Acanthocyclops trajani Mirabdullayev et Defaye (Copepoda, Cyclopoida) as An Indicator of the Ecological State of Water Bodies in Kazakhstan

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Abstract. In 1997-2007, the structure of populations of Acanthocyclops trajani Mirabdullayev et Defaye (Copepoda, Cyclopoida) in water bodies of Kazakhstan was studied. It was shown that cyclops prefers water bodies with TDS up to 3.0 g/dm³. The abundance of cyclops increased in the gradient of phosphate concentrations statistically significantly. In the same direction the dominance of males in the populations of cyclops increased. The appearance of individuals with morphological anomalies was associated with toxic pollution of water bodies. The results demonstrate that the structure of cyclops populations can be an indicator of the ecological state of aquatic ecosystems.

1 Introduction
The freshwater cyclopoid genus Acanthocyclops (Kiefer, 1927) consists of about 100 species (WoRMS, 2010) which has a world-wide distribution [1]. The morphological plasticity of the species of the genus makes it difficult to identify them. The search for new criteria that are used for species identification made it possible to bring greater clarity to the taxonomy of the genus Acanthocyclops and describe a number of new species [2, 3].

Acanthocyclops trajani Mirabdullayev et Defaye was described relatively recently from water bodies of Central Asia and Kazakhstan [4]. At present, it is known from the territory of Southeast, South, Central and Western Kazakhstan [5-7], Hungary [8], Czech Republic [9], Egypt [10], Mexico [11], Africa [4].

The wide distribution and high abundance of cyclops determines its leading role in zooplankton and, as a consequence, its high indicator significance for assessing the ecological state of water bodies in various natural and climatic zones. For bioindication purposes, information on the environmental preferences of Acanthocyclops trajani is required. There is no such information in references. This article partially fills this gap. Its purpose is to analyze the distribution of the total abundance, sex ratio, and the proportion of individuals with morphological anomalies in cyclops populations from water bodies of Kazakhstan in the gradient of external factors.

2. Material and Methods
Zooplankton studies were carried out in 40 water bodies of Kazakhstan in 1997-2007. Zooplankton samples were collected and processed using standard methods [12, 13]. To characterize the structure of Cyclops populations, the number of females, females with eggs, males, copepodites, and nauplii was separately counted in each sample. The sex ratio was found as the ratio of the number of sexually mature females to the number of males. When sampling zooplankton, water samples were taken to determine the total dissolved solids of water (TDS), the content of nutrients, heavy metals (zinc, copper, cadmium, and lead). Conventional methods of chemical analysis of water samples were used [14]. Heavy metal measuring was performed by mass spectrometry with inductively coupled plasma
by using Agilent 7500 A manufactured by Agilent Technologies, USA (National Standard RK ISO). Statistical data processing was performed using the Statistica 10 software.

3. Results and Discussion

TDS of water in the studied water bodies varied from 0.2 to 27.0 g/dm$^3$. The content of phosphates in water reached 7-300 g/dm$^3$, zinc 3.2-44.4, copper 3.8-58.8, cadmium 0.1-5.9, lead 8.2-30.4 μg/dm$^3$.

Scatterplots analysis showed that A. trajani inhabits water bodies with water TDS up to 3.0 g/dm$^3$ (Figure 1). In fresh and brackish water, the abundance of cyclops varied from 0.2-137.3 thousand ind./m$^3$. The maximum abundance of populations was recorded in water bodies with a high anthropogenic load (wastewater storages, industrial reservoirs). The relationship between the abundance of cyclops and the content of phosphates (as indicators of nutrient load) was statistically significant (R = 0.79, p <0.05). The average abundance of its populations reached 0.3±0.1 thousand ind./m$^3$ when a phosphorus concentration was less than 20 μg/dm$^3$. It increased to 3.3±2.3 thousand ind./m$^3$ and up to 44.8±17.9 thousand ind./m$^3$ when a phosphorus content reached 25-50 μg/dm$^3$ and 55-200 μg/dm$^3$ accordingly (Figure 2). Along with an increase in the total abundance, the proportion of A. trajani in zooplankton increased from 6±1.2% to 8.9±5.7% and to 31.2±9.3%, respectively.

![Figure 1](image1.png)

**Figure 1.** The abundance and sex ratio in the *Acanthocyclops trajani* populations in the gradient of TDS in water bodies of Kazakhstan.

![Figure 2](image2.png)

**Figure 2.** The abundance and sex ratio in the *Acanthocyclops trajani* populations in the gradient of phosphate content in water bodies of Kazakhstan.
The sex ratio in cyclops populations varied from 0.15-0.60 (female dominance) to 1.5-55.0 (male dominance). The most pronounced dominance of males in populations of this species was recorded in reservoirs with a high level of mixed pollution (wastewater storage, technical water storage). A positive statistically significant relationship was found between male dominance and phosphate content ($R = 0.72, p < 0.05$).

The high abundance of males, in comparison with the females, testified to the violation of the sex structure of the Acanthocyclops trajani populations in the water bodies of Kazakhstan. Typically, females are slightly more numerous than males in populations of cyclopoid copepods [15-18]. This is explained by the fact that one male can fertilize several females, and there is no need for an equal sex ratio [19]. The influence of external factors on the sex structure of planktonic invertebrates is poorly studied. Deviations from the usual sex ratio in crustacean populations are induced by stress factors, including changes in water temperature, TDS, and pH [20, 21]. Our results showed the influence of the nutrient load on the dominance of males in the Acanthocyclops trajani population. The regional and climatic conditions of Kazakhstan determine the low content of phosphates in the water bodies of the region. As a result, phosphates are an indirect indicator of the intensity of nutrient load on the aquatic ecosystems of the region [22].

In the populations of A. trajani from the most polluted reservoirs (wastewater storages of southeastern and northern Kazakhstan, the Sharda, Samarkan, Intymak, Kok-Uzek reservoirs), individuals with morphological anomalies were constantly found. Ugly cyclops were sporadically present in certain parts of natural water bodies (Lake Balkhash, small lakes in the Ili River delta). All of them are characterized by mixed pollution (organic combined with toxic). The abundance of such animals was low and varied within 1-87 ind./m$^3$. Their share reached 0.01-1.90% of the population abundance (excluding nauplial stages). In some periods of research, the occurrence of individuals with morphological anomalies reached 50-100% in a water body.

Positive statistically significant relationships were found between the relative abundance of the individuals with morphological anomalies and the content of heavy metals (table 1). The highest values of the Spearman correlation coefficient were observed between the proportion of such individuals in the population and the copper content. They were found already at a copper concentration of 4.0-4.5 μg/dm$^3$ and were constantly observed in a copper concentration gradient of more than 10.0 μg/dm$^3$.

Table 1. Spearman’s correlation coefficient ($R$) between the concentrations of heavy metals in water and the proportion of individuals with morphological anomalies in Acanthocyclops trajani populations from water bodies of Kazakhstan.

| Variable | Number of samples (N) | R     | t (N-2) | p-level |
|----------|-----------------------|-------|---------|---------|
| Zn       | 25                    | 0.365 | 1.752   | 0.095   |
| Cu       | 25                    | 0.647 | 3.790   | 0.001   |
| Pb       | 25                    | 0.439 | 2.182   | 0.041   |
| Cd       | 25                    | 0.154 | 0.695   | 0.495   |
| Total heavy metals | 25 | 0.543 | 2.893   | 0.009   |

Copper is highly toxic to most living organisms [23]. For cyclops, copper is more harmful than zinc, chromium, and nickel [24]. The genotoxic impacts of copper mixed with pesticides were found to embryonic development and DNA integrity of the Pacific oyster, Crassostrea gigas Thunberg [25]. There are few data on the effect of toxic pollution on the frequency of occurrence of individuals with morphological deviations [26, 27]. Our results demonstrate the indicator significance of this biological variables for assessing the level of toxic pollution of aquatic ecosystems.

4. Conclusion
Acanthocyclops trajani prefers fresh and brackish water with high nutrient content. This species tolerates a wide range of toxic contamination. The dominance of males and the emergence of individuals with morphological anomalies is a species response to stressful environmental conditions. The results obtained can be used to assess the ecological state of aquatic ecosystems using bioindication methods.

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