The plankton community structure in the zones with different thermal condition (Kharanorskaya TPP cooling pond, Transbaikalia)

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Abstract. The research results of plankton biocenoses in the Kharanorskaya TPP cooling pond in different temperature conditions are presented in paper. The species diversity of hydrobionts in the heated zone is higher compared to the unheated one. The dominant complex of plankton community in the two thermal zones is similar and includes species with a high temperature optimum. The absence of significant differences in the spatial-temporal dynamics of plankton quantitative indicators is associated with the morphometric features of the reservoir and the mechanical factors influence. The main abiotic factors influencing the distribution of hydrobionts are the water chemical composition in the unheated zone, and are hydrochemical and hydrophysical parameters in the heated zone.

1. Introduction
The most important change of aquatic environment as a result of electric power plant’s influence is increasing of water temperature. Receipt of additional heat is a powerful permanent exodynamic factor. It is a structuring factor, because it causes a seasonal change of species and their spatial distribution, determining the speed of vital processes of hydrobionts and the nature of the influence of other environmental factors [1]. The area of thermal influence of power plants is conceptually divided into three zones [1, 2]: constant strong heating, moderate heating and weak heating. Temperature gradually decreases during distribution of heated waters in the water area of the cooling reservoir. In summer, in the zone of minimum heating, temperature exceeds the natural one no more than 0.5-3.0 °C. [2]. The separation of circulating water masses into warm and cold influence on a change of the spatial-temporal characteristics of hydrobionts, and flows and their speed form the characteristic features of the structure of organisms. The area of distribution of heated water depends on the size and configuration of the cooling reservoir, as well as on wind conditions [3].

The aim of the work is to determine the structure of plankton communities and the relationship with environmental factors in areas with different temperature conditions using the example of the Kharanorskaya Thermal Power Plant (TPP) cooling pond.

2. Materials and methods
The Kharanorskaya TPP cooling reservoir is located in the arid zone with of the south of Transbaikalia in a highly continental climate. The reservoir is formed by the embankment of the floodplain of the Onon River floodplain at the confluence of the Turga River. It is a self-leveling flat reservoir of
floodplain-valley type of seasonal regulation. The water surface area at a normal retaining level is 4.1 km$^2$, the volume of water mass is $15.6 \times 10^6$ m$^3$ and the average depth is 3.8 m. During the open water period, the filling and feeding of the reservoir takes place due to the supply of water from the Onon River through the water supply channel, and during the freeze-up period – from the drainage channel. The technical water supply system of the power plant is mixed (straight-through-circulating) in summer and fully circulating in winter. Water enters into the power station through the water intake channel from the cooling reservoir and then it is discharged into the spillway channel [4]. The circular pattern of circulation of the flow of water mass causes a high intensity of internal water exchange (up to 35 times a year). The ice cover is formed only in the central part of the reservoir (about $\frac{2}{3}$ of the area), where the ice thickness does not exceed 0.5 m.

Hydrobiological researches were conducted from February to October, 2013 at two sites: 1 – Coastal pumping station (CPS, water pumping) – unheated zone and 2 – Spillway channel (SC, discharge of heated water) – heated zone (figure 1).

![Map-scheme of the Kharanorskaya TPP cooling pond and sampling sites](image)

**Figure 1.** Map-scheme of the Kharanorskaya TPP cooling pond and sampling sites

Legend: 1 – Coastal pumping station (CPS), 2 – Spillway channel (SC), A – Water supply channel, B – Drainage channel, C – Water intake channel.

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). The material was fixed with 4% formaldehyde solution. Plankton samples were processed according to standard hydrobiological techniques [5, 6]. The phytoplankton biomass was determined by the volume of individual cells or colonies of algae [6]. Taxon classification and synonymy of each group of algae were given according to algological site AlgaeBase [7]. Data of the biomass of zooplankton was obtained by determining the individual mass of organisms, taking into account their size [8, 9]. The collection and processing of hydrochemical samples were carried out by employees of the industrial and sanitary laboratory of the “Kharanorskaya TPP branch” of JSC “INTER Russian Joint Stock Company–Power Generation” (“Kharanorskaya GRES” AO “INTER RAO–Eletroenergosiya”), according to generally accepted methods [10]. At the same time with sampling, the depth, the transparency of the water on the Secchi disk and the water temperature were being measured. Primary data were subjected to statistical and mathematical processing using the software package Microsoft Excel 2010 and add-in for the program Microsoft Excel XLSTAT (Addinsoft, USA). The principal
component method (Principal Component Analysis, PCA) was used to research the relationship of the structural characteristics of plankton and environmental factors.

3. Results
Changes in physical and chemical parameters of the environment and hydrobiological indicators in different thermal zones of the cooling pond are shown in the table 1.

Table 1. Hydrophysical and hydrochemical parameters and plankton quantitative characteristics in the different thermal zones (CPS/SC) of cooling pond in 2013.

| Data, units | Feb 20 | Apr 18 | Jun 12 | Aug 15 | Sep 25 | Oct 23 |
|-------------|--------|--------|--------|--------|--------|--------|
| H, m        | 5.0/2.2 | 5.4/2.4 | 5.5/2.1 | 6.0/2.8 | 6.0/2.8 | 6.0/2.1 |
| TR, m       | 2.4/2.2 | 2.1/2.1 | 1.1/1.1 | 0.9/0.8 | 0.8/0.9 | 1.8/1.3 |
| T_s, °C     | 2.9/7.0 | 5.7/10.4 | 23.6/27.4 | 25.8/28.0 | 11.9/16.0 | 9.0/17.5 |
| T_b, °C     | 2.8/6.8 | 5.4/10.2 | 20.3/22.0 | 23.4/25.0 | 10.5/15.8 | 7.2/14.0 |
| Fe_ox, mg l⁻¹ | 0.25/0.14 | 0.11/0.10 | 0.07/0.06 | 0.26/0.09 | 0.34/0.08 | 0.09/0.02 |
| Si, mg l⁻¹  | 2.22/2.13 | 1.80/2.00 | 1.91/2.04 | 2.80/1.87 | 5.16/5.90 | 6.13/6.26 |
| Cu²⁺, mg l⁻¹ | 0.003/0.003 | 0.002/0.002 | 0.001/0.001 | 0.003/0.002 | 0.002/0.002 | 0.002/0.003 |
| Ca²⁺, mg l⁻¹ | 34.07/35.07 | 28.06/32.06 | 38.08/36.07 | 32.06/30.06 | 40.74/32.64 | 44.09/38.08 |
| Mg²⁺, mg l⁻¹ | 10.94/12.77 | 13.38/12.16 | 9.73/9.73 | 15.81/14.59 | 12.16/13.37 | 13.38/12.16 |
| NH₄⁺, mg l⁻¹ | 0.73/0.11 | 0.42/0.29 | 0.17/0.06 | 19.31/0.15 | 0.15/0.27 | 0.29/0.12 |
| NO₃⁻, mg l⁻¹ | 0.28/0.16 | 0.24/0.21 | 0.07/0.05 | 0.10/0.04 | 0.09/0.08 | 0.09/0.12 |
| NO₂⁻, mg l⁻¹ | 0.004/0.003 | 0.005/0.004 | 0.002/0.002 | 0.280/0.005 | 0.023/0.002 | 0.007/0.002 |
| Cl⁻, mg l⁻¹ | 6.05/5.58 | 7.44/7.91 | 6.51/8.37 | 31.62/6.51 | 11.62/6.04 | 11.25/6.30 |
| SO₄²⁻, mg l⁻¹ | 31.44/28.47 | 22.10/25.84 | 37.51/36.58 | 47.32/41.25 | 39.38/31.20 | 67.20/39.14 |
| PO₄³⁻, mg l⁻¹ | 0.04/0.10 | 0.04/0.08 | 0.02/0.02 | 1.71/0.03 | 0.06/0.02 | 0.09/0.02 |
| F⁻, mg l⁻¹  | 0.17/0.14 | 0.04/0.09 | 0.10/0.11 | 0.30/0.12 | 0.26/0.11 | 0.14/0.07 |
| pH           | 7.3/8.0 | 7.9/8.1 | 8.5/8.2 | 7.4/8.4 | 7.7/8.6 | 7.8/8.3 |
| TS, mg equiv l⁻¹ | 2.6/2.8 | 2.5/2.6 | 2.7/2.6 | 2.9/2.7 | 3.0/2.7 | 3.3/2.9 |
| O₂, mg l⁻¹  | 10.80/12.19 | 11.09/12.7 | 10.33/9.64 | 6.67/8.31 | 8.01/8.56 | 5.04/8.95 |
| [O], mgO₂ l⁻¹ | 4.00/4.84 | 4.64/4.48 | 5.36/5.76 | 12.16/8.80 | 4.40/7.40 | 4.48/6.72 |
| BOD₅, mgO₂ l⁻¹ | 2.01/1.89 | 2.08/2.36 | 2.22/2.10 | 6.61/2.90 | 1.90/2.35 | 1.18/2.06 |
| BOD₅, mgO₂ l⁻¹ | 1.87/2.70 | 2.97/3.37 | 3.17/3.00 | 9.45/4.14 | 2.71/3.35 | 1.69/2.94 |
| ASS, mg l⁻¹  | 0/0 | 0/0 | 0.02/0.001 | 0.17/0.004 | 0.005/0.004 | 0.003/0.002 |
| Oil, mg l⁻¹  | 0/0 | 0/0 | 0.009/0.002 | --/-- | 0/0 | 0/0 |
| SS, mg l⁻¹   | 4.0/4.0 | 8.0/8.0 | 7.0/6.0 | 46.0/7.0 | 14.0/9.0 | 10.0/7.0 |
| Col, 10/10 | 10/10 | 10/10 | 20/15 | 15/15 | 10/15 |
| Nₚₙ, x10³ cell l⁻¹ | 63.92/ | 121.1/ | 199.88/ | 317.52/ | 48.43/ | 95.32/ |
| Bₚₙ, mg m⁻³  | 121.2 | 700.66 | 253.1 | 1661.22 | 370.44 | 45.59 |
| Nₚ, 10² ind. m⁻³ | 47.74/ | 1400/ | 125.41/ | 159.94/ | 72.51/ | 49.91/ |
| Nₚ, x10’t ind. m⁻³ | 70.58 | 518.1 | 683.81 | 232.2 | 176.85 | 17.45 |
| Bₚ, mg m⁻³    | 8.42 | 48.72 | 362.24 | 182.50 | 70.63 | 101.72 |
| Nₚ, x10’t ind. m⁻³ | 107.25/ | 98.68/ | 1088.94/ | 1078.49/ | 531.25/ | 1151.41/ |
| Bₚ, mg m⁻³    | 208.72 | 182.99 | 1430.40 | 1635.29 | 612.38 | 1101.36 |
| nₑ            | 6/4 | 9/9 | 14/10 | 13/12 | 9/10 | 4/6 |

Note: * – data for surface water layer; **— data is absent; H – depth, TR – transparency, T_s / T_b – surface/bottom water temperature, O₂ – oxygen, Fe_ox – total iron, Si – silicon, TS – total stiffness, SS – suspended substances, ASS – anionic synthetic surfactants, Oil – oil products, [O] – oxidability, BOD₅ and BOD₅ – biochemical oxygen demand (5 and 20 days), Col – chromaticity; N – abundance, B – biomass, n – species number, ph – phytoplankton, z – zooplankton.
The difference between the two studied zones in water temperature was 3.8-8.5 °C for surface water layers and was 1.6-6.8 °C for bottom layers. On the CPS, the upper water horizons were warmer than the lower ones by 0.1-3.3 °C, on the SC were by 0.2-5.4 °C. There was a high negative correlation between temperature and transparency (r = -0.97, p = 0.008) and between temperature and nitrates (r = -0.95, p = 0.015). No other significant correlations were found.

In total, 8 algae taxa and 7 invertebrate species were found in the unheated zone, and 7 and 2, respectively, in the heated zone.

At CPS, the total abundance of phytoplankton varied within 48.43-1211 × 10³ cells/L, the total biomass within 47.74-1400 mg/m³, with a spring (April) maximum. The most species diversity of algae was noted in June (32 taxa), the lowest was in August (7 taxa) (Table 1). Seasonal succession of the dominant species of phytoplankton was in the direction of: chrysophytes (Chrysococcus cystophorus Skuja (44 % of the total abundance)) → chrysophytes (C. cystophorus (37 %) + Kephyrion spirale (Lackey) Conrad (15 %) → cyanobacteria and charophytes (Anabaenonemon flos-aqua Ralfs ex Bornet & Flahault (28 %) + Staurastrum sp. (21 %)) → cyanobacteria (Oscillatoria fulgens Böcher (61 %)) → greens (Chlamydomonas globosa J.W. Snow (50 %)) → greens and cyanobacteria (Scenedesmus quadricauda (Turpin) Brébisson in Brébisson & Godey (20 %) + Dolichospermum scheremetievae (Elenkin) Wacklin, L. Hoffmann & Komárek (11 %)).

In zooplankton there were from 4 to 14 species. The total abundance varied from 8 to 306.56 × 10³ ind./m³ and total biomass from 98.68 to 1088.94 mg/m³. The maximum of quantitative indicators was observed in June (Table 1). The direction of the seasonal dynamics of dominants was as follows: copepods and rotifers (Cyclops vicinus Uljanin (56 % of the total abundance) + Keratella quadrata (Müller) (23 %)) → rotifers and copepods (K. quadrata (36 %) + Kellicottia longispina (Kellicott) (17 %) + C. vicinus (17 %)) → rotifers (K. longispina (77 %)) → copepods and cladocerans (Thermocyclops crassus (Fischer) (54 %) + Bosmina longirostris (O.F. Müller) (43 %)) → cladocerans and copepods (B. longirostris (51 %) + T. crassus (43 %) → cladocerans (B. longirostris (92 %)).

At SC, the abundance of algae varied within 45.59-1661.22 × 10³ cells/L, the biomass varied within 17.45-683.81 mg/m³, the species number varied from 20 (in October) to 31 (in September). The most development of phytoplankton was observed at high summer temperatures (June and August) (Table 1). Seasonal dynamics of algae dominants was as follows: chrysophytes (C. cystophorus (58 % of the total abundance)) → chrysophytes and diatoms (C. cystophorus (24 %) + Synedra actinastroides Lemmermann (18 %)) → cyanobacteria (A. flos-aqua (30 %)) → cyanobacteria (A. flos-aqua (84 %)) → greens (S. quadricauda (36 %)) → cyanobacteria D. scheremetievae (38 %)).

The total abundance of zooplankton was 8.42-652.24 × 10³ ind./m³ and total biomass was 182.99-1635.29 mg/m³. The species composition varied from 4 to 12 taxa. The maximum of indicators was in the summer (Table 1). Seasonal dynamics of dominants was next: copepods (C. vicinus (83 % of the total abundance)) → rotifers and copepods (K. quadrata (42 %) + Eudiaptomus graciloides Lilljeborg (19 %)) → rotifers (K. longispina (89 %)) → cladocerans and copepods (B. longirostris (50 %) + T. crassus (47 %)) → cladocerans and copepods (B. longirostris (49 %) + T. crassus (42 %)) → cladocerans (B. longirostris (92 %)).

As a result of the PCA, two components were identified; the total contribution to the variability of the plankton community was 63.99 % (for CPS) and 62.37 % (for SC) (figure 2). The share of the remaining components in the total dispersion was insignificant.

In the unheated zone, the first component (F1), describing 39.4 % community variability, has the structural characteristics of Cyanobacteria and the species number of Cladocera as parameters with the greatest positive weight loads. The contribution of the second component (F2) to the explanation of the variability of the plankton community is 24.59 %. Factor load is positive and is determined by quantitative indicators of Chlorophyta. Among abiotic environmental parameters, the concentrations of chloride, anionic synthetic surfactants and suspended substances (on F1) and calcium content (on F2) have the greatest influence on the structure of the plankton biocenosis.
In the heated zone, the contribution of the first component (F1) to the explanation of ecosystem variability is 39.31%. The signs of quantitative indicators of Charophyta are characterized by the greatest positive weight loads on the first component. The second component accounts for 23.06% of the variance. In the positive direction, it is loaded with phytoplankton biomass. The main abiotic factors that influence on the structural organization of the plankton community are water transparency, nitrates and oxygen contents (on F1) and total stiffness (on F2).

**Figure 2.** PCA biplots of ordination between planktonic community and environment at the different thermal zones (1 – unheated and 2 – heated) of the Kharanor cooling pond in 2013.
Legend: B5 и B20 – biochemical oxygen demand; chl – Chlorophyta, chr – Chrysophyta; bac – Bacillariophyta; din – Dinophyta; xan – Xanthophyceae; cya – Cyanobacteria; cha – Charophyta; eug – Euglenophyta; z – zooplankton; cop – copepods; clad – cladocerans; rot – rotifers.

4. Discussion
The thermal regime in the Kharanorskaya TPP cooling pond is determined both by climatic features and morphometric parameters, as well as by changes in hydrodynamic processes, the volume of warm water discharges, and the temperature difference between the intake and discharge water. According to previous data [11], the temperature throughout the water column was the same. The difference between the horizons was no more than 0.1-0.6 ºС. The commissioning of the third power unit of the station (in 2012) led to an additional thermal load on the reservoir. The difference in water temperature between intake and discharge had increased from 7.7-10.2 ºС in 2011 to 9.2-11.5 ºС in 2013. The water temperature on the SC in summer had been increases by more than 30 ºС [12]. The spreading of still warmer waters in the surface layer lead to vertical thermal stratification in 2013.

Most of the marked hydrobionts in the Kharanor reservoir are inhabitants of a wide temperature range. In the heated zone, the species composition of plankton is more diverse, mainly due to green algae (*Tetradesmus obliquus* (Turpin) M.J. Wynne, *Tetrastrum elegans* Playfair, *Scenedesmus ellipticus* Corda, *Messastrum gracile* (Reinsch) T.S. Garcia in T.S. Garcia et al., *Chlorotetraedron incus* (Teiling) Komárek & Kováčik, *Lagerheimia longiseta* (Lemmermann) Printz, *Coelastrum pseudomicroporum* Korsikov и др.) and cladocerans (*Bosminopsis deitersi* Richard, *Monospilus dispar* Sars, *Ilyocryptus sordidus* (Lievin)). The dominant complex in both thermal zones does not significantly differ. During the freezing-up period on the reservoir, cold-loving species of chrysophytes (*C. cystophorus*), rotifers (*K. quadrata*), copepods (*C. vicinus*) dominate. Cyanobacteria (*Aphanizomenon flos-aqua, D. scheremetieviae*), greens (*C. globosa*) and crustaceans (*B. longirostris, T. crassus*) with high temperature optimum are dominants at the rest of the time [13, 14].
The greatest development of plankton on CPS is observed in the spring-summer period, on SC – in the summer. A water temperature increase and improvement of the light and oxygen regimes (absence of ice) contributes to an increase in the growing season in the cooling reservoir [1, 14-17].

There are no significant differences in the spatial and temporal dynamics of quantitative indicators of plankton biocenoses in the Kharanorskaya TPP cooling reservoir. The abundance of hydrobionts in the discharge area does not significantly differ from the remote area, where the temperature regime is close to the natural one. The absence of a pattern in the distribution of organisms in different thermal zones is associated with shallow water and a small area of the reservoir. In small reservoirs, this distribution is very mobile due to the influence of the prevailing wind mixing [3] and intensive water circulation [1, 18].

In the unheated area of the Kharanorskaya TPP reservoir, the highest factor loadings accounts for the sings of Ca, Cl, ASS concentrations, and in the heated area for signs of water transparency and temperature and NO₃ and O₂ contents. The development of plankton communities, both under the influence of heated waters and under natural temperature conditions, takes place in an interconnected multi-factorial system of hydrochemical and hydrophysical parameters. Accordingly, the temperature factor cannot be the only mechanism determining the hydrobiocenoses functioning, but it can make a significant contribution to the other factors action [17].

5. Conclusion
The phyto- and zooplankton in different thermal zones of the Kharanorskaya TPP cooling pond are characterized by no significant differences in the dominant complex and the spatial and temporal dynamics of abundance and biomass. This is due to the morphometric features of the reservoir and the significant influence of mechanical factors. Structural characteristics of plankton communities in the unheated zone depend on the calcium, chloride, suspended substances and ASS contents, in the heated area depend on transparency, temperature, nitrates and dissolved oxygen concentrations.

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