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The Influence of the Baikalsk Pulp and Paper Mill (BPPM) on Baikal plankton: A Comparative Study of Phytoplankton and Zooplankton Responses to BPPM Purified Waste Water in 2005-2006

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Abstract

In general, our research sought to disentangle differences in phytoplankton community composition and structure near areas of high pollution in relation to relatively pristine locations. For this, we compared an area near the south-eastern shore of Lake Baikal, where purified waste water from the Baikalsk Pulp and Paper Mill (BPPM) enters Lake Baikal relative to a pristine area (Point #1), located at a remote location on the Western shore of Lake Baikal. Phytoplankton communities at Point #1 were generally characterized by higher biodiversity, although functional diversity was relatively similar between the two locations. The lack of markedly different community compositions may be a production of peculiarities to the time of sampling. In 2005, zooplankton communities at both locations were anomalously high with respect to diversity and biomass, exceeding four times the average long-term observations from 1981 to 2003. Community composition was unusual, in that the consistently dominant *Epischura baikalensis* occupied a smaller proportion of present species, whereas rotifers and cosmopolitan cladocerans exceeded long-term averages. In contrast, 2006 was characterized by having anomalously low zooplankton abundance at both polluted and pristine locations. In 2006, *E. baikalensis* returned as the dominant present taxon; however, there were no significant differences between locations. We suggest that the lack of a significant difference implies a trophic equilibrium within phytoplankton and zooplankton communities in the southern area of Lake Baikal.

Key words: Lake Baikal, Zooplankton, Phytoplankton, Human influence, BPPM.

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1. Introduction

The Biology and Geography Institute (now – Institute of Biology) of Irkutsk State University (Russian Federation) performs regular, intensive monitoring of planktonic communities near areas of potential environmental concern, such as purified waste water effluent of the Baikalsk Pulp and Paper Mill (BPPM), where monitoring started 8 years before (1960) Mill began to operate (1967) [1-2]. Potentially contaminated locations are compared relatively pristine reference locations, such as Point #1, where monitoring has been occurring since 1945 [3].

Purified waste water effluent from BPPM is characterized as containing high total minerals, such as Na_2SO_4, and dilutes organic compounds, such as volatile phenolic compounds [4]. Although the BPPM is no longer operational, the years prior to its closure offer potential insights to its direct environmental impact on the immediate nearshore zone. Given the potential for the BPPM to have significantly affected biotic communities within the nearshore area, our work aims to compare plankton community structure over time between one site proximal to the BPPM and a relatively pristine location, Point #1. Phytoplankton and zooplankton were of primary concern because they are often the main sentinels of decreased water quality in Lake Baikal [2].

2. Experimental

2.1. Site Descriptions and Methods

2.1.1. "Point #1" is situated 2.7 km from the south-western shore of Lake Baikal, where depth is approximately 800 m (N – 51° 52′ 48″, E – 105° 05′ 02″). Point #1 is often considered a good representative for Lake Baikal's entire Southern basin [2, 3, 5-7]. Samples were collected approximately every 7-10 days July through October, 2005 and 2006.

2.1.2. "Testing Area #7", located proximal to the BPPM, is 7 km from the eastern coast of Southern Baikal, where depth is approximately 900 m (N – 51° 33′.19, E – 104° 19′.5). It is adjacent to discharge of purified wastewater effluent from the BPPM.

Water samples for chlorophyll *a* content, phytoplankton diversity analyses were collected with a 7-L Van Dorn bottle (bathometer) from the depths of 0, 10, 25, 50, 100 m. Water temperature was measured with a mercury thermometer inserted in the bathometer, and water transparency was estimated with a 35-cm in diameter Secchi disk. Zooplankton samples were taken from depth layers of 0–25, 25–50 and 50–100 m with a closing zooplankton net (0.375 m in diameter and mesh size 100 μm). Samples were immediately fixed with formalin (4%).

Chlorophyll *a* concentration was determined with standard spectrophotometric methods [8] after filtration with 0.7 μm-diameter nucleopore filters. Phytoplankton samples were fixed with Utermöhl solution, settled for 2 weeks, and analyzed with light microscope. Zooplankton samples were allowed to settle for 3 weeks and then analyzed under a light microscope.

3. Results for 2005

3.1. Plankton Communities at "Point #1"

In the beginning of summer, mean surface water temperature was 3.7 °C, and then warmed to a maximum of 15.1 °C by the beginning of August. The warming period continued for the entire layer of 0-50 m till the end of September, with a final weighted average of 10.8 °C.

Water transparency in 2005 varied from 4 m at the end of July till 21 m in October.

Chlorophyll *a* concentration in 0-50 m layer from July through October varied widely. The total time series is characterized as such:

Average	1.04	Excess	-0.42
Standard error	0.14	Asymmetry	-0.69
Median	1,10	Interval	1.58
Standard deviation	0.49	Minimum	0.09
Sampling variance	0.24	Maximum	1.66

Phytoplankton community composition from July through October was characterized by the presence of 60 algae taxa, belonging to 6 orders. The list of dominant species (with a maximal concentration of at least 100x10^3 cells l^{-1}) is described in Table 1.

Total abundance of phytoplankton (without taking into account nano–, picoplankton, and flagellates) started to rise rapidly from the middle of July, reached its maximum (weighted average for 0-50 m greater than 825x10^3 cells L^{-1}) in late August, remained high for September and the beginning of October, and finally declined in the end of October. Total number of phytoplankton including nano–, picoplankton and flagellates was maximal in the beginning of August (weighted average in 0–50 m was greater than 90x10^6 cells l^{-1}).

Table 1. Dominant species of phytoplankton (exceeded 100x10^3 cells l^{-1}) maximum weighted average in 0-50 m number in 2005-2006 (according to [9] modified).

Year	**Species of alga**	**Number, 10^3 cells l^{-1}**
2005	**In 2005**	
	At reference clean "point #1"	
	Chroomonas acuta	807.22
	Chrysidalis sp.	542.38
	Dinobryon sociale var. sociale	384.46
	Ankistrodesmus pseudomirabilis	278.67
	Chrysochromulina sp.	219.15
	At "testing area P7"	
	Chrysidalis sp.	625.62
	Chroomonas acuta	286.23
	Dinobryon bavaricum var. bavaricum	199.98
2006	**At reference clean "point #1"**	
	Synechocystis limnetica	19887,13
	Chroomonas acuta	471.24
	Chrysidalis sp.	352.82
	Stephanodiscus hantzschii var. *pusillus*	205.96
	Stephanodiscus sp.	185.52
	Ankistrodesmus pseudomirabilis	155.95
	Dinobryon sociale var. sociale	105.27
	At "testing area P7"	
	Synechocystis limnetica	12628.00
	Chroomonas acuta	900.94
	Chrysidalis sp.	480.44

Zooplankton composition and abundance at point #1 was highly variable from July through October and ranged from 28.5 to 11964.15 10^3 individuals m^{-2} in the layer 0-50 m as such:

Average	3166.88	Excess	5.40
Standard error	860.12	Asymmetry	2.00
Median	2471.17	Interval	11935.63
Standard deviation	3101.21	Minimum	28.52
Sampling variance	9617540	Maximum	11964.15

These data represent a four-fold decrease in typical annual abundances. The maximal number of zooplankton was in September.

The number of *Epischura baikalensis*, an endemic species in Lake Baikal, gradually decreased from 3479x10^3 individuals m^{-2} (July) to 732x10^3 individuals m^{-2} (October). It dominated zooplankton from July through August. In September, its share decreased to 26%, while the number of rotifers increased to 44%. The most abundant among rotifers was *Conochilus unicornis* (1128.3x10^3 individuals m^{-2} in September), *Keratella quadrata* (345.2x10^3 individuals m^{-2} in August), *Kellicottia longispina* (168.9x10^3 individuals m^{-2} in September). Among Cladocera, Bosmina *longirostris* (587.9x10^3 individual's m^{-2} in September) were most abundant.

Biomass of zooplankton was also very high, varying in July-October from 1 to 122 g m^{-2} in the layer 0-50 m:

Average	34.52	Excess	3.77
Standard error	9.03	Asymmetry	1.70
Median	32.523	Interval	120.98
Standard deviation	32.54	Minimum	1.08
Sampling variance	105923.00	Maximum	122.06

In July and August, the share of *Epischura baikalensis* was more than 90%, in September 43 % of biomass belonged to Cladocerans, 17 % to *Cyclops kolensis* and rotifers.

3.2. Plankton Communities at "Testing Area P7"

Interannual weighted averages of the layer 0-50 m was considerably warmer than in prior years, with water temperatures still above 6 °C in October.

Water transparency was approximately 10 m.

Chlorophyll *a* concentration at "Testing Area P7" was effectively no different from "Point #1" for the entire sampling period. The total data are not significantly different from those from "Point #1", and they can be considered as the same general population:

Average	1.12	Excess	0.72
Standard error	0.04	Asymmetry	0.74
Median	1,10	Interval	3.17
Standard deviation	0.63	Minimum	0.05
Sampling variance	0.40	Maximum	3.22

We identified 45 algae taxa in "Testing Area P7".

Total abundance of phytoplankton, including small-cell forms, was maximal in August with a weighted average in the 0-50 m layer of 50,339x10^3 cells L^{-1}. Total zooplankton abundance at "Testing Area P7" was high. Monthly averages in the 0-50 m layer consisted of 4130.7x10^3 individuals m^{-2} in August, 3131.6x10^3 individuals m^{-2} in September, and 5622.5x10^3 individuals m^{-2} in October. These numbers exceed long-term average for this layer four to six-fold.

From August through September, *Epischura baikalensis* dominated the zooplankton community, though its share shrank from 60% in August to 24% in October. There was extremely high number of rotifers (*Keratella quadrata*: 203.0x10^3 individuals m^{-2}, *Conochillus unicornis:* > 1000 x0^3 individuals m^{-2}) and cladocerans (*Bosmina longirostris*: 619.0x10^3 individuals m^{-2}). Total zooplankton biomass at "Testing Area P7" was high, varying from 3.7 to 4.7 g m^{-2} in the 0-50 m layer.

3.3. Results for 2006

3.3.1. Plankton Communities at "Point #1"

Surface temperature of water varied from 3.2 °C (June) to 14 °C (August) with an average of 7.4 °C, and a weighted average temperature of 4.9 °C. The transparency changed from 33 m (June) to 4 m (August), and increased to 6 m by the end of October. Weighted average concentrations of chlorophyll *a* in 0-50 m layer from July to October 2006 were characterized by the following parameters:

Average	1.05	Excess	–1.56
Standard error	0.18	Asymmetry	0.04
Median	1.17	Interval	2.10
Standard deviation	0.72	Minimum	0.07
Sampling variance	0.51	Maximum	2.17

Approximately 70 taxa of alga, belonging to 6 orders, were observed at "Point #1" from June through October 2006. The most abundant species (i.e., those exceeding 100 10^3 cells L^{-1}) are summarized in Table 1. The 2006 species composition contrasted markedly from 2005. *Chrysochromulina* sp. was not present. *Stephanodiscus hantzschii*, *Stephanodiscus pusillus*, and *Synechocystis limnetica* were not as dominant as in 2005.

The weighted average phytoplankton abundance in June through October 2006 for 0-50 m layer varied from 106 10^3 cells L^{-1} to 938 10^3 cells L^{-1}.

Zooplankton abudance at "Point #1" in the 0-50 m layer varied in July-October from 190.4 to 2206.5x10^3 individuals m^{-2} as such:

Average	774.6	Excess	1.1
Standard error	143.2	Asymmetry	1.1
Median	515.3	Interval	2016.2
Standard deviation	572.8	Minimum	190.4
Sampling variance	328096.1	Maximum	2206.5

The maximal zooplankton abundance was observed in September. *Epischura baikalensis* dominated the zooplankton community until August (100% in July, 97 % in August). In September its share decreased (63%, 42% in October) and rotifers began to dominate (31% in September, 49% in October).

Biomass of zooplankton at "Point #1" in the 0-50 m layer varied from June through October from 1.8 to 19.2 m^{-2} as:

Average	7.6	Excess	0.6
Standard error	1.2	Asymmetry	1.0
Median	6.3	Interval	17.4
Standard deviation	4.9	Minimum	1.8
Sampling variance	23.6	Maximum	19.2

Biomass was dominated by *Epischura baikalensis* (100% in June-July, 98% in August, 93% in September, 87% in October).

3.3.2. Plankton Communities at "Testing Area P7"

In 2006, surface layer temperature was significantly higher than at "Point #1". In July and September, it was 12.6 and 12.5 °C, compared to 5.8 and 9.9 °C at "Point #1". Nevertheless, weighted average temperatures for "Testing Area P7" and "Point #1" for 0-50 m were not so significantly different – 5.2 °C at "Testing Area P7" and 4.9 °C at "Point #1".

Water transparency at stations "Testing Area P7" and "Point #1" were different in July (8.5 m and 15.5 m,) but not in September (8.5 and 7.0 m).

Chlorophyll *a* concentration in July and September at "Testing Area P7" was slightly higher than at "Point #1". Weighted average chlorophyll *a* concentration for 0–100 m was 0.64 mg m^{-3} in July and 0.91 mg m^{-3} in September.

From July through September 2006 19 taxa of algae were identified. The dominant species are listed in Table 1.

The small-cell endemic Cyanophyta, *Synechocystis limnetica*, was superdominant. Phytoplankton community at eastern shore of Southern Baikal was similar to that of 2005. This group consisted from Cryptophyta and Chrysophyta: *Chroomonas acuta* and *Chrysidalis* sp. Diatoms were present but generally in low abundances.

Zooplankton abundance at "Testing Area P7" in July was some higher (305.4×10^3 individuals m^{-2} in the 0-50 m layer), in September some lower (919.4×10^3 individuals m^{-2} in the 0-50 m layer) than at "Point #1". Similarly, biomass was higher in July (7.6 g m^{-2} in the 0-50 m layer), lower in September (12.9 g m^{-2} in the 0-50 m layer).

Zooplankton community structure at "Testing Area P7" also was quite similar to one at "Point #1". The dominant copepod *Epischura baikalensis* dominated the rest of zooplankton species by both number (85-99%) and biomass (97.5-98.8%). The number of rotifers at "Testing Area P7" was lower (20.3-115.4 10^3 individuals m^{-2}), while the number of *Cyclops kolensis* was higher (4.0×10^3 individuals m^{-2}). Among rotifers *Keratella quadrata* (43.5×10^3 individuals m^{-2}) and *Conochilus unicornis* (32.4×10^3 individuals m^{-2}) were most abundant.

4. Discussion

The comparison of plankton communities between the relatively pristine "Point #1" and at "Testing Area P7" is based on a long-term investigation of plankton dynamics at these sampling sites, initiated in 1960 [1], prior to BPPM's operation in 1967. Previous studies have shown these communities to be practically identical before BPPM's operation [5, 10-12]. The later studies have suggested divergence in plankton communties [6, 13, 14], prompting us to investigate if these divergences have continued following BPPM's closure.

From July through October 2005 and 2006, variability of chlorophyll *a* concentration in the photic layer was within typical concentration ranges for Baikal [2] and did not differ significantly at western and eastern shores.

The super-dominants for phytoplankton of Southern Baikal were small-cell algae, including endemic *Synechocystis limnetica*. According to degree of summer plankton development, 2005 can be considered a "rich year", whereas 2006 can be considered a "medium year".

Judging by species richness, algal diversity was higher at western shore in 2005. Here, 60 algal taxa were observed, while at eastern shore 45 were observed. Endemic Baikal diatoms were present in both regions, but were not abundant, which is typical for this season [15]. Quantitative characteristics of phytoplankton development in 2006 were lower than for 2005, including large-cell plankton, and total phytoplankton. By species diversity phytoplankton community at the western shore in 2006 was richer (70 forms) than at eastern one (19 forms). These estimates can imply a stable equilibrium state of autotrophic chain of Southern Baikal ecosystem.

Zooplankton abundance and biomass at "Point #1" as well as at "Testing Area P7" in 2005 was extremely high, exceeding long-term averages for this layer and season by 4-6 times. By species composition, it was dominated by *Epischura baikalensis* from July through August at both sites. In September, its share decreased to 23% at "Point #1", while remaining near

60% at "Testing Area P7". In October, *Epischura baikalensis*'s shares were 41% at "Point #1" and 24% at "Testing Area P7". There was great increase in number of the rotifers *Conochilus unicornis, Keratella quadrata* and Cladocera *Bosmina longirostris* at both sites. In 2006, zooplankton abudance and biomass were relatively low and within the usual limits for Southern Baikal at both sites. Species composition was characterized by strong dominance of the endemic *Epischura baikalensis*, at "Testing Area P7" even more expressed than at "Point #1".

5. Conclusion

Principal similarity of the processes occurring in plankton communities near western shore and near eastern shore of Southern Baikal are demonstrated. Though in both years phytoplankton community at "Point #1" was characterized by higher biodiversity, principal composition of phytoplankton was similar and processes occurring in both locations resemble each other.

2005 can be counted as "phytoplankton rich year", whereas 2006 can be considered as "phytoplankton moderate year".

In 2005, zooplankton communities at both sides of Baikal were characterized by extremely high abudances and biomasses. They exceed long-term, average observations four-fold. The abundance of *Epischura baicaliensis* was generally high, although this varied at times. The abundance of rotifers and cladocerans exceeded their long-term average number by several orders.

In 2006, zooplankton communities in both locations were two-fold lower than their respective long-term averages, although *Epischura baikalensis* still consistently dominated the plankton community.

In conclusion, both phytoplankton and zooplankton at "Point #1" as well as "Testing Area P7" had similar dynamics, and they had no principal differences. Our estimates can conclude stable equilibrium state of both autotrophic and herbivorous sectors of trophic chain of Southern Baikal ecosystem. The changes observed are of natural character, though with the same probability they can be explained by global and or local climate changes, as well as human induced influence in part.

6. Conflict of Interest

The author(s) report(s) no conflict(s) of interest(s). The author along are responsible for content and writing of the paper.

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