LONG TERM CHANGES OF CRUSTACEAN ZOOPLANKTON COMMUNITIES IN LAKE WIGRY AS A RESPONSE TO CHANGING TROPHIC CONDITIONS – 100 YEARS OF OBSERVATIONS

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Abstract

Wigry Lake has one of the longest zooplankton data sets in Poland and has been investigated for over 100 years. Therefore, our goal was to present long-term changes in zooplankton structures against the background of changing trophic conditions. The species composition of crustacean zooplankton in the first half of the 20th century was typical for a large mesotrophic lake, with a high share of *Daphnia cucullata* and stenotherm species: *Eurytemora lacustris*, *Heterocope appendiculata*, *Cyclops lacustris*, *Bythotrephes brevimanus*, *Daphnia longiremis*. The results of the research from the years 1965-1985 were very pessimistic, because the lake was exposed to intense eutrophication and there were important changes in zooplankton communities. The glacial relicts and species characteristic for low trophic condtions declined, while the share of species typical for high trophic conditions (*Mesocyclops leuckarti*, *Thermocyclops oithonoides*, *Diaphanosoma brachyurum*) increased. As a result, species characteristic for eutrophic conditions made up to 70 % of crustacean zooplankton, when in 1921 their share did not exceed 25%. The results of hydrochemical and biological studies of the last 30 years indicate a gradual tendency to improve the trophic state of Lake Wigry, due to biomanipulation activities carried out in the lake and its catchment area. We also have observed a marked increase in the occurrence of glacial relicts and the dominance of large *Daphnia* individuals, which indicates an improvement in water quality.

Keywords: crustacean zooplankton, long-term changes, water quality, glacial relicts, reoligotrophication

Introduction

Wigry is a large lake with an area of 21.7 km^2 and a maximum depth of 73 m, which makes it one of the largest lakes in Poland. The lake is located in northeast Poland, and the Czarna Hańcza River flows through its North Basin. Lake Wigry is unusual due to its diversified morphometry, shape, and bathymetry, which create diverse habitat conditions, although most parts of the lake have mesotrophic conditions (Karpowicz et al. 2019). However, in the 70's and 80's the lake underwent strong eutrophication and its ecological status significantly decreased. Nowadays we are observing a reoligotrophication process (Kamiński 1999) due to the construction of sewage water treatment plants in the catchment area and active protection through biomanipulation (Karpowicz et al. 2019). The composition of zooplankton has also changed with the trophic status. Research on Lake Wigry began in 1920 by setting up the Hydrobiological Station, managed by Dr. Alfred Lityński, which contributed greatly to the European limnology until 1939. The scientists of the Station and its visitors published about 100 research papers on hydrography, hydrochemistry, phytoplankton, zooplankton, bottom fauna, vegetation, fish, and other groups of water organisms of Lake Wigry. The outbreak of World War II halted the activity at the Hydrobiological Station and its work has never been resumed. After the war, fragmentary information about zooplankton came only from studies of lake fisheries. Comprehensive hydrochemical and biological studies of Lake Wigry have been conducted in 1981-1995 by the Polish Academy of Sciences, and then by the Department of Hydrobiology of the University of Bialystok. Thus, with 100 years of observations, Lake Wigry is probably the best understood Polish lake in terms of planktonic fauna (Karpowicz et al. 2013).

Long-term data is integral to understanding and quantifying complex processes in ecosystems and for predicting their response and future development under changing ambient conditions (Straskrabova et al. 1999). Therefore, our goal was to describe the long-term changes in the zooplankton composition of Lake Wigry in the context of changing trophic conditions. The zooplankton can very quickly respond to changes in the environment and is widely used as an indicator of trophic status (Andronikova 1996; Jeppesen et al. 2011; Ejsmont-Karabin 2012; Ejsmont-Karabin et al. 2013; Karpowicz et al. 2020). Generally, zooplankton of eutrophic lakes is characterized by high abundance, low diversity, and small body size (Hillbricht-Ilkowska et al. 1979; Jekaterynczuk-Rudczyk et al. 2012). While in oligotrophic lakes zooplankton is characterized by low abundance, high diversity, large body size, and the presence of stenotherm species with high environmental requirements (Andronikova 1996; Karpowicz et al. 2020)

Materials and methods

Lake Wigry and 41 other lakes in the Wigry National Park are located in NE Poland close to the Lithuanian border. The landscape was shaped during the last glaciations (Marks 2005). We analyzed long-term changes based on the North Basin of Lake Wigry (Figure 1). The samples were collected in the midsummer in the years 2007, 2009, 2015, and 2016. The samples were taken using a 5l Limnos sampler from the epilimnion, matalimnion, and hypolimnion. For zooplankton analysis, 10-20 liters of water were filtered through a 40 µm plankton net and were preserved in a 4% formalin solution. The animals were identified to species level and 10 individuals of each species were measured for estimated biomass, using length-weight regression relationships (Błedzki et al. 2016). Our results were presented against the background of long-term changes in the structure of crustacean zooplankton (Lityński 1922; Adlerówna 1929; Karabin et al. 1992). The zooplankton structure was also used to calculate trophic status based on the equation proposed by Ejsmont-Karabin and Karabin (2013). Comparative limnology studies were conducted to present the effect of environmental conditions on crustacean communities. The trophy of the lake was calculated using the Carlson trophic status index (TSI) as an average of three parameters: Secchi disc visibility (SDV), chlorophyll *a*, and total phosphorus (Carlson 1977). Chlorophyll *a* concentration in water was determined by spectrophotometry, after homogenization filtered on GF/C and extraction with boiling 90% ethanol (Lorenzen 1965; Nush 1980). For the determination of phosphorus forms, we used the standard molybdate colorimetric method (Murphy and Riley 1962). Assay of total phosphorus accomplished after prior digestion with UV radiation, with concentrated H_2SO_4 and 30% H_2O_2. We measured *in situ* the Secchi disc visibility (SDV), and dissolved oxygen concentrations in the hypolimnion using an HQ40D Multi Meter (Hach-Lange GmbH, Germany).

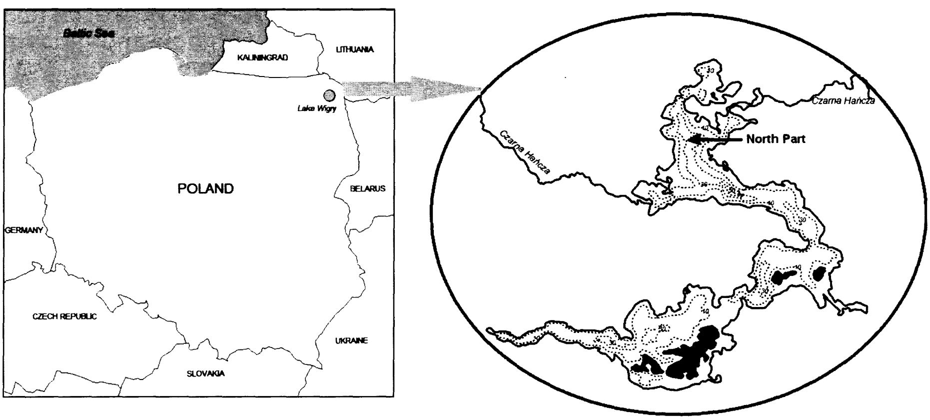

Figure 1. Lake Wigry bathymetry with the location of the sampling site.

Results and discussion

In the early twentieth century, Lake Wigry was characterized by high water transparency, which ranged from four to six meters in July (Figure 2A), while in winter it was more than 11 meters (Lityński 1926). In the 80s, when the lake underwent strong eutrophication, water transparency decreased significantly to a maximum of 1.8 m. Low water transparency persisted until 1998 and then slightly increased in the following years, reaching 3.5 meters (Figure 2A). There were also changes in oxygen concentrations in the hypolimnion, which were caused by intense eutrophication. High oxygen concentrations in the hypolimnion were observed in the 70s (Figure 2B). Then, the concentration of dissolved oxygen in the lower layers decreased to only 1.6 mg/L, indicating a hypoxic state disturbing biotic interactions and causing significant changes in food webs (Kolar et al. 1993). From 2002 we have observed improving oxygen conditions in the hypolimnion (Figure 2B) and nowadays oxygen concentration in hypolimnion ranges from 8.2 to 9.6 mg/L.

In the 20s, high water transparency and good oxygen conditions indicated low trophic conditions, which were also emphasized by Dr. Lityński (1922). However, there is a lack of data on hydrochemistry from that period, causing a gap in the calculations of the Carlson Trophic State Index (TSI). TSI values in 1986-2007 ranged from 50.5 to 54 (Figure 3A), which indicates eutrophic conditions. Since 2009 we observed improving trophic conditions and TSI values ranging from 34 to 48.5 indicate mesotrophic conditions.

We also analyzed the concentrations of orthophosphates in the surface and lower layers of the lake. From 1986 to 2002, the concentrations of orthophosphates in the surface layer oscillated between 15 and 22 µg/L and in the lower water layers these values were particularly high, ranging from 95 to 106 µg/L (Figure 3B). This was caused by the uncontrolled inflow of nutrients to the northern part of the lake with the Czarna Hańcza river, which provided 80% of pollutants as a recipient of sewage from nearby Suwałki (70 thousand inhabitants) and it also collects pollution from its catchment area of 170 km^2 (Kamiński 1999). Since 2007, the values both in the upper and lower water layers were at the same level, ranging from 6 to 20 µg/L (Figure 3B). We can observe an improvement in orthophosphates levels, thanks to the launch of the sewage treatment plant in Suwałki in 1986 and its modernization in the years 1993-1995, introducing the dephosphatation process (Ćwikła et al. 2011).

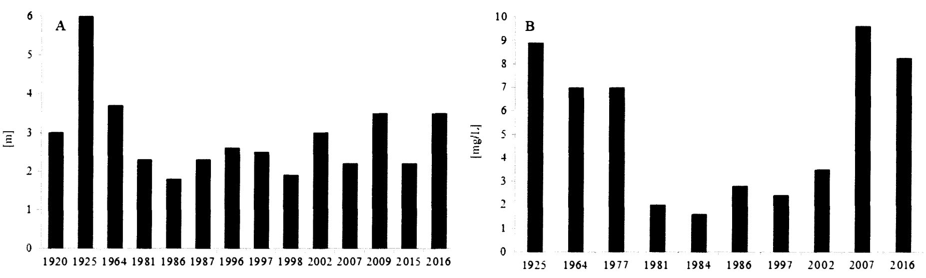

Figure 2. Long-term changes of the Secchi disk visibility (A) and hypolimnetic oxygen concentrations (B) in Lake Wigry during 1920-2016.

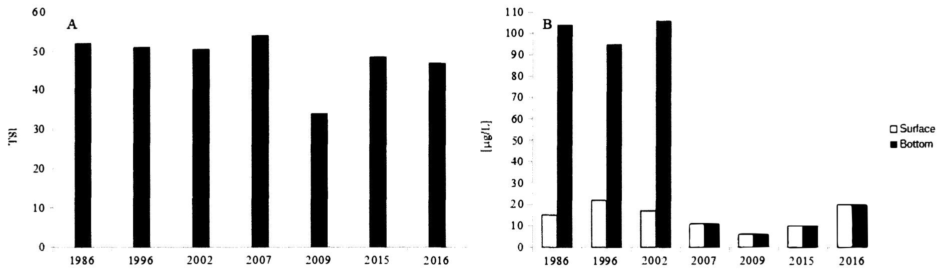

Figure 3. Changes in the value of Carlson's Trophic State Index (A) and concentrations phosphorus forms (B) in surface and bottom water layers on Lake Wigry.

During the activity of the Hydrobiological Station, many detailed studies were carried out on the structure and ecology of crustacean zooplankton in various parts of Lake Wigry. Lityński (1922) noticed qualitative and quantitative differences in the composition of zooplankton in the northern part of the lake, where biomass was much higher than in other parts of the lake. In the 1920s and now, sampling methods are slightly different, which makes a comparison of abundance very difficult. Therefore long-term succession was analyzed based on the percentage of species in groups. The share of the main zooplankton groups was similar over the years, but nowadays the share of Cladocera is increasing with a decrease in copepods (Figure 4A), which indicates an improvement in water quality. The Cladocera at the beginning of the 1920s was dominated by *Daphnia cucullata* and *Eubosmina coregoni*, while *Diaphanosoma brachyurum* and *Daphnia cristata* had a smaller share (Figure 4B). The share of *D. cucullata* in 1986-2009 increased (Figure 4B) and larger individuals of this species dominating in recent years (Karpowicz et al. 2019). The body size of *D. cucullata* is a good indicator of the trophic state (Karpowicz et al. 2020), and increasing body size also indicating improvement of environmental conditions of Lake Wigry. In the eighties decreased share of *E. coregoni* and increased share of species characteristic for eutrophic conditions like *Chydorus sphaericus*, *Ceriodaphnia quadrangula*, *Bosmina berolinensis* (Figure 4B). The greatest changes took place in Calanoida. At the beginning of the twentieth century, *Eurytemora lacustris* and *Heterocope appendiculata* dominated the Calanoida (Figure 4C), both of these species are stenotherm and are considered as glacial relicts (Karpowicz et al. 2021). In the second half of the twentieth century, the share of this species significantly decreased (Figure 4C). Recent studies from 2007 and 2009 show increased importance of Calanoida in the overall zooplankton biomass and also more common were *E. lacustris* and *H. appendiculata*. In the Cyclopoidae was observed slow change in the dominance from *Thermocyclops oithonoides* to *Mesocyclops leuckarti* (Figure 4D). Last research from 2007 and 2009 also showed the decline importance of this group, which is one of the indicators for the trophic state proposed by Karabin (1985).

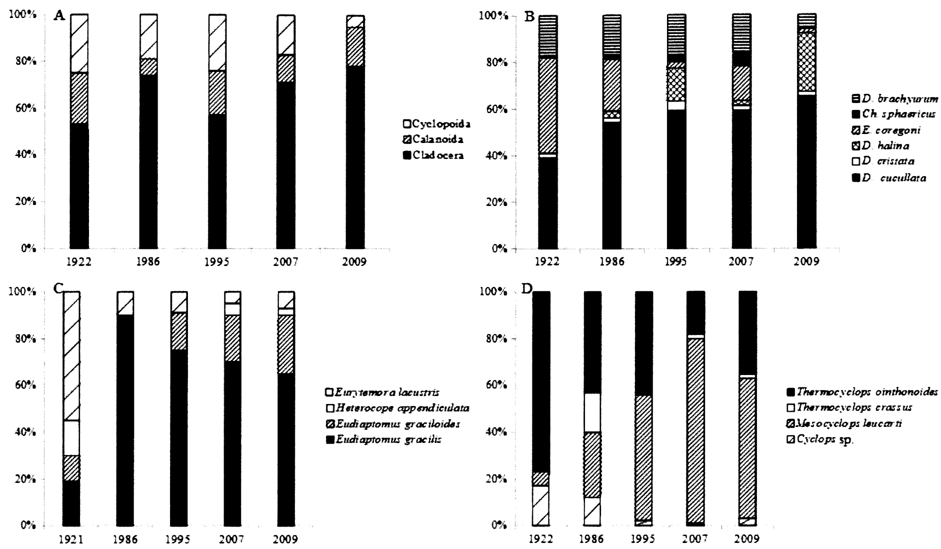

Figure 4. Long-term changes of crustacean zooplankton structure. A – main crustacean groups; B – Cladocera; C – Calanoida; D – Cyclopoida.

During progressive eutrophication in the second half of the twentieth century, changes in the structure of zooplankton took place. However, thanks to protection activities carried out in the lake and its direct catchment area, nowadays the structure of the zooplankton indicates low trophy, which is a good sign for the future. In the summer, at the majority of the stations, the *Daphnia cucullata* dominates in zooplankton biomass. High species diversity of the pelagic zooplankton gives a very specific value to the lake, particularly due to the occurrence of relic and rare crustaceans species, like *Eurytemora lacustris, Heterocope appendiculata, Cyclops lacustris, Bythotrephes brevimanus,* and *Daphnia longiremis.* These rare species in recent years were more frequent at most sampling sites, which indicates improving environmental conditions in the lake.

Conclusions

The species composition of crustacean zooplankton in the first half of the 20th century was typical for a large mesotrophic lake. In the second half of the twentieth century, increased anthropopressure resulted in: decreased water transparency, increase of phosphorus contents, and lack of oxygen in the hypolimnion. Studies conducted in the eighties have shown changes in zooplankton structure, with increased the importance of species typical for eutrophic conditions (*Mesocyclops leuckarti, Thermocyclops oithonoides, Diaphanosoma brachyurum*), while stenotherm species, which prefer cool oxygenated waters (*Eurytemora lacustris, Heterocope appendiculata, Cyclops lacustris, Bythotrephes brevimanus,* *Daphnia longiremis*) were found occasionally. However, thanks to protection activities carried out in the lake and its direct catchment area, in the early twenty-first century we have observed improvement of trophic conditions and increasing water transparency. Nowadays relict species, which are especially sensitive to environmental deterioration are more frequently found.

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