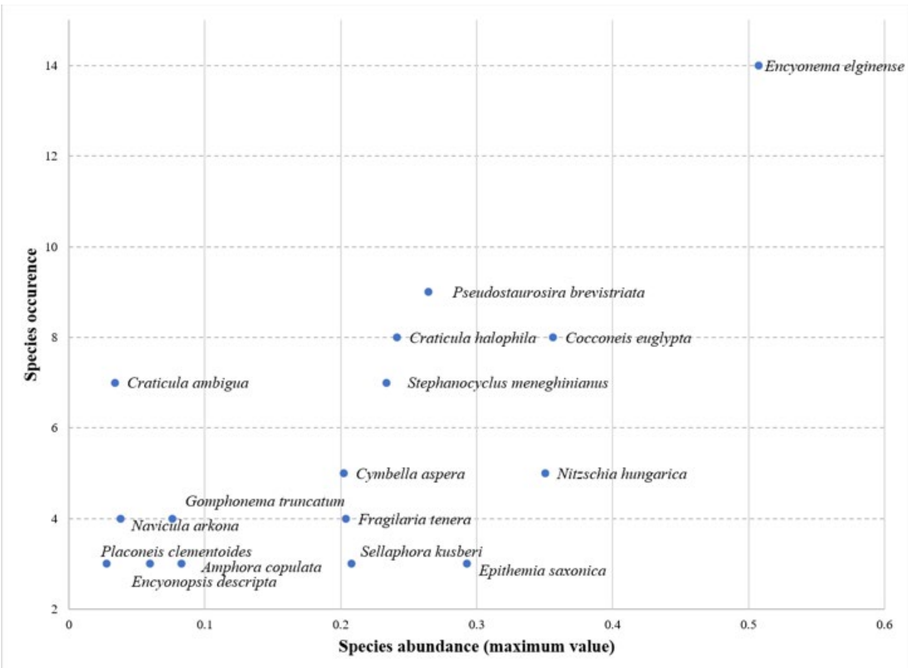

Fig.5. Occurrence and maximum relative abundance of newly recorded diatom taxa in Lake Ugii in 2024.

illustrated patterns of variation in community composition among sampling sites. The two-dimensional NMDS solution yielded a stress value of 0.208, whereas the three-dimensional solution reduced stress to 0.144, indicating a substantially improved representation of community structure in three-dimensional ordination space. A three-dimensional solution provided a better fit (stress = 0.144) than the two-dimensional ordination (stress = 0.208) (Fig. 7).

As Table 2 displays, PERMANOVA revealed significant differences in diatom community composition among sampling sites (p = 0.001), whereas PERMDISP indicated no significant differences in within-group dispersion (p = 0.087). Analysis of multivariate homogeneity of group dispersions (PERMDISP) indicated no significant differences in dispersion among sites (F = 2.15; p = 0.087). Therefore, the significant PERMANOVA result likely reflects differences in community composition rather than differences in within-group variability.

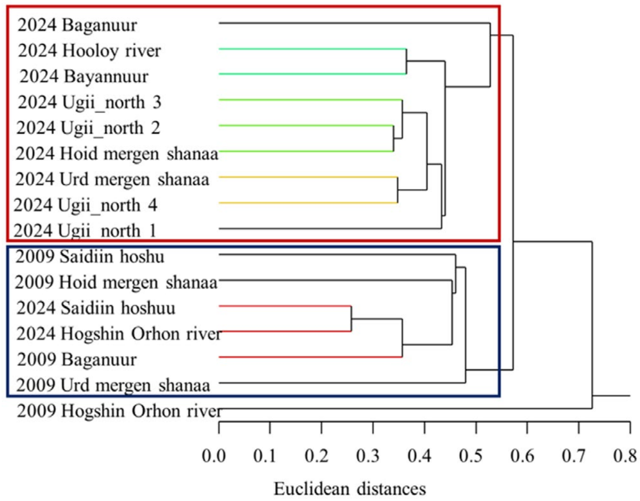

Fig.6. Cluster analysis of diatom species composition recorded in 2009 and 2024. Colors indicate major clusters identified based on species similarity. Samples from the two survey periods formed largely distinct groups, reflecting substantial temporal turnover in diatom assemblages.

3.3. Indicator taxa and ecological guilds

Indicator Species Analysis (IndVal) identified five statistically significant indicator taxa associated with particular sampling sites. *Diatoma vulgaris* exhibited the highest indicator value (IndVal = 1.000; p = 0.019), followed by *Nitzschia paleae* (IndVal = 0.935; p = 0.005), *Encyonema elginense* (IndVal = 0.934; p = 0.037), *Epithemia sorex* (IndVal = 0.889; p = 0.042), and *Diatoma tenuis* (IndVal = 0.871; p = 0.036).

The diatom ecological group classification showed statistically significant differences between the study sites. The low-profile and plankton guilds were statistically different (P > 0.0312* and 0.0069), and the motile and high-profile were not statistically different (Table 3, Fig. 8).

3.4. Diatom-based environmental indicators

The salinization process of the lake water was df = 10; F = 5; P is 0.0027*; mean value was 0.07 ± 0.02; maximum value was 0.42; in the Hooloy River–0.35-0.41; in Bayannuur–0.4; in Baga Nuur–0.11-0.12; and in the Hogshin Orhon River–0.18. The nitrogen concentration indicator was df = 10; F = 5.5; P was 0.0016*; mean was 0.07 ± 0.02; maximum was 0.58; in the Hooloy River–0.33-0.57; in Bayannuur–0.38; and in the Khogshin Orkhon River–0.18. The salinization process was most pronounced in the Hooloy River and the Hogshin Orhon River, while the Hooloy River, Bayannuur, and the Hogshin Orhon River showed high nitrogen concentrations. The nitrogen concentration index was df = 10; F = 5.5; P was 0.0016*; mean value was 0.07 ± 0.02; maximum value was 0.58; in the

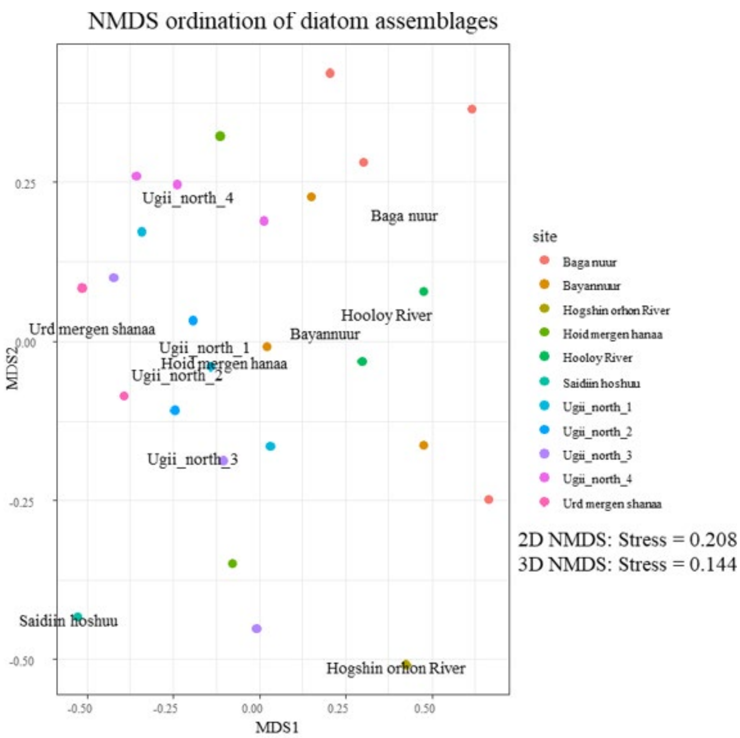

Fig.7. Non-metric multidimensional scaling (NMDS) ordination of diatom assemblages based on Bray–Curtis dissimilarities among sampling sites in the study area and associated habitats. Colors represent sampling sites. The two-dimensional solution yielded a stress value of 0.208. Significant differences in community composition among sites were confirmed by PERMANOVA (R^2 = 0.554; p = 0.001). Points represent individual samples (n = 26), while colors denote sampling sites. Samples originating from the same site share the same color.

Table 2. Results of PERMANOVA and PERMDISP analyses

Analysis	Df	F-value	R^2	p-value
PERMANOVA	10	1.865	0.554	0.001
PERMDISP	10	2.154	–	0.087

Table 3. Analysis of variance

Guild	Df	MS	F	P >
Low-profile	10	0.038	2.89	0.0312*
Motile	10	0.074	1.05	0.4510
High-profile	10	0.074	0.88	0.5701
Plancton	10	0.005	4.12	0.0069*

Hooloy River–0.33-0.57; in Bayannuur–0.38; and in the Hogshin Orhon River–0.18. However, the phosphorus indicator was df = 10; F = 0.76; P was 0.6629; mean value was 0.1 ± 0.02; maximum value was 0.4; at site 1 in Ugii_north–0.23; at site 3 in Ugii_north–0.38; at Hoid mergen shanaa–0.12-0.28; at site 4 in Ugii_north 0.24-0.28; at Bayannuur–0.39; and at Baganuur–0.2-0.23. It was high on the north, northeast, and east shores of the lake (Fig. 9).

The relative abundance of species indicating lake shore soil erosion was df = 10; F = 6.46; P was 0.007*; mean value 0.06 ± 0.02; maximum value was 0.5, and the highest values were recorded at Hoid mergen shanaa (0.14–0.15); Bayannuur (0.35), and Hogshin Orhon River (0.50) than at other sites. The relative abundance of species indicating soil erosion of the riparian zone was df = 10; F = 6.48; P was 0.0007*; mean value was 0.09 ± 0.02; maximum value was 0.56, and the highest values were recorded at Hoid mergen shanaa (0.15–0.28), Saidiin hoshuu (0.35), Urd mergen shanaa (0.13), and Hogshin Orhon River (0.56) than at other sites. The lowest values were recorded in the Hooloy River, and none–in Saidiin hoshuu (Fig. 10).

3.5. Relationships between diatom communities and environmental variables

The influence of environmental variables on diatom community composition was assessed by fitting environmental vectors onto the NMDS ordination using the envfit procedure. None of the measured physicochemical variables, including conductivity (Cond), temperature (Temp), total dissolved solids (TDS), salinity, and pH, showed a statistically significant relationship with community structure (p > 0.05). Correlation analysis further revealed very strong positive relationships among conductivity, TDS, and salinity (r > 0.99), indicating substantial redundancy among these variables (Table 4).

4. Discussion

Comparison with surveys conducted by Bukhchuluun and Soninkhishig (2009) revealed substantial temporal turnover in diatom assemblages. Only 22% of taxa were shared between 2009 and 2024, while 78 previously recorded taxa were no longer observed,

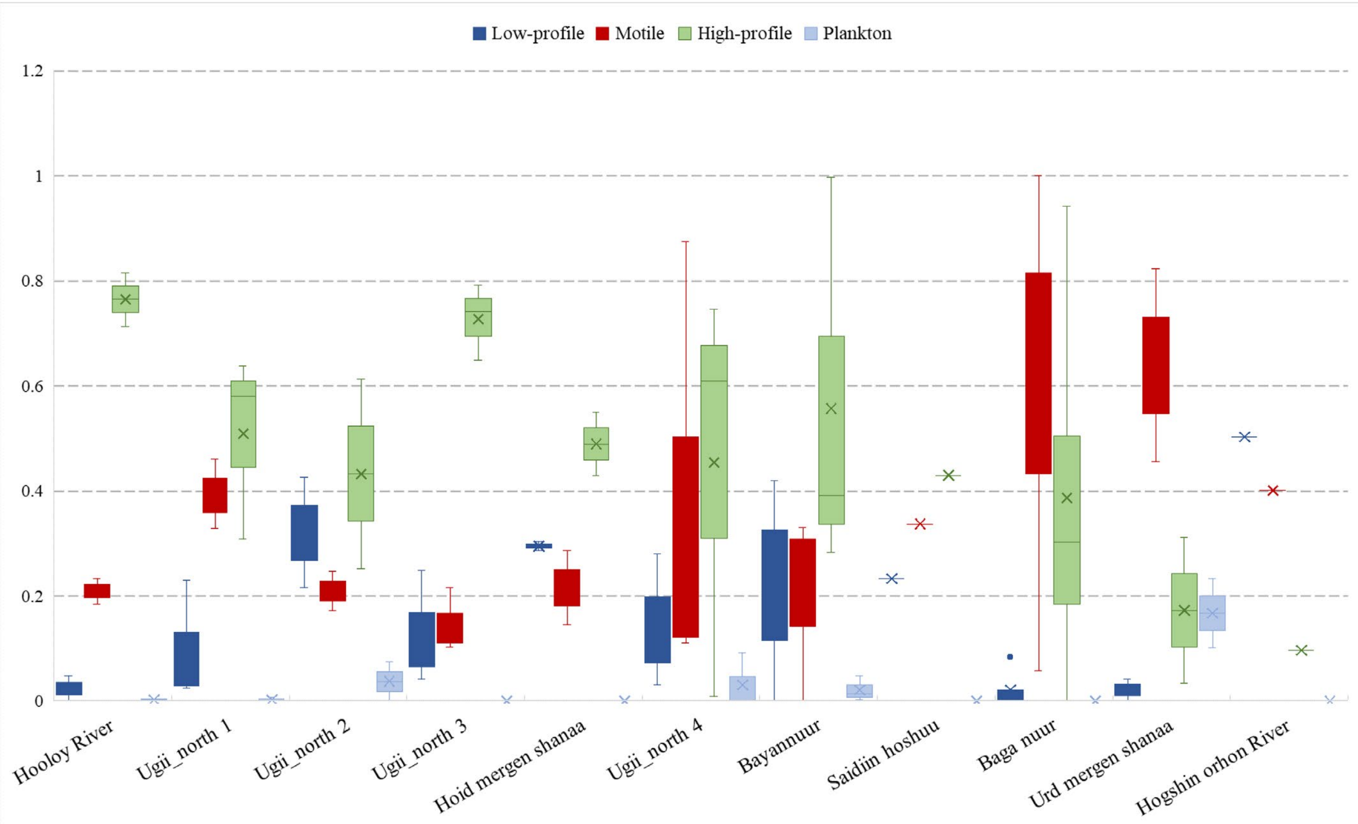

Fig.8. The relative abundance of ecological guilds at the study sites.

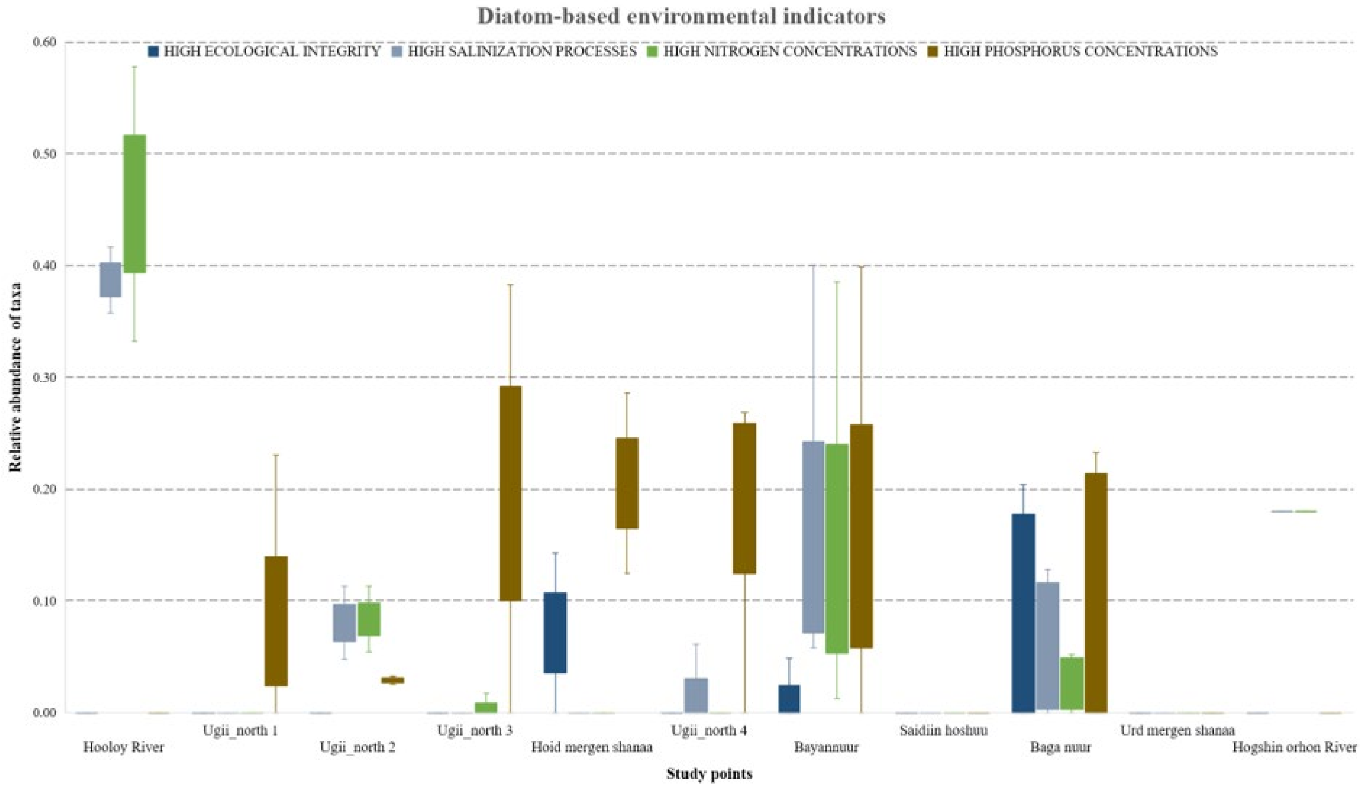

Fig.9. Diatom variables at the study sites.

and 56 taxa were newly recorded. The appearance of 56 newly recorded taxa does not necessarily imply that all species became important components of the community. Most newly recorded taxa were rare and occurred in only one or a few samples. In contrast, *Encyonema elginense*, *Pseudostaurosira brevistriata*, *Craticula halophila*, and *Cyclotella meneghiniana* were recorded frequently across sampling sites and therefore represent ecologically important additions to the contemporary diatom assemblage. Taxonomic turnover was especially obvious within the genera Navicula and Nitzschia, which together accounted for 30 of the 78 taxa not observed in 2024. Given the ecological diversity of these genera, their disappearance may reflect changes

Table 4. Results of environmental fitting (envfit)

Variables	r^2	p-value
Conductivity (µs/cm)	0.016	0.845
Temperature (C°)	0.041	0.641
TDS (ppm)	0.015	0.86
Salinity (ppt)	0.016	0.854
pH	0.033	0.687

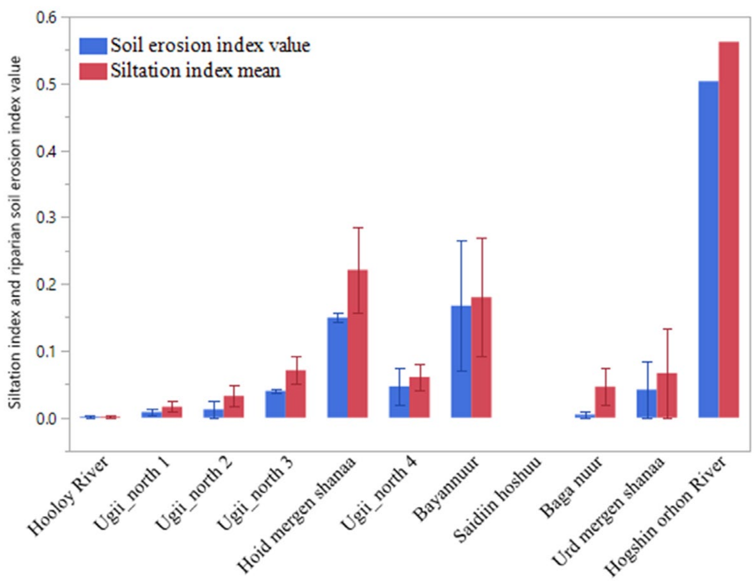

Fig.10. Indicator values of soil erosion in the riparian zones of the study sites.

in habitat conditions and environmental heterogeneity within the littoral zone of Lake Ugii.

This high species turnover suggests considerable ecological change within the Lake Ugii ecosystem during the past 15 years. The observed temporal changes coincide with increasing anthropogenic pressure and landscape transformation within the watershed, including the expansion of road networks, changes in land-use patterns, and greater human influence. These landscape-scale changes may have altered shoreline habitat conditions and ecological processes, thereby contributing to the observed restructuring of diatom assemblages. These long-term environmental changes may have altered habitat conditions and contributed to the restructuring of shoreline diatom communities. Diatom assemblages in Lake Ugii exhibited moderate diversity (mean Shannon index = 1.8 ± 0.06), while species composition differed substantially among sampling sites. Although the diversity and evenness indices did not differ significantly among sites, multivariate analyses revealed pronounced differences in community composition, indicating that spatial turnover in species assemblages occurred without major changes in overall diversity. The absence of significant differences in diversity and evenness among sites suggests that changes in community structure were driven primarily by species replacement rather than by changes in overall diversity. Direct comparisons with other Mongolian lakes are difficult because long-term repeated surveys of diatom assemblages remain scarce. Nevertheless, environmental changes associated with climate variability, grazing pressure, and land-use change were documented in several Mongolian lake basins, indicating that the ecological changes observed in Lake Ugii may reflect broader regional trends.

Based on the gradient of environmental resources, diatoms are classified as low-profile, high-profile, motile, and plankton (Passy, 2007), which is very useful for understanding the structure, organization, and evolution of benthic diatom communities (Tsoi et al., 2017).

When flow velocity, turbidity, or nutrient and light availability to the biofilm decrease, low-profile species crowd out high-profile species (Steinman, 1996; Peterson, 1996; McCormick, 1996; Tuji, 2000). When sediment content increases due to natural or human activities, the abundance of motile species increases (Stevenson and Bahls, 1999; Bahls, 1993; Fore and Grafe, 2002), and when sediment content decreases, the proportion of low-profile species increases (Dickman et al., 2005).

PERMDISP revealed no significant differences in within-group dispersion ($F = 2.154$; $p = 0.087$), suggesting that the significant PERMANOVA result reflects genuine differences in community composition rather than differences in within-site variability.

The occurrence of indicator taxa is especially important because diatoms are highly sensitive to local environmental conditions. Significant indicator taxa identified in this study further support the presence of habitat-specific assemblages and highlight the ecological heterogeneity of the Ugii Lake shoreline. The identification of distinct indicator species at different shoreline sites suggests that habitat characteristics, substrate conditions, nutrient availability, and shoreline processes vary considerably within the lake ecosystem. Therefore, spatial differences in community composition are not merely the result of random variation but reflect ecological differentiation among habitats.

Although conductivity, temperature, TDS, salinity, and pH did not largely explain variation in diatom assemblages, substantial landscape changes occurred around Ugii Lake between 2000 and 2020. Increasing road density, human influence, and land-use modification may have altered habitat conditions, nutrient dynamics, sediment inputs, and shoreline structure, thereby contributing to the spatial differentiation of diatom communities observed among sampling sites. The significant indicator taxa and high temporal turnover recorded between 2009 and 2024 further suggest that local habitat conditions and long-term environmental change have played important roles in shaping community structure. Overall, increasing anthropogenic pressure and landscape transformation in the Ugii Lake watershed have coincided with substantial temporal turnover and pronounced spatial differentiation of shoreline diatom assemblages.

5. Conclusion

Diatom diversity in Lake Ugii has declined compared to previous observations, indicating ongoing ecological change within the lake ecosystem. Significant spatial differences in community composition among shoreline sites revealed pronounced habitat heterogeneity around the lake.

Between 2000 and 2020, the Ugii Lake watershed experienced increasing anthropogenic pressure, including expansion of road networks, land-use change, population growth, and greater human influence. These landscape-scale changes likely contributed to the observed restructuring of shoreline habitats and diatom assemblages. Indicator species analysis further confirmed the presence of distinct habitat-specific communities.

Overall, increasing anthropogenic pressure and landscape transformation in the Ugii Lake watershed have coincided with substantial temporal turnover and pronounced spatial differentiation of shoreline diatom communities. Continued conservation and management efforts are needed to reduce human disturbance and maintain the ecological integrity of the lake ecosystem.

Conflict of interest

The authors declare no conflicts of interest.

References

Amgalan M., Matsumoto T., Ulaanbaatar T. et al. 2020. Estimation of evaporation from Ugii Lake using the energy budget method. Journal of Japan Society of Civil Engineers, Ser. G (Environmental Research) 76(5): I_301-I_309. DOI: 10.2208/jscejer.76.5 I 301

Amgalan M., Matsumoto T., Ulaanbaatar T. et al. 2020. Changes and Causes of Environmental Characteristics of Ogii Lake and Orkhon Valley, Mongolia. Journal of Water and Environment Technology 18(4): 199–211. DOI: 10.2965/jwet.19-093

Bahls L.L. 1993. Periphyton bioassessment methods for Montana streams. Water Quality Bureau, Department of Health and Environmental Sciences.

Baker A. 2003. Land use and water quality. Hydrological Processes 17(12): 2499–2501. DOI: 10.1002/hyp.5140

Birks H. 2010. Numerical methods for the analysis of diatom assemblage data. In: The Diatoms: Applications for the Environmental and Earth Sciences. Cambridge University Press, pp. 23–54.

Bukhchuluun Ts., Soninkhishig N. 2009. Diatom species composition in Lake Ugii, Mongolia. Scientific Journal of the Institute of Botany, Mongolian Academy of Sciences 21: 34–43.

Dagvadorj D., Batjargal Z., Natsagdorj L. 2014. MARCC-2014: Mongolia second assessment report on climate change-2014. (Ministry of Environment and Green Development of Mongolia).

Deeksha Shukla A.K., Rama Devi N. 2023. Impact of Land Use and Land Cover in Water Resources. In: Rai P.K. (Ed.), River Conservation and Water Resource Management. Springer Nature Singapore, pp. 217–231. DOI: 10.1007/978-981-99-2605-3 11

Dickman M.D., Peart M.R., Wai-Shu Yim W. 2005. Benthic Diatoms as Indicators of Stream Sediment Concentrationin Hong Kong. International Review of Hydrobiology 90(4): 412–421. DOI: 10.1002/iroh.200410806

Fore L.S., Grafe C. 2002. Using diatoms to assess the biological condition of large rivers in Idaho (U.S.A.): River diatom assessment. Freshwater Biology 47(10): 2015–2037. DOI: 10.1046/j.1365-2427.2002.00948.x

Cazorla P.B., Cabello J., Reyes A. et al. 2020. A remote sensing-based dataset to characterize the ecosystem functioning and functional diversity of a Biosphere Reserve: Sierra Nevada (SE Spain). Earth System Science Data Discussions, 2020, 1-20.

Chen L., Li Q., Ye H. et al. 2022. Identifying the effects of environmental factors on benthic diatom assemblages in typical tributaries of Taizi River, northeast China using the CCA method. Water Supply 22(8): 6576–6584. DOI: 10.2166/ws.2022.287

Jüttner I., Kelly M.G., Evans S. et al. 2021. Assessing the impact of land use and liming on stream quality, diatom assemblages and juvenile salmon in Wales, United Kingdom. Ecological Indicators 121: 107057. DOI: 10.1016/j.ecolind.2020.107057

Kapelkina L., Teplyakova T. 2021. The conditions and methods of biological diversity preservation and restoration on post-technogenic lands. BIO Web of Conferences 31: 00010. DOI: 10.1051/bioconf/20213100010

Krammer K., Lange-Bertalot H. 1991. Süßwasserflora von Mitteleuropa. Bacillariophyceae: Centrales, Fragilariaceae, Eunotiaceae. Vol. 2/3. Stuttgart & Jena: Gustav Fischer Verlag.

Krammer K., Lange-Bertalot H. 1991. Süßwasserflora von Mitteleuropa. Bacillariophyceae: Achnanthaceae. Kritische Ergänzungen zu Navicula (Lineolatae) und Gomphonema. Vol. 2/4. Stuttgart & Jena: Gustav Fischer Verlag.

Krammer K., Lange-Bertalot H. 2000. Bacillariophyceae. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. Süßwasserflora von Mitteleuropa. Vol. 2/3. Heidelberg: Spektrum Akademischer Verlag.

Legendre P., Gallagher E.D. 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129(2): 271–280. DOI: 10.1007/s004420100716

Mbao E.O., Gao J., Wang Y. et al. 2020. Sensitivity and reliability of diatom metrics and guilds in detecting the impact of urbanization on streams. Ecological Indicators 116: 106506. DOI: 10.1016/j.ecolind.2020.106506

McCormick P.V. 1996. Resource competition and species coexistence in freshwater benthic algal assemblages. In: Algal Ecology: Freshwater Benthic Ecosystems. (EdˆEds R.J. Stevenson & M.L. Bothwell & R.L. Lowe). Academic Press.

Metzeltin D., Lange-Bertalot H., Soninkhishig N. 2009. Diatoms in Mongolia Iconographia Diatomologica. In: Lange-Bertalot H. (Ed.), Vol. 20, A. R. G. Gantner Verlag K. G., Ruggell, pp. 691.

Moe S.J., Mentzel S., Welch S.A. et al. 2023. From national monitoring to transnational indicators: Reporting and processing of aquatic biology data under the European Environment Agency's State of the Environment data flow. Frontiers in Environmental Science 11: 1057742. DOI: 10.3389/fenvs.2023.1057742

New M., Hulme M., Jones P. 2000. Representing Twentieth-Century Space–Time Climate Variability. Part II: Development of 1901–96 Monthly Grids of Terrestrial Surface Climate. Journal of Climate 13(13): 2217–2238. DOI: 10.1175/1520-0442(2000)013<2217:RTCSTC>2.0.CO;2

Nomindari D., Tuya S., Bayartugs T. 2024. The Effects of Anthropogenic Loads on Vegetation Cover and Natural Water Quality in the Ugii Lake Basin, Mongolia. Mongolian Geoscientist 29(58): 80-93. DOI: 10.5564/mgs.v29i58.3413

Pan Y., Herlihy A., Kaufmann P. et al. 2004. Linkages among land-use, water quality, physical habitat conditions and lotic diatom assemblages: A multi-spatial scale assessment. Hydrobiologia 515(1–3): 1–3. DOI: 10.1023/B:HYDR.0000027318.11417.e7

Passy S.I. 2007. Diatom ecological guilds display distinct and predictable behavior along nutrient and disturbance gradients in running waters. Aquatic Botany 86(2): 171–178. DOI: 10.1016/j.aquabot.2006.09.018

Peterson C. 1996. Response of benthic algal communities to natural physical disturbance. In: Stevenson R.J., Bothwell M.L., Lowe R.L. (Eds), Algal Ecology: Freshwater Benthic Ecosystems. Academic Press.

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

Prommi T.O. 2023. Water quality assessment in an irrigation pond based on adult caddisfly (Insecta: Trichoptera) assemblages. Ecologica Montenegrina 62: 87–100. DOI: 10.37828/em.2023.62.11

Santos M.J., O'Connor J.C., Nguyen K. et al. 2023. Effects of land use change on water-related ecosystem services in the Amazon Basin. Egusphere. DOI: 10.5194/egusphere-egu23-14983

Shannon C.E. 1948. A mathematical theory of communication. Bell System Technical Journal 27: 379–423, 623–656.

Spaulding S.A., Potapova M.G., Bishop I.W. et al. 2021. Diatoms.org: Supporting taxonomists, connecting communities. Diatom Research 36(4): 4. DOI: 10.1080/0269249X.2021.2006790

Steinman A.D. 1996. Effects of grazers on freshwater benthic algae. In: Stevenson R.J., Bothwell M.L., Lowe R.L. (Eds), Algal Ecology: Freshwater Benthic Ecosystems. Academic Press.

Stevenson R.J., Bahls L.L. 1999. Periphyton protocols. In: Barbour M.T., Gerritsen J., Snyder B.D. et al. (Eds.), Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish (2nd ed., EPA 841-B-99-002). U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Stevenson R.J. 1997. Scale-dependent determinants and consequences of benthic algal heterogeneity. Journal of the North American Benthological Society 16: 248-262.

Stoermer E.F., Edlund M.B., Pilskaln C.H. et al. 1995. Siliceous microfossil distribution in the surficial sediments of Lake Baikal. Journal of Paleolimnology 14(1): 1. DOI: 10.1007/BF00682594

Taylor J., Harding W., Archibald C. 2007. A methods manual for the collection, preparation and analysis of diatom samples. Water Research Commission (WRC).

Trábert Z., Duleba M., Bíró T. et al. 2020. Effect of Land Use on the Benthic Diatom Community of the Danube River in the Region of Budapest. Water 12(2): 479. DOI: 10.3390/w12020479

Tsoi W.Y., Hadwen W.L., Sheldon F. 2017. How do abiotic environmental variables shape benthic diatom assemblages in subtropical streams?. Marine and Freshwater Research 68(5): 5. DOI: 10.1071/MF15388

Tuji A. 2000. The effect of irradiance on the growth of different forms of freshwater diatoms: implications for succession in attached diatom communities. Journal of Phycology 36(4): 659–661. DOI: 10.1046/j.1529-8817.2000.99212.x

Wang Y.-K., Stevenson R.J., Metzmeier L. 2005. Development and evaluation of a diatom-based Index of Biotic Integrity for the Interior Plateau Ecoregion, USA. Journal of the North American Benthological Society 24(4): 4. DOI: 10.1899/03-028.1

Zakharenko M.O., Kurbatova I.M., Poliakovskyi V.M. 2022. Assessment of the ecological state of waters by the species composition of zooplankton and phytoplnakton. Biolohichni Systemy 14(1): 72–81. DOI: 10.31861/biosystems2022.01.072

Zou Y., Mao D. 2022. Simulation of Freshwater Ecosystem Service Flows under Land-Use Change: A Case Study of Lianshui River Basin, China. Sustainability 14(6): 3270. DOI: 10.3390/su14063270