Ecological analysis of higher aquatic and semi-aquatic plants of Lake Alakol

Yelena Zaparina[1], *Zarina* Inelova[1*], *Aitzhan* Mengtay[1], *Azamat* Mukhitdinov,[1] and *Emil* Boros[2]

[1]al-Farabi Kazakh National University, Almaty, 050040, Kazakhstan
[2] Institute of of Aquatic Ecology, HUN-REN Centre for Ecological Research, Budapest, H-113, Hungary

Abstract. From an ecological perspective, the study of biological diversity is a key element for maintaining the sustainability of ecosystems and for developing and implementing effective conservation and natural resource management strategies. Lake Alakol, a slightly saline, endorheic lake in Kazakhstan, is a unique natural object with rich biodiversity. According to research results, diversity indices such as Simpson (0.99), Shannon (3.48), Margalef (0.78), have similar values, which indicates a sufficient variety of macrophytes. Four ecological groups were identified, with a significant number being hygrophytes (Hg) - 30 species and hygromesophytes (HgM) - 26 species. The hydrophytic index of Lake Alakol was 0.7, which indicates the sustainability of the aquatic flora and a high proportion of true aquatic plants. Among the life forms, perennials (75 species) and annuals (16 species) predominate, which is explained by the morphological and anatomical characteristics of aquatic plants and determines their adaptation to the aquatic environment. Thus, ecological study of macrophytes of Lake Alakol can offer important data for devising successful management and conservation strategies for water basins and their surrounding environment.

1 Introduction

Lake Alakol is a slightly saline, endorheic lake in Kazakhstan, which is situated on the area of two regions: Abay and Zhetysu. It is a unique natural object with rich biodiversity and an ecosystem exposed to various environmental factors. Under the perspective of global climate change and the active impact of human activity over recent decades, issues of conservation and sustainable use of the natural resources of Lake Alakol are becoming the subject of increasingly relevant research [1].

The ecosystem of a lake consists of both abiotic (light, ph, temperature) and biotic components (algae, plants, animal, microorganism). As it knows, macrophytes also belong to the biota, perform an important maintenance of biological balance, and play significant role in water reservoir: habitat for different living organisms (such fish, insects, waterbirds), natural water purifier, providing mechanical support to strengthen the shorelines, preventing algal blooms, supporting diverse ecosystems, performing an important function in purifying water from contaminants, adsorbing toxins and improving its quality; strengthening, preventing erosion and maintaining coastal stability etc.[2]. The studied (aquatic) plants are

[*] Corresponding author*:* *Zarina.Inelova@kaznu.edu.kz*

indicators of the state of the aquatic environment, because, unlike many other organisms, they lack the ability to move and change their location due unfavorable conditions. That is why changes in aquatic vegetation can indicate possible problems such as water pollution, the presence of excess nutrients, especially nitrogen and phosphorus, changes in climatic conditions, etc. [3].

The aim of this research is to conduct a comprehensive ecological analysis of macrophytes to identify their structure, dynamics and impact on the ecosystem of Lake Alakol. The study is also aimed at identifying factors influencing the distribution and condition of aquatic plants, as well as assessing their role in maintaining ecological balance in the given region. Providing accurate and comprehensive information on the vegetation of Lake Alakol can serve as a basis for developing effective management and conservation strategies for this unique natural resource.

2 Materials and Methods

In the research done in the period of 2021-2023, 2 main geobotanical methods were used: field and route-reconnaissance. The first analysis is necessary for familiarization with research objects on the ground, material and data collection [4]; the second method serves to identify how plants species and plant communities are distributed in the study area [5]. Geobotanical description of vegetation was carried out in 15 localities of Lake Alakol's small area (Figure 1) (on sample plots of standard size laid in 3-fold repetition, 1 m x 1 m in size), along with the consecutive herbarization of selected plants and their inclusion in geobotanical forms.

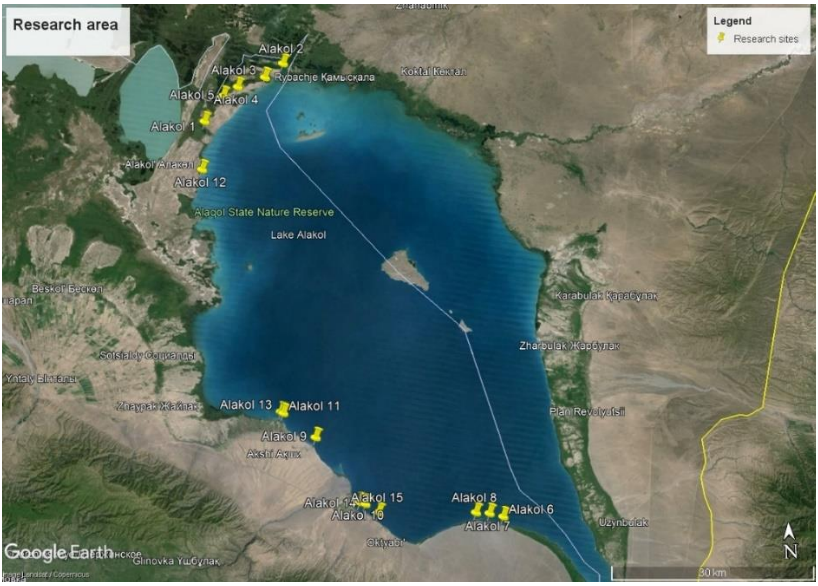

Fig. 1. The distribution of the study sites.

To assess the species richness of the identified flora, the diversity indices of Margalef, Menkhinik and Shannon were used [6].

Shannon diversity index was calculated using the formula:

$$H = -\sum p_i \log_2 p_i \qquad (1)$$

where:
∑- a symbol, which is indicates sum
log - natural logarithm
pi – the proportion of the entire community made up of species i.

Margalef diversity index was calculated using the formula:

$$d=(s-1)/\ln N \quad (2)$$

where:
s – number of species,
N – total number of individuals.

Simpsons diversity index was calculated using the formula:

$$C = \sum(ni/N) \quad (3)$$

where:
ni – number of individuals of each species,
N – total number of individuals of all species.

Diversity indices allow to access the species richness in an observed territory. The plant community is characterized by a great species richness with high index values. The higher the index value, the greater the species richness the community is characterized by. To calculate the indices, the absolute value is used, and it makes the analysis extremely sensitive to the sample size [6].

Ecological analysis of lake flora was done by using the classification introduced by V.G. Papchenko [7]. The proportion of hydrophytes in the flora itself or in the part of it was assessed by the flora hydrophyte index proposed by B.F. Sviridenko (formula 4) [8]. The index value varies from +1 (with complete hydrophytic composition) to -1 (with the absence of hydrophytes in the sample).

$$Ihd = (2A / B) – 1 \quad (4)$$

where A is the number of aquatic species; B – the number of all flora species under consideration.

Life forms were analyzed on the basis of I.G. Serebryakov's classification [9]. The analysis of the results was statistically processed in the PAST 4.1 program [10].

3 Results and Discussion

There are 91 species of higher plants identified as part of the flora of Lake Alakol, belonging to 27 families and 36 genera. The Margalef, Simpson and Shannon indices were used to analyze the species diversity of macrophytes (Table 1).

Table 1. The Margalef, Simpson and Shannon indices of aquatic plants.

Diversity indices	lake Alakol
Taxa_S	91
Individuals	2536
Simpson_1 - D	0.99
Shannon_H	3.48
Margalef	0.78

The obtained analysis results have close values, which confirms their reliability. Margalef diversity index of Lake Alakol is 0.78, indicating the presence of many different species, but with an uneven distribution. Simpson Diversity Index is 0.99. A value close to 1 indicates high dominance of some species. Shannon's diversity index = 3.48, indicating that Lake Alakol has a significant level of species diversity of macrophytes (Formulas 1-3), [6].

Ecological analysis of lake flora was done by using the classification introduced by V.G. Papchenkov [7], it is based on association with aquatic ecological groups (Table 2).

Table 2. Ecological groups of Lake Alakol plants.

No.	Ecological groups	Number of species	%
1	Hydrophytes (Hd)	14	15. 89
2	Hydrohygrophytes (HdHg)	21	20.56
3	Hygrophytes (Hg)	30	33.64
4	Hygromesophytes (HgM)	26	29.9

According to Table 2, the dominant position in the territory of the studied lakes is occupied by hygrophytes 30 species and hygromesophytes 26 species. A third place is occupied by hydrophytes (true aquatic plants) - 21 and last one - hydrohygrophytes (airborne) 14 species, respectively.

When distributing aquatic plants into ecological groups, vertical distribution is important (Table 2). The depth is a significant physical parameter, which the vertical distribution directly depends on. Relatively small hydrohygrophytes grow in shallow waters from 1 to 1.5 m (*Equisetum palustre* L., *Alisma plantago - aquatica* L., *Typha latifolia* L. and etc.). Some species (*Butomus umbellatus* L., *Sparganium erectum* subsp. *microcarpum* (Neuman) Domin etc.) are most often found at a depth of up to 1 m, but during 1-2 growing seasons they are able to withstand a rise in water level up to 1.5-2 m. Hydatophytes are confined to shallow waters and grow at a depth of 0.5-1.5, the examples are *Potamogeton pusillus* L., *Ruppia maritima* L., *Zannichellia palustris* L. At a depth of 1.5-2.5 (sometimes up to 3.5) the following species can be found: *Nuphar lutea* (L.) Smith., *Myriophyllum spicatum* L., *Potamogeton crispus* L. Some species of hydatophytes can be found at a depth of 2.5 – up to 3 m. such as *Ceratophyllum demersum* L., *Stuckenia vaginata* (Magnin) Holub.Thus, speaking about the distribution pattern of aquatic plants in reservoirs, we can note an increase in the diversity of plant species to a depth of 0.5 m, the most optimal depth for growth is 0.5-1.5 m, then a decrease in the number of macrophyte species is noted at a depth of 2.5- 3 m, which is due to low water transparency at these depths.

The hydrophyte index was applied to measure the hydrophyte occurrence rate (Formula 4). The calculations done for Alakol lakes resulted in the index I*hd* of 0.7, which shows that the lake has sustainable aquatic flora and a high proportion of true aquatic plants.

An analysis of the life forms of the studied aquatic plants is shown in Figure 2.

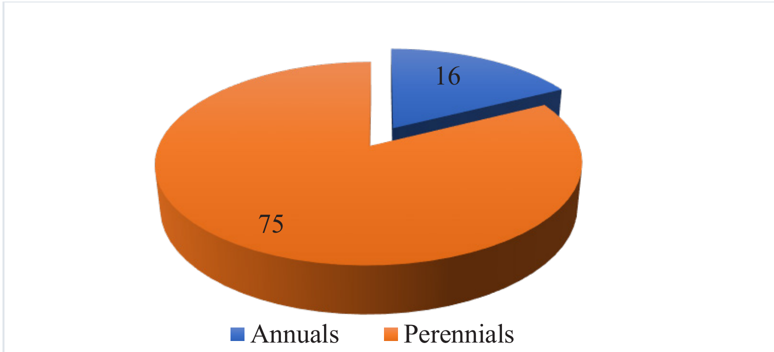

Fig. 2. Life forms of higher aquatic and semi-aquatic plants of Lake Alakol.

The distribution analysis of macrophytes of Lake Alakol by life forms has shown that perennials are predominant (75 species or 82%). Annuals account for 18%, which is 16 species.

Table 3 represents an analysis of the life forms of higher aquatic and semi-aquatic plants according to I.G. Serebryakov.

Table 3. Distribution of studied plants of Lake Alakol according to the classification of I.G.Serebryakov [9].

Life form	No of plant species	%
V. Herbaceous perennial	75	82
VII. Monocarpic herbs	16	18
Total	91	100

The table 3 outlines data that aquatic and semi-aquatics plants of Lake Alakol are divided into only 2 groups: herbaceous polycarpics accounting for 75 species, monocarpic herbs accounting for 16 species.

The rather meager difference in life forms is explained by the morphological and anatomical characteristics of aquatic plants and determines their adaptation to the aquatic environment. For instance, heterophily (floating, submerged and emerged leaves may have very different types of shape and size), low proportion of root biomass, complete absence of roots and stems, predominance of aerenchyma (tissue capable of conducting air) and insignificant content of mechanical and vascular tissues in stems [11]. Coastal plants have large air cavities (intercellular spaces) and channels to effectively transport oxygen from above-water stems and leaves to submerged roots [12]. Some aquatic plants have floating leaves to help them absorb light for process of photosynthesis [13].

4 Conclusion

Therefore, as a result of our research, 27 families, 36 genera and 91 species have been identified forming the aquatic and semi aquatic flora of Lake Alakol. The diversity indices have similar values, which indicates the reliability of the results obtained and the sufficient diversity of macrophytes. Simpson's diversity index is 0.99, Shannon's diversity index is 3.48, Margalef's diversity index is 0.78. As a result of the ecological analysis of the studied plants of Lake Alakol, 4 ecological groups were identified, a significant proportion of which are hygrophytes – 33.64% and hygromesophytes - 29.9% of the all flora of the studied territory. Hydrohygrophytes contain 21 species and only 14 species belongs to Hydrophytes.

The hydrophytic index of Lake Alakol was 0.7, which indicates the sustainability of the aquatic flora and a high proportion of true aquatic plants. The distribution of aquatic vegetation of Lake Alakol by life forms showed that perennials are predominant containing 75 species, followed by annuals with 16 species representatives. The rather meager difference in life forms is explained by the morphological and anatomical characteristics of aquatic plants and determines their adaptation to the aquatic environment.

The analysis described in the article is an integral part of scientific research aimed at understanding and preserving biological diversity and the sustainability of natural ecosystems. Ecological study of macrophytes can provide important information about water quality, the degree of pollution of the reservoir and the content of toxic substances, which are key aspects to assessing the general condition of the aquatic ecosystem. It also allows to identify potential problems at the early stage and take measures to solve them.

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Author’s contribution

Authors' contributions Methodology, data curation, validation, writing – original draft: Z. Ye.; project administration, conceptualization, funding acquisition, validation, and writing – review and editing: I. Z.; methodology, data curation, visualization, writing – original draft: M. A.; data curation, investigation, writing – original draft: A. M.; formal analysis, investigation, and writing – original draft and writing – review and editing: E. B.

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