Spatial structure of vegetation in Lake Gusinoe (Republic Byriatia)

B B Bazarova and A P Kuklin
Institute of Natural Resources, Ecology and Cryology, Siberian Branch of RAS, 16A Nedorezov Street, Chita, 672014, Russia
E-mail: bazarovabb@yandex.ru

Abstract. Lake Gusinoe is the second largest lake in the Baikal Natural Area (after Lake Baikal). The conducted research presents current water flora and the spatial pattern of vegetation at Lake Gusinoe mainly depend on the littoral structure and anthropogenic stressors. Macrophytes grow up to the depth of 13.0 m on the southwestern shore of the lake. In the other part of the lake, the plants are observed at 8.5-11.0 m. The littoral zone to the depth of 11 m occupies 50.7 per cent of total area of the lake. At present, the reduced areas of Ph. australis are detected with small groups of P. crispus, P. pectinatus on the western shore at the depth of 1.5 m. P. praelongus communities are only found in the littoral opposite the Tobkhor River. Generally, Charophytes and Bryophyta remain predominant in the lake as registered in the previous years. Presumably, the benthic vegetation complex contributes to a stable ecological status. Overgrowing Charophyta and Bryophyta maintain the self-purification of the ecosystem.

1. Introduction

Water macrophytes are one of the important environmental components of the lake ecosystem. The spatial distribution and composition of phytocenoses serve as informative indicators of the state of the ecosystem, its changes under the influence of climatic and anthropogenic factors; this is becoming the subject of an increasing number of studies [1].

Lake Gusinoe is the second largest lake in the Baikal Natural Area (after Lake Baikal). The Gusinozersk industrial complex, one of the biggest in the Republic of Buryatia, is located nearby the lake and the city of Gusinozersk. It includes power plants, processing sites and transportation providers with the dumps of the Gusinozersk State Regional Power Plant (SRPP) and non-reclaimed coal mining wastes in the spoil tips left by the Kholbolginsky Coal Mine being the greatest anthropogenic stressors. The lake is the main source of drinking and industrial water in the region. Additionally, it receives purified household waste waters from the Gusinozersk biological treatment station and untreated sewage from the village of Gusinoe Ozero [2].

The lake is used for fishery and recreation. The first data compilation on the biota of the lake was conducted by M.M. Kozhov [3]. Further milestone investigation was a monograph “The Ecology of Gusinoe Lake” [4] describing its biota (zooplankton, zoobenthos, fishes and fish parasites). The next survey dealt with the dynamics of the hydrochemical composition [5] and bathymetry of the lake [6]. As for the biota, zooplankton communities [7], fish populations [8, 9] and their parasitophauna [10, 11], zoobenthos communities [12, 13], and bacterial plankton [14] are the most extensively studied while the vegetation of the lake remains almost unexplored. The observations on water macrophytes are only
available for 1927 [15], 1936 [16], and 1947 [3]. As of 1990-1991, the recordings on the chemical composition of *Potamogeton praelongus* Wulf are available.

Since Lake Gusinoe is connected to the Selenga River, the main tributary of Lake Baikal, it carries a potential risk of contaminating the Baikal basin. In general, growing anthropogenic disturbances in the ecosystem of the lake entail monitoring, assessment of a current status and further development of the lake.

The aim of this study present in the spatial structure of aquatic vegetation in Lake Gusinoe.

2. Materials and methods
Lake Gusinoe is oval in shape lying in a southwest-northeast direction «figure». It was only in the 18th century when the lake’s actual contours appeared after the Tsagan-Gol River had inflown from the Temnik River flooding smaller lakes in the current whereabouts of Lake Gusinoe [15]. The lake has a catchment area of 924 km² with a surface area of 164 km² and an average long-term annual lake volume of 2.4 km³ and an average lake depth of 15 m. The length of the lake is 24.8 km, an average width – 8 km, a minimum width – 5.1 m, a prevailing depth – 15-20 m [4]. The maximum depth of the lake measured by Shestakovich [16] in 1936 was 28 m reaching 25 m in 1990-1991 [4]. The bed of the lake is U-shaped with smooth contours of the shoreline disturbed by occasional sand spits and river fans and several shallow bayous. The promontory Cape Chan enters the lake in the northwest dividing it into two basins: a southern basin with smaller but deeper area; and a northern basin forming the main part of the lake. Most shallow areas are located on the northern and southwestern shores [4, 17]. Bottom sediments do not have a high diversity with sand and sand-and-shingle in the littoral zone while the benthic zone and littoral zone of the western shore are composed of tough silts of black or sometimes grey color [13]. Lake Gusinoe is a water body with a low level of outflow. The conventional water balance ratio equals to 0.0125 with 9 rivers flowing into the lake and the only outflow, the Bayan-Gol River, occurring at a high level of the lake and located in the southeastern basin.

![Figure 1. Schematic map of the lake Gusinoe: I – XII hydrobotanical profiles (explanations in the text).](image-url)
Hydro-vegetation dynamics was analyzed in July 2013-2014 using conventional procedures and methods field-proven on the water bodies of Transbaikal Region. The vegetation was studied on 12 ecological lines «figure» located along the area from the shoreline to the maximum depth. The classification was produced using dominant vegetation communities. The sampling of plants phytomass was conducted using an instrument for quantitative assessment of Gammaridae (QAG, with the catch area of 0.25 m²) that the authors applied when studying aquatic plants communities on other water bodies as well [18]. In total, 89 stations are described. The defined parts of plants phytomass were weighed oven dry.

3. Results

Currently, macrophytes grow up to the depth of 13.0 m on the southwestern shore of the lake. In the other part of the lake, the plants are observed at 8.5-11.0 m. The littoral zone to the depth of 11 m occupies 50.7 per cent of total area of the lake.

The survey was performed along two ecological lines on the northern shore opposite the Zagustai River (hydrobotanical profiles I) and the Tobkhor River (III) «figure». Line I is located along a steady depth gradient with a length of 2.5 km from the shoreline to the depth of 12 m and with predominant silt soils. Plants communities are distributed along the depth gradient in the following order: Ph. australis (swampy shore areas up to the depth of 0.5 m, thick vegetation) → P. crispus + P. perfoliatus + P. amphibia (0.5-1.0 m) → P. crispus + M. sibiricum+ S. pectinatus (up to 3.5 m) → Charophyta + S. vaginatus (from 4.0 to 8.5 m) → Charophyta (up to 10.0 m). The average phytomass of communities is represented by P. crispus 124 g/m²; P. perfoliatus 84 g/m²; M. sibiricum 48 g/m²; S. vaginatus 72.0 g/m²; F. antipyretica 1.1 g/m², Charophyta and L. trisulca both 0.1 g/m². Charophyta occur from the depth of 4 m.

The littoral zone at the Tobkhor River (Profiles III) «figure» is 2.3 km long and composed of silt soils. Plants communities are ordered as follows: Ph. australis (up to 0.3 m) → P. praelongus (1.0-2.0 m) ↔ F. antipyretica ↔ Chara (1.0-8.5 m). Phytomass of P. praelongus is 2.0 g/m², F. antipyretica 157.16 g/m², Chara 661.52 g/m².

The southern basin of the lake is investigated at the mouth of the Tsagan-Gol (Profiles VIII) near the village of Gusinoe «figure». This area features a complicated morphometrical bottom configuration and a longer littoral with a length of about 5.0 km to the depth of 13 m. A steady depth gradient to 4.0 m (with a length of 1.2 km from the shoreline) is interrupted by an area known as a “braid bar” with a depth of 2.0 m and located at ≈ 2.0 km far from the shore. At 4.2 km a steep depth gradient drops to 10.0 m. The littoral is composed of sand and shingle to the depth of 1.0 m with silt at deeper levels and puddled shingle on the “braid bar”. Vegetation communities are formed by the following groups: Ph. australis (rugged shore area up to the depth of 0.3 m) → P. amphibia (in the mouth, sand, shingle, at 1.0-1.5 m) ↔ N. peltata (sand + silt, at 1.5-2.0 m) ↔ E. canadensis (silt, 1.0-2.0 m) → Charophyta (silt, at 3.0-4.0) → P. perfoliatus (sand, silt, at 2.5 m) + P. amphibia (shingle, silt, at 2.0 m) → Charophyta+ F. antipyretica (silt) → A. linnaei (silt, deeper than 9.0 m) Phytomass of E. canadensis ranges within 84-221.28 g/m²; Charophytae 60.8 g/m²; moss 875.28 g/m²; P. amphibia 15.0 g/m², N. peltata 14.6 g/m², A. linnaei 15.4–494.5 g/m².

The littoral zone of the western shore of the lake is analyzed on 4 lines (IV, V, VI, VII) «figure» located opposite the water intake area of the SRPP, the Barata River, the Sangine River and the Narin-Gorkhon River respectively. The area features a steady depth gradient with alternating soils of sand-and-shingle, sand, and silt. The length of the littoral is 1.0-1.8 km. The vegetation communities are distributed in the following order: P. perfoliatus ↔ S. pectinatus ↔ E. canadensis → P. amphibia (from the shoreline to 1.5 m) → Fontinalis ↔ Nitella sp. ↔ Chara sp. (from the depth of 1.5-2.0 to 8.5 m). The phytomass of predominant communities Fontinalis ranges within 652-4,168 g/m², Chara sp. 226.4-4,084 g/m², Nitella sp. 3,226.0 g/m², E. canadensis 8.0 g/m², L. trisulca 2.0 g/m². Between hydrobotanical profiles VII and profiles VIII at the depth of about 5 m P. vaginatus was observed.

The eastern shore of the lake (II, IX, X, XI, XII) «figure» is affected by high wave energy contributing to soils distribution and low diversity of communities. The bottom from the shoreline to
the depth of 4.0 m is composed of sand with silt deeper than 4.0 m. The littoral from 1.4 to 2.3 km is formed by a smooth isobath curve and represented by Chara algae with the phytomass ranging within 29.0–129.44 g/m².

Lines II and IX are slightly different from the above. Profiles II is situated on the northeastern shore. Thin belt of *N. peltata* was recorded at 1.5 m replaced by Chara algae. During the investigation at the depth of 2.0 m filamentous algae bloom was detected. Profiles IX is set at the outflow of the Bayan-Gol River with the recordings of *M. sibiricum* and *P. perfoliatus*.

4. Discussions

The conducted research presents current water flora and the spatial pattern of vegetation at Lake Gusinoe mainly depend on the littoral structure and anthropogenic stressors. The littoral zone of the northern part of the lake is strongly affected by the heated waters discharge from the Gusinozerosk SRPP with a sturgeon farm in its tail-water canal. Treated waste waters from the city of Gusinozerosk are discharged at the mouth of the Zagustai River bringing biogenic substances into the lake. These conditions cause wide-scale mosaic development of the macrophytes communities at the depth of 3.0 m. These communities are represented by species indicating eutrophic conditions (*S. pectinatus, P. crispus, M. sibiricum,*). This area of the lake shows a later die-off of water plants and an earlier start of vegetation growing season, which is not typical for background stations. Filamentous algae blooming at the depth of 2.0 m indicate an increased biogenic pressure. Ecologically, thick belts of macrophytes serve as an effective biofilter locking and processing contaminants. A filter barrier in this part of the lake was reported in the study on microorganisms by [14]. On the southern shore, the structure of vegetation is influenced by a mosaic pattern of soils and a changing depth gradient with favorable environment for alien species of *E. canadensis*. Differences between the patterns of spatial distribution of plants on the western and eastern shores are due to their position against prevailing winds. The shoreline of the leeward western shore is more rugged with calm areas of harbors and bayous favorable for plants growth and protected from high tidal energy. As for the windward eastern shore, the littoral type and soil structure are uniform which leads to a lower diversity and thin vegetation.

The comparative analysis of the water flora and vegetation of Lake Gusinoe is incomplete without detailed exploration of macrophytes. The previous studies [15, 16] only reported on dominant species interfering with fishing industry. The study by M.M. Kozhov [3] covers plants of the lake in a more detailed manner. The author notes that in 1947 *Ph. australis* occupied the area along the northern and western shores and southwestern end at the mouth of the Tsagan-Gol River. The communities of *P. crispus, P. pectinatus* showed a well-marked belt along the western shore. *Chara* species (*Ch. fragilis, Gh. foetida*) mixed with *Potamogetonaceae* from the shore area were recorded. The data include Nitella species and mosses growing at the depth of 6.0 m [3].

Available findings allow for an analysis of long-term changes in the spatial distribution of the lake vegetation. At present, the reduced areas of *Ph. australis* are detected with small groups of *P. crispus, P. pectinatus* on the western shore at the depth of 1.5 m. *P. praelongus* communities are only found in the littoral opposite the Tobkhor River. Generally, Charophyte and mosses remain predominant in the lake as registered in the previous years. However, a certain trend in a higher depth and lower area of their growth is detected. Previously, Chara algae were observed at 15–20 m, whereas currently they grow up to 11.0 m. *Fontinalis* communities only survived on the western shore forming thick belts with high values of phytomass. At present, the phytomass density has significantly increased. Unfortunately, the previous studies do not provide data on the phytomass values, although indicating their thin nature.

The spatial structure and species composition of submerged vegetation are regarded as an indication of ecological conditions in lakes’ [19, 20]. According to the hypothesis of stable alternative states, lake ecosystems may have two states of equilibrium: one characteristic of clear waters with great transparency dominated by macrophytes, and the other one with considerably opaque waters dominated by phytoplankton [1, 21]. Following this hypothesis, Lake Gusinoe is classified as a macrophyte reservoir. The state of the ecosystem of lake Gusinoe in largely due to the abundant development of Charophyta and Bryophyte. An indicative role of stoneworts in lakes with high calcium content has been
already emphasised by many authors [22, 23, 24]. Particularly, in shallow lakes, stoneworts are believed to play an important role in regulating water quality. By competing with phytoplankton and periphyton for nutrients and other resources, by exerting an allelopathic influence on phytoplankton development and by inhibiting sediments from resuspension and erosion, dense Chara meadows have a strong positive effect on water transparency and they stabilise the clear water state [1, 19, 25, 26].

As per the EU Water Framework Directive 2000/60/EU, in terms of water plants development, the ecological status of the lake can be classified as good. Increasing macrophytes contribution to the primary production mainly leads to a more stable ecosystem of the lake and its self-purification [27, 28, 29].

Regardless of significant anthropogenic load and several alterations in structure, the structure and function of the vegetation in Lake Gusinoe remain unchanged. As of 2013-2014, Lake Gusinoe is referred to as a mesotrophic lake with eutrophication in the areas of contamination.

The analysis of the temporal dynamics of the flora and vegetation at Lake Gusinoe reveals its current stable ecosystem with eutrophic areas despite significant anthropogenic pressure. Presumably, the benthic vegetation complex contributes to a stable ecological status. Overgrowing Charophyta and Bryophyta maintain the self-purification of the ecosystem.

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