Development of plankton communities in the anthropogenic hydrothermal conditions of Kenon Lake as a cooling reservoir (Transbaikalia)

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Abstract. The long term study results (2010-2015) of plankton biocenoses in the anthropogenic hydrothermal conditions of the cooling-lake Kenon are presented. Seasonal successions of the dominant complex and quantitative indicators in phyto- and zooplankton were determined. For abiotic parameters, a direct correlation of water temperature with transparency and depth was revealed. The main factors affecting the development of hydrobionts in the anthropogenic hydrothermal lake area were water chemistry and temperature.

1. Introduction

The influence of various type power plants on the physico-chemical water parameters, as well as the biological regime of the water bodies on which they are located, is multilateral [1-4]. The most obvious change in the aquatic environment as a result of the impact of the work of power plants is water temperature increase. The research of areas directly affected by the discharge of heated water allows us to identify several zones, the boundaries of which are determined by the temperature gradient [5]. Such sites can be considered as «hydrothermals». The term proposed by Z.A. Filatova [6], serves to refer to biotopes arising around underwater hydrotherms. Similar conditions are also formed in continental waters in the areas of discharge of heated water from energy facilities. These areas of the hydrosphere can be considered as «anthropogenic hydrothermal» [7]. This term is understood as an artificially heated area of a reservoir used by hydropower facilities. In these specific ecosystems, the main anthropogenic factor is the wastewater temperature. This exogenous permanent parameter is structuring, as it causes the seasonal change of species and their spatial distribution, determining the rate of flow of vital processes of hydrobionts, as well as the nature of the impact of other environmental factors [5]. An example of «anthropogenic hydrothermal» in Zabaikalsky Krai is the reservoir-cooler of the Kharanorskaya TPP [8] and the Kenon as cooling lake. Kenon is a natural reservoir included in the technological scheme of a combined heat and power plant. In this case, the term «reservoir» can be applied to the Kenon Lake, since its natural regime features have been practically lost and transferred to the natural-anthropogenic ones, determined by the technological regime of the thermal power station [2].
The aim of the paper is to determine the relationship between environmental factors of the hydrothermal zone and the main plankton characteristics in the Kenon Lake as a TPP cooling reservoir.

2. Materials and methods
The drainageless Kenon Lake, located within the boundary of the regional center (Chita City, Transbaikalia), is one of the large reservoirs of the Upper Amur River basin. The water surface area is 16.2 km², the water mass volume is 77 million m³, the average depth is 4.4 m, and the coastline stretches for 18 km. The lake and its drainage basin are experiencing a significant anthropogenic load: since 1967 it has been exploited as a cooling reservoir; adjacent to it are residential and industrial areas of the city, transport communications, agricultural land; it is surrounded by roads; there is the Trans-Siberian Railway along the southern coast. To maintain the lake level, water transfer from the Ingoda River, up to 15-16 million m³ in a year. The volume of ejected warm water is more than 109 million m³ in a year. At the discharge point of warm water, a «thermal area» of about 1.3 km² that does not freeze in winter is formed, affecting the entire water area of the lake [9].

The collection of field material was carried out in the thermal zone (the area of TPP heated water discharge) during 2010-2015 (figure 1).

![Figure 1. Schematic map of Kenon Lake and thermal zone.](image_url)

Phytoplankton samples were taken from the surface and bottom water layers using a Patalas bathometer. Zooplankton samples were carried out totally by the Juday net (mesh size = 64 μm). We fixed the samples with 4% formaldehyde solution. Plankton samples were processed according to standard hydrobiological techniques [10, 11]. The phytoplankton biomass was determined by the volume of individual cells or colonies of algae [11]. Data of the biomass of zooplankton was obtained by determining the individual mass of organisms, taking into account their size [12, 13]. At the time of sampling, we measured the abiotic environment parameters (total dissolved solids (TDS), dissolved oxygen content (O₂), pH, water temperature (T), redox potential (ORP), electrical conductivity (E)) using an Aquaread multiparametric sensor for water analysis (Great Britain). Water transparency and depth were measured by Sechi disk. We took the data on nutrients (total phosphorus (P₉₅), phosphates (PO₄), nitrates (NO₃), nitrites (NO₂), ammonium (NH₄)), organic and mineral substances (COD, PI) contents from [14, 15]. Findings were subjected to statistical and mathematical processing using the software package Microsoft Excel 2010 and add-in for the program Microsoft Excel XLSTAT.
3. Results
At the sampling site the depth was 3.4-4.1 m, the transparency was 1.7-4.0 m. Low transparency is noted in August-September. The highest temperature of the surface water layer was observed in summer with its peak in July, the lowest was in freezing period (figure 2).

The water temperature change in depth was 1.0-8.8 °C. The temperature in the thermal zone was warmer by 3.2-9.8 °C compared with unheated lake areas. There was a direct correlation of water temperature with transparency \((r=0.52, p=0.02)\) and depth \((r=0.66, p=0.001)\). No other significant correlations between temperature and other abiotic environmental parameters of the hydrothermal zone are found.

There were 85 algae taxa (Cyanobacteria – 4, Chrysophyta – 4, Bacillariophyta – 35, Dinophyta – 2, Chlorophyta – 34, Charophyta – 5, Euglenophyta – 1) and 38 invertebrate species (Rotifera – 17 видов, Cladocera – 12 и Copepoda – 9) in the heated zone of Kenon Lake.

Seasonal dynamics of phyto- and zooplankton abundance and biomass in the thermal zone of cooling-lake were characterized by a one-peak curve with a summer maximum (August for algae, July-August for invertebrates) during 2010-2015 (figure 3).

Green algae \((Tetraëdron minimum\) (A. Braun) Hansgirg, \(Monoraphidium komarkovae\) Nygaard) grew up in early spring plankton; they were for 40-100% of total abundance. Subdominants were chrysophytes \((Chrysococcus rufescens\) Klebs, \(Pseudokephyrion conicum\) Schiller), who’s share was up to 40-100% of total phytoplankton abundance. In late spring and early summer, diatoms \((Asterionella formosa\) Hassall, \(Lindavia comta\) (Kützing) Nakov, Galluly, Julius, Theriot & Alverson) dominated (up to 60-70 %). Small-cell chlorococcales green algae \((T. minimum, Lemmermannia komarekii\) (Hindák) C. Bock & Krienitz in Bock et al., \(Scenedesmus quadricauda\) (Turpin) Brébisson in Brébisson & Godey, \(M. komarkovae\)) also actively developed (40-60% of total phytoplankton abundance). In the middle summer (season of the greatest water warming up), all algae groups developed intensively. However the general background was created by cyanobacteria \((Snowella lacustris\) (Chodat) Komárek & Hindák, \(Gloeocapsa sp.\) and \(Dolichospermum flosaquae\) (Brébisson ex Bornet & Flahault) P. Wacklin, L. Hoffmann & J. Komárek), greens \((T. minimum, Oocystis submarina\) Lagerheim) and dinophytes \((Ceratium hirundinella\) (O.F. Müller) Dujardin and \(Peridinium sp.\)); they
were for 80% of the total abundance. In autumn and winter, diatoms (*Ulnaria ulna* (Nitzsch) Compère, *A. formosa*) dominated, accounting for up to 70-90% of phytoplankton abundance.

![Image of phytoplankton and zooplankton abundance and biomass](image_url)

**Figure 3.** Seasonal dynamics of phytoplankton (1) and zooplankton (2) abundance and biomass in the thermal zone of Kenon cooling lake during 2010-2015.

The basis of the spring and early summer zooplankton was formed by the juvenile copepod stages (*Cyclops vicinus* Uljanin (25-37 % of total abundance) and rotifers. Among them the dominants were *Conochilus unicornis* Rousselet (58 %), *Filinia longiseta* (Ehrenberg) (21-44 %), *Keratella cochlearis* (Gosse) (28 %), *Polyarthra remata* Skorikov (26-34 %), *Synchaeta styliata* Wierzejski (25 %), *Keratella quadrata* (Müller) (16-28 %) in some years. Crustaceans, such as *Thermocyclops crassus* (Fischer), *Mesocyclops leuckarti* Claus и *Bosmina longirostris* (Müller) multiplied intensively. The greatest diversity and abundance of zooplankton were recorded in summer. Small crustaceans (*T. crassus* – 23-50% of total abundance, *Cerodaphnia quadrangula* (Müller) – 26-58%) were dominants, which continued to prevail in autumn plankton, forming a total of up to 70-80% of total abundance. In some years, rotifers (*Synchaeta oblonga* Ehrenberg (44 %), *K. quadrata* (27 %)) were as subdominants.

As a result of the component analysis, three components were identified; the total contribution to the plankton community variability was 72.02 % (table 1). The share of the remaining components in the total dispersion was insignificant.

The first component (F1) describing 42.01 % community variability has the structural characteristics of Cladocera (in particular C. quadrangula) and total phytoplankton (mainly Dinophyta и Chlorophyta) as parameters with the greatest positive weight loads. The contribution of the second (F2) and third (F3) components to the explanation of the plankton community variability are 17.31% and 12.7% respectively. Negative factor loads are determined by abundance and biomass of Cyanobacteria (in particular Gloeocapsa sp.), and positive factor loads are determined by total zooplankton abundance (in particular B. longirostris). Among abiotic environmental parameters
The use of Kenon Lake as a cooling reservoir of TPP leads to a change in its natural temperature regime, which is determined not only by climatic features and morphometric indicators, but also by changes in hydrodynamic processes, the volume of warm water discharges, and the temperature difference between the intake and discharge water. According to 2010-2015 the greatest difference between the water temperature in the heated and unheated zones is no more than 10 °C. The spreading of warm water in the surface layer leads to a vertical thermal stratification. In the thermal zone, the temperature difference between the layers is up to 9 °C, in the other lake area is no more than 2-3 °C.

Increasing of water temperature and improving the light and oxygen regimes (ice lack) contribute to increase of the vegetative season in the thermal lake zone. This is manifested in the earlier development of all algae groups, rotifers and crustaceans. At the same time, the seasonal changes of hydrobions are similar to areas without heat [16]. As noted by some researchers [2, 3-5, 9], the reaction to an increase in the temperature of the environment is manifested in lengthening of the

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**Table 1. Component analysis of plankton community**.

| Parameters          | Factors | Parameters          | Factors |
|---------------------|---------|---------------------|---------|
|                     | F1      | F2      | F3      | F1      | F2      | F3      |
|                     | (42.01%)| (17.31%)| (12.70%)| (42.01%)| (17.31%)| (12.70%)|
| H. m                | 0.540   | 0.268   | 0.117   | B_{dim} | 0.746   | -0.384  | 0.067   |
| T. °C               | 0.683   | 0.299   | 0.013   | N_{G.sp.}| 0.454   | -0.678  | -0.276  |
| pH                  | 0.077   | 0.068   | 0.774   | N_{A.f.} | 0.218   | 0.378   | -0.665  |
| TDS. mg l^{-1}      | 0.093   | 0.079   | 0.757   | N_{C.p.} | 0.563   | 0.107   | 0.307   |
| ORP. mV             | 0.236   | 0.247   | 0.728   | N_{O.sp.}| 0.549   | -0.523  | 0.026   |
| O_{2}. mg l^{-1}    | 0.083   | 0.167   | 0.661   | N_{T.m.} | 0.700   | -0.516  | -0.140  |
| E. μS cm^{-1}       | 0.206   | 0.259   | 0.805   | N_{L.k.} | 0.530   | -0.404  | -0.005  |
| P_{sex}. mg l^{-1}  | 0.641   | -0.175  | 0.115   | N_{S.o.} | 0.125   | -0.504  | -0.199  |
| PO_{4}. mg l^{-1}   | 0.641   | -0.212  | 0.289   | N_{z}    | 0.627   | 0.673   | -0.127  |
| NO_{2}. mg l^{-1}   | 0.626   | -0.093  | 0.490   | B_{z}    | 0.730   | 0.560   | 0.027   |
| NO_{3}. mg l^{-1}   | 0.522   | -0.007  | 0.387   | N_{rot}  | 0.057   | 0.623   | -0.243  |
| N_{ph}              | 0.845   | -0.343  | -0.287  | B_{rot}  | 0.210   | 0.612   | -0.153  |
| B_{ph}              | 0.724   | -0.535  | -0.291  | N_{cop}  | 0.665   | 0.597   | -0.099  |
| n_{pl}              | 0.816   | -0.205  | -0.269  | B_{cop}  | 0.709   | 0.516   | -0.032  |
| N_{cya}             | 0.453   | -0.688  | -0.273  | N_{clad} | 0.846   | 0.383   | 0.094   |
| B_{cya}             | 0.456   | -0.651  | -0.284  | B_{clad} | 0.736   | 0.426   | 0.151   |
| N_{bac}             | 0.576   | 0.253   | -0.377  | N_{K.Q.} | 0.049   | 0.601   | 0.076   |
| B_{bac}             | 0.603   | 0.260   | -0.454  | N_{A.P.} | 0.263   | 0.607   | -0.273  |
| N_{cha}             | 0.587   | -0.408  | -0.233  | N_{D.g.} | 0.614   | 0.308   | -0.166  |
| B_{cha}             | 0.577   | -0.369  | -0.283  | N_{C.q.} | 0.789   | 0.079   | 0.318   |
| N_{chl}             | 0.733   | -0.456  | -0.049  | N_{B.I}  | 0.446   | 0.643   | -0.306  |
| B_{chi}             | 0.704   | -0.359  | 0.061   | N_{N.I}  | 0.680   | 0.491   | 0.050   |
| N_{din}             | 0.742   | -0.367  | 0.055   | N_{T.C.} | 0.634   | 0.285   | 0.095   |

Note: «*» – the table includes data with factor load ≥ 0,500; N – abundance, B – biomass, ph – phytoplankton, z – zooplankton; cya – Cyanobacteria, bac – Bacillariophyta, cha – Charophyta, chl – Chlorophyta, din – Dinophyta, rot – Rotifer, clad – Cladocera, cop – Copepoda; G. sp. – Gloeocapsa sp., A.f. – Asterionella formosa, C.p. – Cocconeis placenta, O.sp. – Oocystis sp., T.m. – Tetraedron minimum, L.k. – Lemmermannia komarekii, S.o. – Scenedesmus obtusus, K.q. – Keratella quadrata, A.p. – Asplanchna priodonta, D.g. – Daphnia galeata, C.q. – Ceriodaphnia quadrangula, B.I. – Bosmina longirostris, N.I. – Neutrodiaptomus incongruence, T.c. – Thermocylops crassus.
growing season and increasing of biomass (for phytoplankton) and in lengthening of the active life, increasing of the number of generations and transition to acyclic (for zooplankton).

According to our data, water temperature has a positive relationship with transparency. For the anthropogenic hydrothermal of the Kharanor cooling-pond, the correlation between these indicators is negative. Cyanobacteria bloom contributes to the reduction of water transparency during the maximum water warming period in the reservoir, which prevents the penetration of light into the depths. On Kenon Lake cyanobacteria bloom is not observed during our researches. In the thermal zone the basis of phytoplankton abundance is determined mainly by small-cell Chlorophyta (Chlorococcales) during the growing season.

The principal component method shows that the temperature factor is not the main one in the anthropogenic hydrothermal zone of Kenon Lake. Factor load on this indicator is not the highest. In comparison, in the cooling-pond of Kharanorskaya TPP, this factor is decisive [8], probably due to the greater thermal load on this reservoir, its smaller area and high water exchange [17]. In the thermal zone of Kenon Lake, the dissolved salt contents (electrical conductivity, pH, TDS) have the highest factor loads. These interrelated parameters are directly dependent on temperature. It is proved that the higher the temperature is, the greater the conductivity of water is. The temperature factor cannot be the only mechanism determining the functioning of hydrobioncenes, but it can make a significant contribution to the action of other factors [18].

5. Conclusion
Anthropogenic hydrothermal phytoplankton and zooplankton are formed by ubiquitous native species with a wide temperature range. The main reaction of organisms to the temperature increase is the lengthening of periods and the shift of the hydrobionts development periods. During the maximum warming period, an increase in species diversity and quantitative development of algae and invertebrates is noted. The main factors causing the development of organisms are electrical conductivity, pH, total dissolved solids and temperature. Cyanobacteria and Cladocera are the most sensitive taxa to the environmental factors effects.

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