Dynamics of Biogens to Estimate Ecological State of Coastal Waters of Southern Baikal

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Abstract. The issue of biogenic pollution of the coastal waters of Lake Baikal has been considered, an inventory of their sources performed, and an ecological estimation of the coast anthropogenic pollution factors given, which, in turn, indicate the increased content of biogens in coastal waters and, according to scholars, affect the growth of spirogyra (Spirogyra Link and Stigeoclonium Ktz).

The studies performed have covered the southern coast of Lake Baikal from Kultuk Bay to Novosnezhnaya settlement since it is the most populated area with developed infrastructure, and the alluvial-accumulative coast has excellent beaches and good access roads to them.

To estimate the biogen ingress, studies have been performed in the summer months (navigation season) and in March (ice period). The actual research results are represented in tabular and graphic material.

The own research results have shown that the biogen content is rather significant; it is high during the ice period. The intake of domestic wastewater is supported by the high content of biogens in samples taken at the water's edge also during the ice period. In summer, the biogen content in coastal waters may be higher than in the ice period, however, due to the navigation season currents, their concentrations are ‘washed out’.

1. Introduction
Lake Baikal and its basin are a region with a special nature management regime; therefore, the current problems include preventing ingress of dangerous anthropogenic pollutants, including biogenic substances causing eutrophication of water reservoirs, into the Lake Baikal. To do this, reliable information about the water pollution sources located, as a rule, on the lake coast is required. According to the traditions established, the scientific community performed hydrochemical and hydrobiological studies in the pelagic part of the Lake Baikal water area, the Selenga shallow water, and the coastal area in the former Baikal Pulp and Paper Mill (BPPM) zone of influence, and the coastal waters outside the BPPM and in the Selenga River delta were studied extremely poorly [1, 2, 3, 4, 5, 6]. As studies have shown, just the coastal water area of the lake is currently exposed to anthropogenic impact [7, 8]. Also, the coastal part of Lake Baikal is characterized by an increased solid flow sedimentation rate and slow water exchange with the pelagic zone under the effect of runoff currents [9]. The inflow of industrial and domestic wastewater directly into this part of the reservoir is transformed and accumulated just in the coastal part of the lake.
2. Relevance
Currently, there is not enough data on the ingress of pollutants, including biogens, into the coastal waters, and their impact on the deep lake waters, bottom sediments, and hydrobionts. However, there is a hypothesis about the growth of spirogyra in the lake due to the ingress of biogens; the main sources of the growth of spirogyra (filamentous algae of the Spirogyra Link and Stigeoclonium Ktz genera) are supposedly biogens and especially phosphorus-containing substances [10, 11, 12].

3. Research objective
Therefore, to estimate the current state of the Lake Baikal coastal waters in the areas of pronounced anthropogenic impact, the below studies were performed:
- materials on the inventory of the coastal water pollution sources were summarized,
- hydrochemical analyzes of the main biogenic substances in coastal waters were performed,
- an analysis of the biogenic substance distribution over the coastal area of the lake was conducted.

4. Research material and techniques
To determine the biogenic substances, water samples have been taken in coastal waters from a surface horizon of 0.5 m in the wastewater discharge and anthropogenic load areas associated with cottage settlements, tourist camps, and horticultural cooperatives, and in summer, beaches with spontaneously arising camping and reference areas. A total of 89 water samples were taken. The below biogenic substances were determined using the quantitative chemical water analysis techniques approved for the state environmental control – PND F 14.1: total nitrogen, ammonium nitrogen, nitrate nitrogen, nitrite nitrogen, mineral phosphorus, organic phosphorus, and total phosphorus.

The studies were performed from the southernmost tip of the Kultuk Bay to the Barguzinsky Bay, but the main research was carried out at Southern Baikal (Fig. 1).

Legend: digits 1, 2, 3, ... 10 are sampling points. 1 – Kultuk settlement; 2 – Shamansky Cape; 3 – Slyudyanka; 4 – Mangutai; 5 – Utulik settlement; 6 – Baikalsk; 7 – Solzan settlement; 8 – Murino settlement; 9 – Pankovka-2 settlement; 10 – Novosnezhnaya settlement

Baikal lake

Figure 1. Scheme of Sampling at Southern Baikal (drawn up by A.A. Slauta).

5. Theoretical
Historically, Southern Baikal is the most developed area with a high population as compared with other regions, developed industry, the Trans-Siberian Railway running along the coast, actively developing tourist infrastructure; moreover, just the coast is intensely developing.
An inventory of pollution sources has shown that wastewater from industrial enterprises and municipal infrastructure of the cities of Slyudyanka, Baikalsk, Babushkin, and other settlements having treatment facilities (Kultuk settlement) have a significant impact on the pollution of the Southern Baikal water area. All treatment facilities on the Southern Baikal do not meet the current requirements and are characterized by the low efficiency of treating wastewaters discharged into coastal waters or lake tributaries [13].

Along with municipal wastewaters, built-up areas located directly on the coast negatively impact on coastal waters; these are new cottage settlements, dacha cooperatives, and tourist camps that are not tied to treatment facilities but have cesspools, drainage water from which may inflow into the groundwaters transporting pollutants into the reservoir.

6. Practical significance

Tables 1, 2, 3 show the content of biogenic substances in the coastal waters of Southern Baikal, sampled in the areas most susceptible to anthropogenic impact, i.e. the water area near tourist camps, cottage villages, and horticultural cooperatives.

According to the long-term observation results, the water masses of open Baikal are characterized by chemical homogeneity and constant component composition [3]. This uniformity is disturbed in the wastewater inflow and anthropogenic load areas, i.e. coastal waters. Coastal waters are one of the areas at risk of lake pollution. Let us consider the state of coastal waters in the anthropogenic load and reference areas based on the factual material. Hydrochemical analysis of biogenic substances was performed in different seasonal periods – in June, August, and March being the ice period. The chosen sampling mode was supposed to characterize the anthropogenic load in different seasonal periods.

Thus, examining wastewater discharged into the Pokhabikha River from the Slyudyanka treatment facilities showed that the concentration of suspended solids, mineral phosphorus, and nitrite nitrogen exceeded the rated values by 1.5-3.5, 2.8-38, and 4 times, respectively. In the monitoring section located 80 m below the discharge, high concentrations of chlorides and phosphate and sulfate ions were observed. Wastewater from the Kultuk settlement treatment facilities, which has undergone biological treatment, is discharged to the filtration fields located near the Kultuchnaya River. The design capacity of the treatment facility is 400 m³/day. To monitor the impact on groundwater, three observation wells have been drilled. According to the study results, by their chemical parameters, the water discharged does not meet the rated content of synthetic surfactants (SS), petroleum products, ammonium and nitrate nitrogen, phosphorus, and highly toxic substances such as heavy metals. Wastewater penetrates the groundwater, as evidenced by the presence of high concentrations of ammonium nitrogen (up to 1.58 mg/dm³) in it. Wastewater from Angusolka settlement also did not meet the rates set for mineral nitrogen forms. Thus, during the observation period, the 4.5 to 13.7-time excess of the ammonium nitrogen content has been detected. The Baikalsk municipal treatment plants discharge poorly treated wastewater; the content of ammonium nitrogen, organic carbon, and total and organic phosphorus exceeds the rated values by 1.2 - 1.7 times, and suspended solids by 3.0 times.

In the coastal water samples taken in June, an increased total nitrogen content (Table 1) is observed as compared with other biogenic substances. According to the State Hydrochemical Institute of the Roshydromet (Rostov on Don), the total reference nitrogen content is within 0.02 to 0.37 mg/dm³; in the Kultuk Bay and the coastal waters of Solzan settlement, the maximum reference values are exceeded by 2.5-3.5 and 1.5-3.5 times, respectively. By other nutrients, no excess was detected in June.
Table 1. Content of Biogenic Substances in the Coastal Waters of Southern Baikal (sampling – the 1st decade of June; digits 1, 2, ... 7, 10 are interpreted in the legend of Fig. 1).

| Index mg/dm³ | 1  | 2  | 4  | 5  | 6  | 7  | 10 |
|--------------|----|----|----|----|----|----|----|
| Total nitrogen | 0.90 | 0.145 | 0.190 | 0.140 | 0.085 | 0.415 | 0.175 |
| Ammonium nitrogen | 0.0 | 0.0136 | 0.0085 | 0.0030 | 0.0035 | 0.011 | 0.0 |
| Nitrite nitrogen | 0.0025 | 0.0030 | 0.0020 | 0.0020 | 0.002 | 0.001 | 0.0022 |
| Nitrate nitrogen | 0.037 | 0.0055 | 0.0675 | 0.0405 | 0.037 | 0.057 | 0.224 |
| Mineral phosphorus | 0.0030 | 0.004 | 0.0050 | 0.004 | 0.004 | 0.0023 | 0.0041 |
| Organic phosphorus | 0.007 | 0.004 | 0.007 | 0.004 | 0.004 | 0.0098 | 0.0085 |
| Total phosphorus | 0.010 | 0.008 | 0.012 | 0.008 | 0.008 | 0.012 | 0.013 |

In water samples taken in August (Table 2), the total nitrogen content did not exceed the reference values; by ammonium nitrogen, nitrate nitrogen, nitrite nitrogen, and mineral and organic phosphorus, no excess was also observed.

Table 2. Content of Biogenic Substances in the Coastal Waters of Southern Baikal (sampling – the 3rd decade of August; digits 1, 2, ... 7, 10 are interpreted in the legend of Fig. 1).

| Index mg/dm³ | 1  | 2  | 4  | 5  | 6  | 7  | 10 |
|--------------|----|----|----|----|----|----|----|
| Total nitrogen | 0.48 | 0.46 | 0.12 | 0.38 | 0.34 | 0.36 | 0.24 |
| Ammonium nitrogen | 0.005 | 0.009 | 0.012 | 0.006 | 0.008 | 0.011 | 0.018 |
| Nitrite nitrogen | 0.002 | 0.002 | 0.0046 | 0.002 | 0.0034 | 0.002 | 0.002 |
| Nitrate nitrogen | 0.058 | 0.049 | 0.035 | 0.036 | 0.055 | 0.045 | 0.037 |
| Mineral phosphorus | 0.004 | 0.004 | 0.005 | 0.003 | 0.006 | 0.008 | 0.006 |
| Organic phosphorus | 0.014 | 0.024 | 0.011 | 0.007 | 0.014 | 0.008 | 0.014 |
| Total phosphorus | 0.018 | 0.033 | 0.016 | 0.010 | 0.020 | 0.016 | 0.020 |

Figure 2 shows the seasonal organic nitrogen dynamics, its maximum content is observed in August and July, and the minimum one in October. The increased organic nitrogen content in the summer months indicates additional anthropogenic impact sources, which may correspond to the peak of the tourist season on the Lake Baikal coast. Increased organic nitrogen concentrations are a factor of deterioration of the Lake Baikal coastal water area state.
Figure 2. Seasonal Organic Nitrogen Dynamics in Coastal Waters in 2019 (digits 1, 2, ... 7, 10 are interpreted in the legend of Fig. 1).

An increased nitrate nitrogen content (Fig. 3) is also typical for the summer months of July-August.

Figure 3. Seasonal Nitrate Nitrogen Dynamics in Coastal Waters in 2019 (digits 1, 2, ... 7, 10 are interpreted in the legend of Fig. 1).

In 2019, 2 surveys were carried out during the ice period (in March) to reveal drainage of domestic wastewater, as usual, in the summer sampling stations and at the water's edge. Since in the navigation
season, littoral currents are very strong, water mixing occurs, and the pollutant concentrations are ‘washed out’ [14, 15].

In the ice period, the increased total nitrogen content is observed at all sampling stations (Table 3). In the coastal part of the lake, mineral nitrogen forms prevail over organic ones. Mineral nitrogen is represented by oxidized forms, mainly nitrate nitrogen. Higher nitrate nitrogen concentrations in the ice period were observed in the area of the Kultuk Bay, Slyudyanka, and the Solzan settlement. In the ice period, the mineral phosphorus content is an order of magnitude higher than in the Baikal navigation period and the reference values in Lake Baikal (minimum reference values – 0.002, maximum values – 0.02).

Table 3. Content of Biogenic Substances in the Coastal Waters of Southern Baikal (sampling – the 3rd decade of March - the ice period; digits 1, 2, ... 7, 10 are interpreted in the legend of Fig. 1).

| Index            | 1  | 2  | 4  | 5  | 6  | 7  | 10 |
|------------------|----|----|----|----|----|----|----|
| mg/dm³           |    |    |    |    |    |    |    |
| Total nitrogen   | 0.59 | 0.48 | 0.46 | 0.58 | 0.52 | 0.64 | 0.84 |
| Ammonium nitrogen| 0.019 | 0.017 | 0.008 | 0.034 | 0.020 | 0.013 | 0.028 |
| Nitrite nitrogen | 0.003 | 0.003 | 0.008 | 0.006 | 0.0045 | 0.0052 | 0.0048 |
| Nitrate nitrogen | 0.068 | 0.055 | 0.048 | 0.043 | 0.065 | 0.060 | 0.049 |
| Mineral phosphorus| 0.038 | 0.034 | 0.019 | 0.026 | 0.017 | 0.026 | 0.018 |
| Organic phosphorus| 0.021 | 0.026 | 0.017 | 0.013 | 0.023 | 0.035 | 0.031 |
| Total phosphorus  | 0.059 | 0.060 | 0.036 | 0.039 | 0.040 | 0.061 | 0.049 |

The accumulation of biogenic substances is noticeable in the ice period; this feature is associated with slower currents during this period; in winter, the physicochemical destruction is also weakened [16]. The increased content of biogenic substances - organic nitrogen, ammonium nitrogen, and mineral and organic phosphorus in the ice period directly indicates the domestic wastewater drainage.

Samples taken at the water's edge showed high concentrations of biogenic substances. The impact at the water's edge is so significant that leads to a change in the Baikal water group from the hydrocarbonate-calcium to the hydrocarbonate-sodium one according to the O.A. Alekin classification [17], which indicates the drainage flow effect. Parameters such as the medium activity index (pH), chemical oxygen demand (COD), and the concentrations of dissolved oxygen and mineral nitrogen forms are also subject to changes caused by the inflow of wastewater from the coast into coastal waters.

7. Conclusions
Thus, estimating the ecological state of the coastal waters of Southern Baikal has shown significant changes in the general hydrochemical characteristics of the lake water quality in the ice period. Naturally, in summer, the content of biogenic substances in the coastal waters may be higher than in the ice period, however, due to the navigation season currents, their concentrations are ‘washed out’.

Coastal waters are significantly affected by polluted wastewater, so the increased content of biogenic substances is likely one of the sources of growing spirogyra of the Spirogyra Link and Stigeoclonium Ktz genera in recent years.
Since the coastal waters of Lake Baikal are closely interconnected with the terrestrial ecosystem, the coastal lake zone should be included in a specially protected area, and the environmental monitoring focus should be shifted to this area.

8. References

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