Biogenic elements and organic matter production in the ecosystem of Lake Arey, Transbaikal region, Russia

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Abstract. Maintaining an ecological balance of Lake Arey is crucial in terms of nature conservation. Lake Arey is located in Eastern Siberia and is a central object of a designated conservation area of regional significance. The lake is used for recreation (organized and unorganized tourism, sport fishing, mud collection for balneological purposes) not only by residents but also by holidaymakers from other regions. In terms of mineralization level, Lake Arey is a freshwater body. Significant factors affecting the aquatic ecosystem are temperature, TDS, pH and dissolved oxygen, depth, and turbidity. High contents of ammonium ions are observed in the ecosystem. The concentration of dissolved inorganic phosphorus is 23.6% of total phosphorus. The ratio of PO (permanganate oxidizing ability of organic matter) to COD (chemical oxygen demand) indicates active processes of production, mineralization, and transformation of organic matter in the water body. Carotenoids prevail in planktonic pigments. The chlorophyll a amount is insignificant. The chlorophyll b content increases from July to September. Currently, Lake Arey belongs to the α-mesotrophic type of water body. However, increased anthropogenic load and high-water years can promote eutrophication processes.

1. Introduction
One of the priorities of hydrobiology lies in the condition assessment and change forecasting for water ecosystems under external and internal factors. The concentrations of biogenic elements (nitrogen and phosphorus) are indicative of changes in ecosystems. Biogenic elements in combination with other conducive factors allow for organic matter synthesis in a water body [1] and, to a significant extent, affect the qualitative composition of organisms [2, 3]. The trophic state of water bodies can increase with growing concentrations of biogenic elements in surface layers due to natural and anthropogenic factors. Eutrophication caused by the anthropogenic load is one of the major ecological threats in the modern world [1, 4-8].

In water ecosystems, autotrophs are the main producers of autochthonic organic matter that constitutes, along with allochthonic organic matter, the material and energy basis for the successive phases of production to organic matter [9]. Planktonic algae make the largest contribution to gross organic production, [10]. Disturbed balance of production-destruction process in an ecosystem under natural and man-made pressure affects self-purification of water bodies. Excessive organic matter and biogenic elements interfere with the development and potential photosynthetic activity of phytoplankton [1, 11, 12].
Maintaining the ecological balance of Lake Arey is crucial in terms of nature conservation; it depends on the functioning of the ecosystem and preserving the biodiversity of the lake. The purpose of this work is to assess the current ecological state and trophic level of Lake Arey by measuring biogenic elements, pigment characteristics of phytoplankton, and the primary production of organic matter in the ecosystem.

2. Materials and Methods
The findings are based on the materials collected during field research on Lake Arey in 2019-2020. Lake Arey is located in Eastern Siberia at 50°59’23” N and 111°14’42” E and is a central object of a designated conservation area of regional significance (figure 1). The surface area is 4.6 km², depth – 13.5 m, level of the water table – 996.2 m.

The lake is used for recreation (organized and unorganized tourism, sport fishing, mud collection for balneological purposes) not only by residents but also by holidaymakers from other regions. There are no large industrial or manufacturing plants in the vicinity. Arey Tourist Camp Centre is located on the southwestern coast of the lake (7); Crystal Tourist Camp Centre and several minor recreation facilities are built on the northeastern coast (3); the southeastern and southern coasts are used by unorganized tourists (figure 1). Waste flow from the mentioned facilities contributes to increasing organic matter input in the lake.

The water was sampled with a Patalas bathometer four times. Abiotic factors were measured at the same time as hydrobiological sampling using a multiparameter portable water-quality test system (Aquaread GPS-AQVAMETER, Great Britain). Water column depth was determined with a measuring gauge, water turbidity was measured using a Secchi disc. Biogenic elements (nitrogen and phosphorus) in chemical composition were detected by standard hydrochemical methods [13]. Spectrophotometer Spekol-1300 was used to estimate the concentration of substances. Ecological classification of water was carried out in correspondence with saprobity classes [14]. Statistical and mathematical analyses of the findings were conducted using Microsoft Excel 2010 and XLSTAT software (Addinsoft, USA).
Primary plankton production was measured in vitro using the light/dark bottle technique in oxygen variation [1, 9]. Water transparency of the lake is insignificant (2-4 m with an average depth of 10 m). In these conditions, sampling in the water and setting up experience at the central part of the lake was conducted over the next horizons, depending on the transparency of the water column (SD): surface – SD – 2 SD – bottom. Primary production and organic matter decomposition were calculated following [15], daily production – following [10].

The suspended matter for determination of chlorophyll content was collected on the nuclear membrane filters with a pore diameter of 1.5 μm. The analysis of chlorophyll content was carried out by standard spectrophotometry. Pigments were extracted using 90% acetone. The chlorophyll concentration was measured as described in [16]. The pheopigments concentration was determined by Lorenzen equation [17], carotenoids – by Parsons equation [18]; Margalef’s pigment index E430/E665 [19, 20] was calculated from the ratio of optical density of extracted pigments at corresponding wavelengths.

3. Results and Discussion

3.1. Physical and chemical properties of the water

Under natural conditions, the physical and chemical state of natural waters depends on the processes of dissolution and chemical erosion of geologic material as well as biogeochemical processes within a catchment area and bottom sediments of water bodies. Significant factors affecting the ecosystem are temperature, mineralization, pH and dissolved oxygen, depth, and turbidity. The values of particular physical and chemical properties of the water in Lake Arey are shown in table 1.

| Sampling sites (figure 1)a | H, m | SD, m | O₂, ppm | ORP, mV | EC, μS/cm | TDS, ppm | Sal, ppt | TURB, NTU | pH |
|---------------------------|------|-------|---------|---------|----------|----------|---------|-----------|----|
| 1                         | 10.0 ± 1.2 | 1.9 ± 0.1 | 11.9 ± 3.4 | 178 ± 22 | 2.44 ± 0.2 | 158 ± 10 | 0.12 ± 0.01 | 48.2 ± 25.1 | 7.9 ± 0.3 |
| 2                         | 0.3 ± 0.02 | 0.3 ± 0.01 | 12.9 ± 5.8 | 176 ± 34 | 2.36 ± 0.8 | 152 ± 15 | 0.11 ± 0.01 | 134.0 ± 58.1 | 8.1 ± 0.4 |
| 3                         | 1.1 ± 0.5 | 1.1 ± 0.5 | 13.1 ± 4.7 | 181 ± 41 | 2.38 ± 0.4 | 154 ± 28 | 0.11 ± 0.01 | 46.3 ± 12.4 | 7.9 ± 0.2 |
| 4                         | 0.3 ± 0.01 | 0.3 ± 0.01 | 13.3 ± 6.6 | 177 ± 19 | 2.46 ± 0.4 | 159 ± 11 | 0.12 ± 0.01 | 79.0 ± 30.1 | 7.9 ± 0.2 |
| 5                         | 0.3 ± 0.01 | 0.3 ± 0.01 | 11.7 ± 3.8 | 110 ± 18 | 2.70 ± 0.6 | 175 ± 14 | 0.13 ± 0.01 | 43.9 ± 16.2 | 7.8 ± 0.2 |
| 6                         | 0.6 ± 0.04 | 0.6 ± 0.04 | 10.6 ± 2.4 | 188 ± 54 | 2.43 ± 0.7 | 158 ± 12 | 0.12 ± 0.01 | 53.0 ± 24.4 | 7.9 ± 0.4 |
| 7                         | 0.3 ± 0.01 | 0.3 ± 0.01 | 11.6 ± 4.4 | 63 ± 15 | 2.14 ± 0.9 | 139 ± 35 | 0.10 ± 0.01 | 53.0 ± 26.1 | 8.7 ± 0.5 |

*a1 – centre of the lake, 2 – northwestern coast, 3 – near Crystal Tourist Camp Centre, 4 – southeastern coast, 5 – mouth of a channel, 6 – near the pier, 7 – near Arey Tourist Camp Centre. H – depth of water, SD – the transparency of the water column, ORP – oxidation-reduction potential, EC – electrical conductivity, TDS – mineralization, Sal – salinity, TURB – turbidity.

In terms of TDS level, Lake Arey is a freshwater body. The values in table 1 show that pH in the lake ranges from 7.9 to 8.7, i.e. the reaction varies from slightly alkaline to alkaline. The water in the lake is turbid with SD values of 1.9 m at 10 m in the central part of the lake.

ORP values measured in the lake vary from 63 to 188 mV with values decreased to 63 mV near Arey Tourist Camp Centre (Sampling site 7) which indicates accumulation of organic substances in bottom sediments. Organic matter in the littoral zone of a lake promotes blooms and an abundance of hydrophytes, which serve as a buffer that absorbs pollutants from the catchment area [21, 22].

3.2. Nitrogen and phosphorus in the ecosystem of Lake Arey

The study conducted in 2019-2020 has revealed the following average concentrations of different forms of inorganic nitrogen (ppb) in the lake: nitrites – 9.4 ± 0.9 (19%), nitrates – 10.5 ± 0.9 (22%), ammonium ions – 27.8 ± 3.8 (59%). High contents of ammonium ions reflect active processes of production, mineralization, and transformation of organic matter in the water body. The concentration of total phosphorus was 32.0 ± 5.7 ppb with 23.6% of dissolved inorganic phosphorus. The ratio of PO₄ (6.7 ± 2.5 ppm) to COD (14.4 ± 7.1 ppm) indicates the autochthonous nature of the organic matter in the lake.
Organic matter produced in a lake catalyses chemical reactions boosting the conversion of matter and energy. Observed contents of \( PO \) in Lake Arey correspond to zonal features of natural waters in mountainous areas [23]. Seasonal variations of concentrations of \( PO \) and \( COD \) are given in figure 2.

![Figure 2. Seasonal variations of \( PO \) and \( COD \) in Lake Arey.](image)

\( PO \) – permanganate oxidizing ability of organic matter, \( COD \) – chemical oxygen demand.

In the composition of organic substances, the amount of highly oxidizable compounds increases in September, whereas those with low oxidation are mostly observed in March and July. The trophic state of the lake in terms of \( COD \) varies within a year from oligotrophic conditions (winter) to mesotrophic states (spring, summer, autumn).

3.3. Pigment composition of plankton

Carotenoids prevail among planktonic pigments (51.5-86.3%) with insignificant content of chlorophyll-\( a \) (9.7-13.6 %) and larger content of chlorophyll-\( b \) in total chlorophyll content from July to September due to the proliferation of green algae in the planktonic community (figure 3).

![Figure 3. The ratio of plankton pigments in Lake Arey.](image)
Under conditions adverse to phytoplankton, chlorophyll $a$ is the first to destroy followed by accumulation of carotenoids that are more resistant to destruction [24-26]. Increasing amounts of yellow pigments in cells indicate that the ecosystem of the lake is under specific anthropogenic pressure that reduces the physiological activity of algae. Although pheophytin content grows higher in more contaminated water bodies [12], the values of pheophytin in Lake Arey are very low. Obtained values of pigment index ($E_{430}/E_{664}$) from $2.3 \pm 0.12$ to $3.6 \pm 0.17$ reveal that heterotrophic metabolism predominates over autotrophic one in the communities of photosynthetic organisms.

3.4. Primary production of plankton
The values of primary production and organic matter respiration in Lake Arey are given in Table 2. The highest values of primary planktonic production ($PP$) were observed in July and September when the most heated surface features high $PP$ which reduces gradually at deeper layers with less sunlight (average water transparency was $1.9$ m).

Organic matter production by phytoplankton reduced at bottom layers in March and September due to competition interactions in nutrient uptake by phytobenthos and phytoperiphyton communities and because of microbial decomposition of organic matter [27]. Plankton productivity increases from December to September as it was observed in other water bodies [1, 28, 29]. Mean annual plankton production in Lake Arey in 2019 and 2020 was $370 \text{ g} \cdot \text{C} \cdot \text{m}^{-2}$ which corresponded to caloric equivalents of organic matter of $1,260.5 \text{ kcal} \cdot \text{m}^{-2}$ per year.

Table 2. Primary production of plankton in Lake Arey in 2019-2020.

| Values, $n=16$ | Sampling times and locations | surface | SD | 2 SD | bottom |
|---------------|------------------------------|---------|----|------|--------|
| $A$, mg O$_2$ \cdot L$^{-1}$ | 0.85 ± 0.29 | 0.57 ± 0.19 | 0.21 ± 0.08 | 0.08 ± 0.04 |
| $R$, mg O$_2$ \cdot L$^{-1}$ | 1.23 ± 0.45 | 0.53 ± 0.14 | 0.15 ± 0.11 | 0.89 ± 0.19 |
| $\sum A_{day}$, mg O m$^{-2} \cdot$d$^{-1}$ | December March July September | 0.52 ± 0.09 | 0.87 ± 0.12 | 4.15 ± 0.32 | 4.33 ± 0.28 |
| $\sum A_{day}$, g C m$^{-2} \cdot$d$^{-1}$ | December March July September | 0.20 ± 0.01 | 0.33 ± 0.09 | 1.55 ± 0.14 | 1.62 ± 0.33 |

$A$ – organic matter production (OM), $R$ – OM respiration, $\sum A_{day}$ – a daily areal rate of primary production expressed in mass of oxygen and carbon.

According to the trophic classification of lakes based on primary production [30], Lake Arey currently belongs to the $\alpha$-mesotrophic type. However, increased anthropogenic load and high-water years can promote eutrophication processes.

4. Conclusion
The findings of 2019-2020 have revealed that variations in the distribution of biogenic elements, planktonic pigment composition, and primary production can serve as ecological indicators for Lake Arey. The ratios of different nitrogen forms and planktonic pigments depend on the season and anthropogenic pressure on the ecosystem. The current trophic state of the lake according to the studied indicators does not rise higher within a mesotrophic level. The ongoing unorganized recreation load on Lake Arey and negligent natural resource management can deteriorate the state of the lake. The remedial measures should include renovation of tourist infrastructure along the coastline and organization and management of accommodation and recreation for private holidaymakers. The above-mentioned developments should be coupled with environmental monitoring of the catchment area and ecosystem of the lake.
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