Photosynthetic activity of plankton in saline lakes under climatic fluctuations conditions

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Abstract. Climate change causes the alternation of high-water and low-water years, which is reflected in morphometric characteristics of lakes. Changes in the depth and volume of water bodies affect the structural and functional activity of the ecosystem, including the growth and development of primary producers. The photosynthetic activity of water body plankton was shown on the example of Dabasa-nor lake and Kudzhertai lake located in the steppe territory of the South-Eastern Transbaikalia. The studied lakes differ in their hydrochemical composition. The content of chlorophyll *a* in Dabasa-nor lake is lower than in Kudzhertai lake. Degraded form of chlorophyll *a* - pheophytin is present only in Dabasa-nor lake, which currently has the least depth of its filling. Carotenoids, as more stable forms of pigments, dominate in the pigment diversity of lake plankton. Chlorophyll *c* was not detected in any of the plankton of both lakes. Factor analysis of the main components showed the interdependence of a number of abiotic agents with the pigment characteristic of phytoplankton. Thus, under the current conditions of the period of lake water availability recovery after a long dry period, the photosynthetic activity of the water body ecosystem is experiencing certain difficulties.

1 Introduction

Salt lakes are widespread in the steppe regions of South-Eastern Transbaikalia. The intra-annual cycles of lake water availability lasting 27-35 years, determined by the amount of atmospheric precipitation, are characteristic of the territory under consideration [1, 2]. At the same time, morphometric characteristics of lakes, such as level, water-surface area, and water volume, change [3-5]. In turn, morphometric changes in water bodies affect the structural and functional activity of the ecosystem. Filling and drying of lakes change the abiotic conditions of the reservoir ecosystem. Changes in abiotic factors indirectly regulate the growth and development of primary producers.

One of the standard methods for determining the functional state of the ecosystem's primary producers is the determination of phytoplankton chlorophyll content. The method is widely used in the system of hydrobiological monitoring of water bodies. This method is used to evaluate the biological productivity and ecological state of water bodies [6-8].

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When atmospheric precipitation increases with storm flow, an excessive inflow of organic matter and biogenic elements is possible, which is reflected in the level of development and potential photosynthetic activity of phytoplankton and ecosystem productivity [6, 9], which characterizes the indicator importance of plant pigments in the monitoring of natural waters [10]. The indicator capacity of photosynthetic pigments of plankton in the water bodies of the Eastern Transbaikalia having different levels of salinity has not practically been investigated. We are conducting the first study of photosynthetic activity of plankton in water bodies in the transitional period between low-water and high-water years, which are currently observed in the South-Eastern Transbaikalia.

The aim of this study is a comparative analysis of photosynthetic activity of plankton in different types of lakes in South-Eastern Transbaikalia during the transitional phase between low-water and high-water periods.

2 Materials and methods

The materials of field studies of photosynthetic activity of lake plankton were obtained by the authors during the complex expedition of two laboratories: aquatic ecosystems and geoecology and hydrogeochemistry of the Institute of Natural Resources, Ecology and Cryology of the Siberian Branch of the Russian Academy of Sciences in July 2021. The location of the lakes is shown in Figure 1. The coordinates of their location are shown in Table 1.

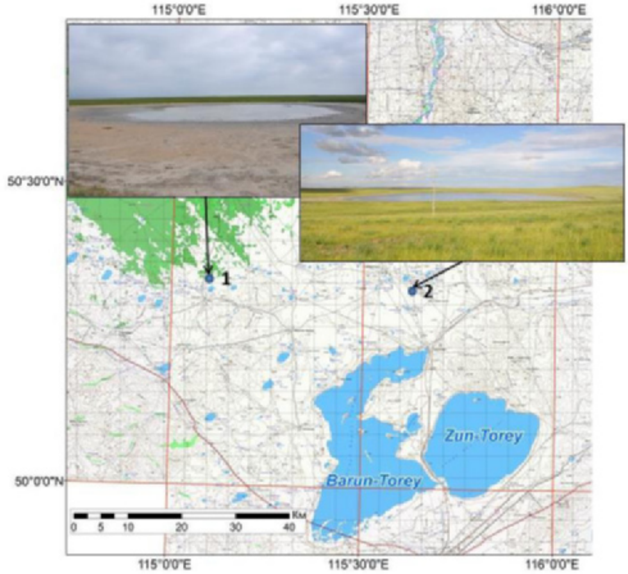

Fig. 1. Schematic map of the studied lakes: 1 - Lake Kudzhertai, 2 - Lake Dabasa-nor.

At present, due to the dry period in the climatic development of the area, the lakes are shallow. Figure 1 shows from the coastal ramparts how much the water surface of the lakes has decreased.

Sampling was conducted in both central and littoral zones of the lakes. Depth and transparency were determined using Secchi disk (d=30 cm). At the same time, physicochemical parameters of water were measured at sampling sites using a multi-channel EXO2 YSI Inc. monitoring probe (pH, salinity, oxygen, water temperature).

Concentrations of nutrients were determined according to common methods described in detail in [11]. Macrocomponent analysis of water samples was performed in the certified laboratory of geoecology and hydrogeochemistry of IPREC SB RAS using atomic absorption, potentiometric, photometric, and titrimetric methods of analysis according to standardized and certified measurement methods [12]. Studies of photosynthetic activity of plankton were conducted in accordance with GOST 17.1.4.02-90 with amendments from 13.07.2017. Pigments were extracted with 90% acetone [13]. The following measuring instruments were used to study the chemical composition of waters: atomic absorption spectrophotometer SOLAAR M6 (Thermo Scientific, USA), high resolution mass spectrometer with inductively coupled plasma ionization ELEMENT 2 (Finnigan MAT, USA), single beam spectrophotometer SPEKOL 1300 (Analytik Jena, Germany), liquid analyzer Expert 001-3-0.1 (Econix-Expert, Russia).

Trophic status is one of the key characteristics of a water body that most adequately reflects the level of eutrophication of natural waters [14, 15]. The trophic status index of water bodies (TSI) was determined according to the following formula [16, 17]:

$$\mathrm{TSI} = \frac{\mathrm{TSI_{TP}} + \mathrm{TSI}_{Chl\,a} + \mathrm{TSI_{SD}}}{3},$$

here TSI by total phosphorus content is:

$$\mathrm{TSI_{TP}} = 14.427 \ln(\mathrm{P}_{tot}) + 4{,}1504$$

TSI by content Chl *a*:

$$\mathrm{TSI_{Chl\,\mathit{a}}} = 9.7552 \ln(Chl\ a) + 30.913$$

TSI by the value of water column transparency:

$$\mathrm{TSI_{SD}} = -14.388 \ln(SD) + 59.909$$

Statistical data processing was performed using the Microsoft Excel 2010 software package. The Principal Component Analysis (PCA) method was used to determine the dependence of pigment characteristics of plankton and abiotic environmental factors. The data were normalized by dividing the initial results by the standard deviation of the corresponding variables [18]. An absolute load value of 0.7 or higher was assumed to be a significant relationship; below 0.7, no relationship was assumed [19].

3 Results

Physico-chemical indicators of lake ecosystems are presented in Table 1. Under natural conditions, the physico-chemical state of natural waters depends on the processes of dissolution and chemical weathering of rocks, as well as on biogeochemical processes occurring in the soils of the catchment area and in the bottom sediments of water bodies.

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Table 1. The main characteristics of researched lakes.

Parameters, units	Kudzhertai	Dabasa-nor
Geographical coordinates	50°12′00″ N, 115°04′12″ E	50°12′00″ N, 115°22′12″ E
Basin bottom elevation, m	664	640
Max depth, m	1.17	0.3
Transparency (CD), m	1.0	0.3
Temperature, °C	21.0	22.4
pH	9.94	8.98
Redox potential (Eh), mV	-479.00	-13.00
Chemical oxygen demand (COD), mgO L^{-1}	4720.00	952.00
Permanganate oxidizability (PO), mgO L^{-1}	724.53	55.9
CO_3^{2-}, mg L^{-1}	55614	203.6
HCO_3^-, mg L^{-1}	13945.82	516.25
SO_4^{2-}, mg L^{-1}	2347.61	6526.39
Cl^-, mg L^{-1}	45943.20	18207.12
Ca^{2+}, mg L^{-1}	1.35	43.10
Mg^{2+}, mg L^{-1}	3.92	1007.47
Na^+, mg L^{-1}	75437.02	13043.86
K^+, mg L^{-1}	271.33	86.29
NO_2^-, mg L^{-1}	<0.003	<0.003
NO_3^-, mg L^{-1}	38925.0	1960.0
NH_4^+, mg L^{-1}	2.65	0.40
P_{tot}, mg L^{-1}	180.48	2.0
PO_4^-, mg L^{-1}	152.83	0.5
TDS, mg L^{-1}	194533.25	39831.27
Electroconductivity, mS cm^{-1}	103000.00	58000.00

These lakes are saucer-shaped and have a shallow depth of 0.3-1.2 m. The bottom of Dabasa-Nor lake is silty pelitic sediments, mosaically covered with bacterial mats. Water in Kudzhertai lake has yellow color and colloidal consistency, the bottom is lined with dark gray silt. Transparency of the water column in both lakes is evident almost to the bottom. The pH values in the ecosystems correspond to alkaline environment (see Table 1).

In accordance with the results of chemical analysis of water samples taken from the lakes under consideration and the accepted geochemical typing 20], Lake Kudzhertai belongs to the I subtype of soda type, as the value of the hydrogen index of its water is 9. 94 pH units, and the anionic composition is dominated by the content of carbonate and hydrocarbonate ions (in total); Lake Dabasa-Nor is a water body of chloride type, as the water pH does not reach 9 units, and chloride ion dominates in anionic composition. Among cations, the highest concentrations are of sodium, which places the lakes in the sodium group (according to O.A. Alekin) [21].

In the content of nutrients in both lakes small concentrations of nitrite and ammonium ions are characteristic. The content of nitrate forms of mineral nitrogen is high. Mineral forms of phosphorus prevail in Kudzhertai lake, and in Dabasa-Nor lake, to a greater extent, phosphorus of organic origin. The content of organic matter in the lakes of autochthonous origin, the ratio of permanganate oxidation (PO) to chemical oxygen demand (COD) does not exceed 40% (Table 1).

Photosynthetic pigments of lake plankton. Analysis of pigment characteristics of plankton in the lakes studied showed the following results (Table 2).

Table 2. Content of phytoplankton pigments of the lakes in July 2021.

Parameters, μ L^{-1}	Kudzhertai	Dabasa-nor
Chl *a*	1.68±0.115	0.11±0.03
Feo	0	0.082±0.015
Chl *b*	11.65±0.195	0.84±0.17
Chl c_1+c_2	0	0
Kar	6±1.7	5.68±1.51
$I_{430/664}$	3±0.88	5±1.96
Note: Chl a is the concentration of chlorophyll a corrected for the presence of pheophytin a (Feo); Chl b is the concentration of chlorophyll b; Kar is the concentration of carotenoids; Chl c_1+c_2 – chlorophyll concentration c_1 and c_2; *I* – pigmental index		

Pigmental diversity of these lakes is represented by chlorophylls a and b and carotenoids. At the same time, values of chlorophyll a and b content in Dabasa-nor lake are lower than in Kudzhertai lake. Small content of pheophytin in the water of Dabasa-nor lake indicates that phytoplankton in this lake is in inactive form compared to Kudzhertai lake. Chlorophyll c was not found in both lakes. The values of pigment index are high in both water bodies.

The ratio of pigments in the ecosystem of the lakes is shown in Figure 2.

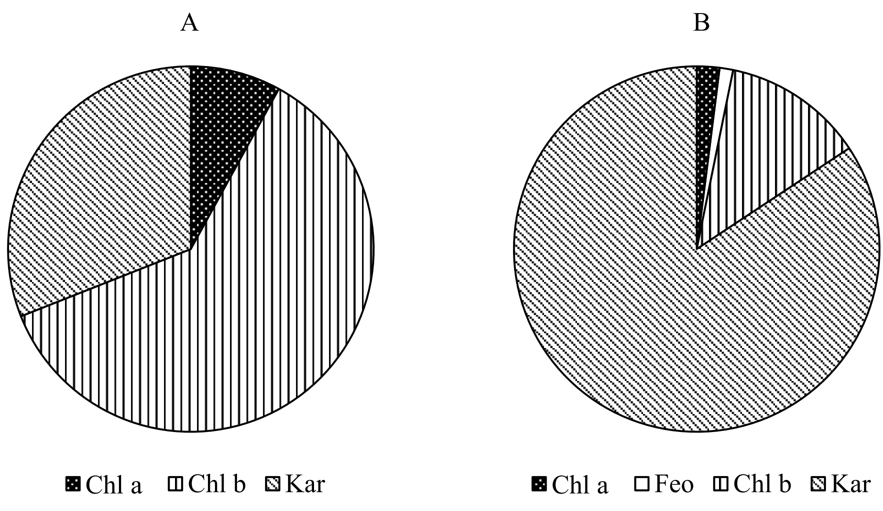

Fig. 2. Ratio of plankton pigments in lakes (%): A - Kudzertai lake, B - Dabasa-nor lake.

The results presented in Figure 2 show the percentage ratio of pigments as follows (in descending order): Chl b → Kar → Chl a (Kudzhertai lake), Kar → Chl b → Chl a → Feo (Dabasa-nor lake). Consequently, chlorophyll b dominates in the pigment diversity in Lake Kudzhertai, and stable carotenoids dominate in Lake Dabasa-nor to a greater extent.

3.1 Trophic state of the investigated lakes

Values P_{tot} and water column transparency are presented in table 1, Chl *a* values are presented in Table 2. Based on these values, the following results were obtained for Kudzhertai lake:

$$\mathrm{TSI}_{\mathrm{TP}} = (14.427 \cdot 2.256) + 4.1504 = 36.7$$

$$\mathrm{TSI}_{\mathrm{Chl}\ a} = (9.7552 \cdot 0.225) + 30.913 = 33.1$$

$$\mathrm{TSI}_{\mathrm{SD}} = (-14.388 \cdot 1) + 59.909 = 45.5$$

$$\mathbf{TSI} = \frac{36.7 + 33.1 + 45.5}{3} = \mathbf{38.4}$$

According to the results of the corresponding values presented in Tables 1 and 2, the following values were obtained for Dabasa-nor lake:

$$\mathrm{TSI}_{\mathrm{TP}} = (14.427 \cdot 0.3) + 4.1504 = 8.5$$

$$\mathrm{TSI}_{\mathrm{Chl}\ a} = (9.7552 \cdot (-0.95)) + 30.913 = 21.6$$

$$\mathrm{TSI}_{\mathrm{SD}} = (-14.388 \cdot 0.3) + 59.909 = 55.6$$

$$\mathbf{TSI} = \frac{8.5 + 21.6 + 55.6}{3} = \mathbf{28.5}$$

The calculated data of the integrated indices of the trophic state of lakes (TSI) were compared with the Carlson scale. According to this scale, ecological state of Kudzhertai lake has mesotrophic level, and Dabasa-nor lake - transitional between oligotrophic and mesotrophic levels of its development.

3.2 Factor analysis of changes in phytoplankton chlorophyll *a* concentrations

Factor analysis by principal component method was carried out on the basis of data array 2021 to reveal the influence of leading environmental factors determining the change of phytoplankton pigment concentrations in the investigated lakes. The factor analysis by principal component method allowed us to distinguish 2 principal components, which take into account 100% variability of the initial indicators (Table 3).

Table 3. Factor coordinates of variables based on correlations of pigment content and abiotic factors of environment.

Variable	Factor 1	Factor 2
Chl *a*	0.989866	-0.135566
Chl *b*	0.993196	-0.108450
Kar	0.249827	0.968290
*h	0.988596	-0.099308
*pH	0.987480	-0.146272
*SO_4^{2-}	-0.991962	0.123942
*Cl^-	0.992852	-0.114604
*Ca_2^+	-0.993405	0.105857
*NO_3^-	0.992856	-0.113977
*TP	0.990676	-0.118961
*Mg_2^+	-0.992751	0.114895
Denotations of pigment values and abiotic environmental factors: Chl a - chlorophyll a concentration; Chl b - chlorophyll b concentration; Kar - carotenoids; h - pond depth; pH - medium reaction; SO_4^{2-} – sulfates; Cl^- – chlorides; Ca_2^+ - calcium ions; NO_3^- – nitrates; TP – total phosphorus; Mg_2^+ – magnesium ions.		

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The criterion for selecting the optimal number of factors was the eigenvalues, which are the variance of the principal components. The final matrix of factor loadings gave us an idea of the pleiotic organization of initial abiotic (depth, medium reaction, sulfates, chlorides, calcium, magnesium, nitrates and total phosphorus content) and biotic (Chl a and b content, phytoplankton carotenoids) indicators and the degree of their relationship with this or that main factor (component).

The presence of a significant relationship indicates a coordinated change in the initial biotic and abiotic indicators under the influence of one or another latent main factor. Thus, chlorophyll a and b (0.98-0.99), pond depth (0.98), pH (0.99), chlorides (0.99) and nitrates (0.99) are positively correlated with the first principal component. Carotenoid content was positively correlated with the second principal component.

The results of the analysis of the first two components of the factor analysis of biotic and abiotic indicators of the surveyed lakes, shown in Figure 3, provided 100% variance.

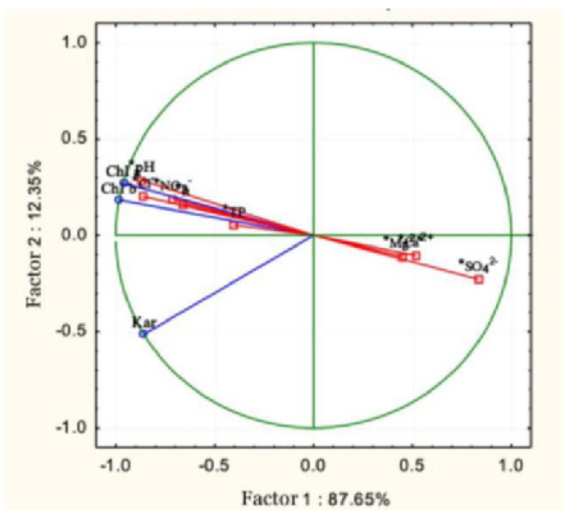

Fig. 3. Analysis of the relationship between pigments and abiotic factors of the lake ecosystem. Notations are the same as in Table 3.

Consequently, to a greater extent, the depth, pH, and nutrient levels determine changes in the pigmental characteristic of saline lakes.

4 Discussion

The impact of natural and anthropogenic factors leads to the transformation of the lake ecosystem [9, 22]. The speed and even the course of many processes in an ecosystem, such as the transfer of nutrients and energy from one trophic level to another, depend not only on the physical and chemical environment, but also crucially on the characteristics of the present species involved in the trophic structure of the ecosystem [23]. Periodic fluctuations in the level of the water mirror of lakes are reflected in changes in the biodiversity of hydrobionts, which contributes to the stability of ecosystems at this stage of its development [24-27]. The physical and chemical parameters of the lake ecosystem associated with changes in the depth of the water column and water salinity levels lead to transformation, including planktonic biocenoses. At the same time, the level of development of primary producers changes towards a decrease in the number, biomass and species diversity of phytoplankton with the predominance of monodominant communities

[28-31]. The tendency for the decrease in the quantity of primary production with decreasing depth and increasing salinity were found in the study of shallow saline lakes of Crimea [24]. Compared to eutrophic and hypereutrophic saline lakes of Crimea, the ecosystems of the lakes we studied do not go beyond the mesotrophic level of their development, which is related to the corresponding parameters of total phosphorus, nitrate and chlorophyll a.

The existing relationship between phytoplankton chlorophyll a concentrations and abiotic environmental factors has been shown by many authors [6, 9, 32, 33]. Factor analysis emphasized the relationship between abiotic factors and photosynthetic activity, indicating a strong dependence of chlorophyll a production on ecosystem condition. Excess input of organic matter and nutrients is reflected in the level of development and potential photosynthetic activity of phytoplankton and ecosystem productivity.

Under unfavorable ecological conditions for phytoplankton, first of all, chlorophyll a is blocked, which is accompanied by an increase in the proportion of auxiliary pigments - carotenoids [7, 34-37]. Consequently, the physicochemical conditions of the ecosystem and the shallow depth of the lake affect the physiological activity of phytoplankton in Lake Dabasa-nor, as evidenced by the low chlorophyll a content compared to Lake Kujertai. Another factor inhibiting the activity of chlorophyll a may be the factor of excessive inflow of biogenic elements into the ecosystem and excessive light at a shallow depth of water bodies [7, 9]. These and other factors inhibiting photosynthetic activity of plankton require further research.

Degradation of chlorophyll a under external and internal adverse influences is associated with its conversion to pheophytin and partial loss of its physiological activity. From the biochemical point of view, pheophytin is a chlorophyll molecule lacking a central ion Mg^{2+} [37]. It is known that pheopigments are well preserved in bottom sediments, especially in anaerobic conditions [38, 39] and may enter the water column during sediment agitation [40]. The studied lakes are currently shallow (Figure 1), in connection with which one cannot ignore their possible entry from bottom sediments, both during sampling and as a result of wind-wave processes. On the other hand, the increase in pheophytin concentration is probably due to the eating of algae by zooplankton [41]. It was found that the degree of chlorophyll destruction depends on both the concentration of algae and the rate of their consumption and the type of consume [42]. The obtained pigment index values (E430/E664) from 3 to 5, indicate the predominance of heterotrophic metabolism over autotrophic in the photosynthetic community [6].

It was established that chlorophyll b is contained in representatives of green and euglena algae, while chlorophyll c is found in the cells of diatoms, golden and euglena algae [6, 43]. Chlorophyll b predominates in Lake Kudzhertai, hence, phytoplankton of the lake is represented to a greater extent by green and euglena algae. Absence of chlorophyll c in the studied water bodies is connected with high mineralization of lakes. It has been established that in the species composition of phytoplankton among diatomic algae, as salinity increases, benthic forms begin to prevail over true planktonic species and mainly monodominant communities are formed [31].

Thus, cyclical changes in climatic conditions associated with repeated high-water and low-water years have an impact on the state of lake ecosystems. During the first years of lake filling, hydrobiological indicators of ecosystems are formed, which is reflected in the state of phytoplankton communities and their photosynthetic activity.

5 Conclusion

Comparative analysis of the two studied lakes (Dabasa-nor lake and Kudzhertai lake) showed that in chloride lake Dabasa-nor a small content of chlorophyll a is noted. Degraded form of chlorophyll a - pheophytin is present in the sample. Consequently, photosynthetic activity of Dabasa-nor lake water is experiencing certain difficulties - phytoplankton is in a depressed state. This may be related to the current physical and chemical conditions of the water body ecosystem - the process of restoration of the lake water content after a long dry period. On the contrary, the concentration of chlorophyll a in soda lake Kudzhertaiis much higher than in Dabasa-nor lake. Pheophytin was not detected, which indicates physiological activity of phytoplankton as the primary link of productive processes.

At the same time, carotenoids, as more stable forms of pigments, prevail in the pigment diversity of plankton in the studied lakes. In Dabasa-nor lake green algae carotenoids prevail, in Kudzhertai lake, diatom carotenoids have a slight advantage over green ones. This confirms the higher content of chlorophyll b in the water of Lake Kudjertai, associated with the presence of green algae in the composition of phytoplankton communities. Chlorophyll c was not found in phytoplankton of the examined lakes. The investigated lakes differ in their trophic state.

Studying the impact of climate variability on biodiversity, productivity and stability is the key to understanding the possible future development of ecosystems under climate change.

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