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A ZOOPLANKTON-BASED STUDY OF COASTAL LAKES

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Abstract

Numerous brackish estuarine water bodies are situated in the Polish Baltic Coastal Zone, including smaller and bigger lakes like Sarbsko, Łebsko, Gardno, Wicko, Kopań, Bukowo, Jamno, Resko Przymorskie, Liwia Łuża, Koprowo and Wicko Wielkie. Despite a similar genesis and geomorphological type, these lakes are characterized by different hydrological and hydrochemical conditions, determined by the predominance of terrestrial or marine factors. The origin of Polish coastal lakes and transboundary water bodies is closely related to the history of the Baltic Sea and the last glaciation. Coastal brackish waters have been inhabited by both marine and freshwater organisms.

Key words: estuary, coastal lakes, zooplankton

INTRODUCTION

I have focused my investigations into zooplankton communities in coastal lakes on the following major research areas:

- structure and functions of selected coastal lake ecosystems exposed to human pressure;
- changes in zooplankton communities in coastal lakes.

CHARACTERISTICS OF RESEARCH AREAS

Structure and functions of selected coastal lake ecosystems exposed to human pressure

A study of coastal lakes was launched in the 1980s, in cooperation with Prof. Ludwik Żmudziński from the Higher School of Teacher Education in Słupsk, within the framework of research problem CPBP (Central Basic Research Program) 04.10 "Environmental Protection and Management". Ecological studies of lakes located at the Southern Baltic Coast were conducted in the years 1986-1989 to investigate the

environmental conditions in estuarine lakes (Łebsko, Gardno, Jamno, Sarbsko, Wicko, Kopań, Bukowo, Resko Przymorskie, Liwia Łuża, Koprowo, Wicko Wielkie) and to determine their effects on seasonal and long-term changes in the abundance and biomass of zooplankton.

Coastal lakes are specific water bodies showing the characteristic features of both marine and terrestrial environments. They are fed by rivers and connected with the Baltic Sea through channels or rivers. The water balance of coastal lakes is dependent on the inflow of fluvial waters rather than of marine waters. These brackish water bodies provide habitat for euryhaline marine, freshwater and brackish-water species. The key ecological factors that affect zooplankton structure in coastal lakes include water salinity and temperature, wind direction and strength, and trophic conditions. All of these factors are known to change over time and space.

The results of a study investigating changes in the abundance of invertebrate fauna under variable environmental conditions in the estuarine Lake Łebsko are presented in an original paper by Żmudziński et al. (1990). Spatial variation in local environmental conditions was reflected in the distribution and density of zooplankton. Based on an ecological analysis, it was found that:

- the variability of environmental conditions is caused not only by temperature differences but also by the different volume of saltwater inflows from the Baltic Sea to the lake. As a result, these interacting factors affect zooplankton communities whose abundance varied widely throughout the study period;
- clear seasonal variation was observed in the abundance of zooplankton, with peaks noted later in the very warm year 1986 than in the much cooler 1987. Probably a gradual rise in water temperature in the summer season supports the development of zooplankton. Cladocera were shown to be most sensitive to adverse thermal conditions;
- significant horizontal differences in lake pollution load were observed. The highest concentrations of biogenic compounds were recorded at the inflow of the Łeba River to the lake (the lowest abundance of zooplankton), while the lowest – in the littoral zone (substantially higher abundance of zooplankton). This is indicative of a negative zoological impact of fluvial waters and a positive influence of marine waters on the biocenosis of the Łebsko Lake.

The production of zooplankton as natural fish food resources was also estimated during a four-years study in different zones of the Łebsko Lake, the Gardno Lake and the Jamno Lake (Żmudziński et al. 1992). Zooplankton abundance in these three water bodies varied greatly (above 1 000 individuals·dm⁻³ in the Jamno Lake, approximately 900 individuals·dm⁻³ in the Łebsko Lake, and approximately 700 individuals·dm⁻³ in the Gardno Lake). Irregular oscillations were also noted for other biological parameters (phytoplankton, zoobenthos). The spatial distribution of zooplankton followed the most regular pattern. In all cases, the lowest abundance of zooplankton was observed at the inflow of the Łeba River to the lake, while considerably higher densities were recorded in the middle part of the lake and in the littoral zone. This could result from the inflow of polluted fluvial waters or, more probably, from the fact that passively floating zooplankton may be easily swept away from the area receiving fresh water.

Lake Jamno was most abundant in fish food resources which, however, could not be fully used due to a decrease in both fish stocks and total catch in consequence of heavy pollution. The food resources available to fish in other two estuaries were much poorer, due to twofold lower abundance of invertebrates.

The trophic status of the Łebsko Lake, the Gardno Lake and the Jamno Lake was assessed based on the structural characteristics of zooplankton as bioindicators of water eutrophication (Paturej and Goździewska 2005). The analysis revealed the presence of many Rotifera and Crustacea species in the zooplankton community, considered to be good indicators of water trophy (ecological group II comprised 8 taxa of Rotifera: *Brachionus angularis*, *Brachionus diversicornis*, *Filinia longiseta*, *Keratella cochlearis* f. *tecta*, *Keratella quadrata*, *Pompholyx sulcata*, *Proales* sp., *Trichocerca pusilla*, and 5 species of Crustacea: *Bosmina coregoni*, *Bosmina longirostris*, *Chydorus sphaericus*, *Diaphanosoma brachyurum*, *Mesocyclops leuckarti*); progressive eutrophication of the lakes was accompanied by a gradual increase in the abundance and biomass of Rotifera and Crustacea; in all lakes the abundance of zooplankton was determined by Rotifera, and their biomass – by Crustacea; a zooplankton-based assessment of the trophic status of the above lakes enabled to classify them as mesoeutrophic and eutrophic with symptoms of polytrophy.

Based on a faunal analysis, the structural characteristics of zooplankton and classical, non-zooplankton-based criteria, the lakes were ordered by increasing trophy: Łebsko, Gardno, Jamno. The other coastal lakes were classified into trophic types based on zooplankton communities, as follows (Paturej 2005a):

- lake Kopań – polytrophic with symptoms of eutrophy;
- lake Resko Przymorskie and lake Liwia Łuża – eutrophic with symptoms of polytrophy;
- lakes: Sarbsko, Wicko, Bukowo, Koprowo and Wicko Wielkie – eutrophic and mesoeutrophic, however a high proportion of the *tecta* form within the *Keratella cochlearis* population indicated water polytrophy. In general, water in the majority of the analyzed lakes showed symptoms of eutrophy and mesoeutrophy.

Further biological studies (Paturej 1999, Paturej and Bogacka 2001a) focused on the specific hydrological and ecological features of the investigated estuaries, and on the ecological role of Rotifera as the predominant group in the analyzed zooplankton community, where they accounted for 60% on average. Only 13 Rotifera species, which formed large populations, were identified in the following lakes: Łebsko, Gardno, Jamno, Kopań, Sarbsko and Bukowo. The presence of brackish water in the examined ecosystems resulted in a low total number of species and high numbers of individuals within a species. The highest abundance and percentage share of zooplankton was reported for the halophilous and thermophilous taxon *Keratella cochlearis* f. *tecta*, followed by *Brachionus angularis* and *Filinia longiseta*, which suggests the domination of species typical of eutrophicated lakes. The presence of Rotifera is an indicator of both water eutrophication and a fast rate of organic matter circulation within the detritus food chain.

Changes in zooplankton communities in costal lakes

The aim of the study was to describe long-term changes in the abundance and biomass of zooplankton inhabiting various lakes and ecological zones of the investigated water bodies, as dependent on variable environmental conditions. Taxonomic diversity and biodiversity of zooplankton communities were also determined.

At the first stage of the study, zooplankton samples collected in the Łebsko Lake in the summer during eight consecutive years were analyzed (Paturej et al. 2000). The abundance of zooplankton ranged from 430 to 3 595 individuals·dm⁻³, and it was correlated with temperature. The highest zooplankton abundance was noted during the warmest summer, in 1994, when Rotifera had their optimal growth temperatures. Crustacea, in particular Copepoda, preferred cooler waters. Summertime temperatures promoted the development of thermophilous species, such as *Keratella cochlearis*, *Brachionus angularis*, *Filinia longiseta* and *Trichocerca pusilla*, whose increasing abundance indicated progressive eutrophication. Among 32 zooplankton species identified in the lake, 12 were classified as dominant species and 4 as species of high constancy. Rotifera were responsible for the high abundance and biodiversity of zooplankton (90%). The proportion of Crustacea was low, as they were eaten by fish in vast quantities or exhibited prolonged diapause to avoid predators and competitors.

The zooplankton communities in the Gardno Lake were studied in more detail, to determine their seasonal changes. This lake was selected as the investigation site since the authorities of the Slovinski National Park commissioned a study to estimate the abundance of its food resources, enabling to find the right proportion between the populations of predatory and cyprinid fish, and to adequately protect threatened species. Therefore, the factors affecting zooplankton densities in the ecological zones of the Gardno Lake were determined.

Lake Gardno is a dynamic ecosystem characterized by a high and constant amplitude of physical and chemical gradients (Paturej and Jabłońska 1999, Paturej 2007). Considerable fluctuations in salinity levels, temperatures, wind strength, oxygen saturation, nutrient availability and organic matter circulation affect the spatial distribution of zooplankton. Wind, or more precisely wind-induced wave motion, is an important factor limiting the abundance and species diversity of invertebrates in shallow polymictic water bodies. A high correlation was found between wind speed and temperature (0.9699), as well as between the communities of Cladocera and Rotatoria and physical parameters (0.8846). A weaker correlation was observed with respect to changes in the abundance of Oligochaeta and Copepoda (0.6351). The variability of the analyzed environmental conditions (temperature, wind strength) had a significant effect on zooplankton abundance.

A similar study was conducted on the Vistula Lagoon (Goździejewska et al. 2006), to analyze the effects of environmental factors on the occurrence of Harpacticoida in the zooplankton community and in the food of the smelt (*Osmerus eperlanus* L.). Wind-induced water mixing to the bottom makes the current carry away the surface layer of bottom deposits, including bottom-dwelling organisms, e.g. Harpacticoida, which then fall prey to pelagic fish, such as the smelt. It was found that the presence

of Harpacticoida in deep waters and in fish food was directly proportional to wind strength and inversely proportional to the depth of a sampling site.

The diversity of zooplankton and benthos communities in the ecological zones of lake Gardno was also studied using the faunal similarity index (Paturej and Jabłońska 2001, Paturej and Jabłońska-Barna 2003). Significant similarities were found between the sites representing brackish water habitats and the zooplankton and zoobenthos communities. Zooplankton densities were twofold higher in the saltwater zone of the lake, compared with the freshwater zone. The community was dominated by Rotifera (86%), among which the largest populations were formed by *Keratella cochlearis* f. *tecta*, whose growth is stimulated by salinity fluctuations.

It may be concluded that the taxonomic structure of invertebrate communities colonizing particular ecological zones of lake Gardno is affected by a variety of physical and chemical factors. However, the key factors determining the presence of a given community are freshwater inflows and saltwater intrusions. The dynamics of water masses, dependent on wind-induced wave motion, also plays a significant role in the distribution of invertebrates in shallow coastal water bodies.

The results of a study investigating the Gardno Lake ecosystem, conducted by a team of researchers, were summarized in a monograph by Paturej (2003). It was found that the occurrence of zooplankton, ecological groups and individual species in the annual cycle, as well as their interrelations, were subject to significant seasonal changes. The qualitative and quantitative composition of zooplankton was determined by the same ecological factors as in previous studies of coastal lake ecosystems. The calculated production of zooplankton confirmed high food abundance in the Gardno Lake (five-year average of 3 993 tons). Some taxa typical of eutrophicated water bodies were identified, including *Keratella cochlearis* f. *tecta*, *Brachionus angularis*, *Trichocerca pusilla*, *Chydorus sphaericus*, *Pompholyx sulcata* and *Anuraeopsis fissa* (a pond species). They were present in great abundance, thus suggesting progressive eutrophication which was confirmed by the values of zooplankton-based indices. An assessment of the trophic status of lake Gardno, with zooplankton as bioindicators of eutrophication, revealed a distinct improvement in water quality over the years 1998-2002, compared with the 1985-1989 period (Paturej 2006a).

Shallow and polymictic coastal lakes are prone to degradation resulting from human pressure, which leads to their gradual eutrophication. On the other hand, the process is inhibited by periodic saltwater intrusions (Paturej and Bogacka 2001b). Long-term studies on coastal lakes in the South Baltic area provided a basis for a thorough analysis of zooplankton communities, taking into account environmental factors. With a few exceptions (Paturej 2001), the ecosystems of these lakes have not been investigated in detail to date. Data on planktonic organisms and their ecology in Polish coastal water bodies are scant. The results of long-term field investigations and laboratory examinations were presented in a postdoctoral dissertation entitled "Zooplankton of coastal lakes of Baltic sea-shore" (Paturej 2005b).

The obtained results show that although the analyzed lakes share certain similarities, each of them is a highly individualized ecosystem. These lakes differ with regard to water circulation dynamics, water chemical composition, the intensity of saltwater

intrusions and freshwater inflows, and water mass temperatures. The hydrological and hydrochemical differences among coastal lakes were manifested in substantial differences in the abundance and biomass of zooplankton ($233\text{--}3\,354$ individuals $\cdot\text{dm}^{-3}$, $1.23\text{--}24.8$ mg $\cdot\text{dm}^{-3}$). Zooplankton communities, although abundant, were characterized by low species diversity (9 to 36 species). Smaller differences were found in respect of the taxonomic structure of zooplankton, but the same species formed populations of various abundance in different water bodies. The spatial distribution of zooplankton in estuaries depended on the interactions between sea water and fluvial water, and on wind-induced wave motion. Both the abundance and biomass of zooplankton were considerably higher in the middle part of lakes (lake Łebsko) and in the littoral zone (lake Gardno, lake Jamno) than at the inflow of rivers to the analyzed water bodies. Cyclical changes in the growth rate of zooplankton were determined by seasonal variations in environmental conditions. Greater abundance and biomass of zooplankton were observed in the spring and summer, in comparison with the autumn and winter. Comparable densities of zooplankton were noted in lake Łebsko and lake Jamno ($969\text{--}767$ individuals $\cdot\text{dm}^{-3}$ and $958\text{--}754$ individuals $\cdot\text{dm}^{-3}$ respectively), while slightly lower values were recorded in the Gardno Lake ($688\text{--}835$ individuals $\cdot\text{dm}^{-3}$). Zooplankton biomass in lake Jamno was over fourfold higher than in the remaining lakes. Most probably, these differences resulted not only from thermal conditions and saltwater intrusions, but also from aerobic and trophic conditions, and biocenotic relations. The values of zooplankton-based indices provided information on the trophic status of the investigated estuaries. The highest eutrophication level was reported in the Jamno Lake, followed by the Gardno Lake and the Łebsko Lake.

The results of long-term studies investigating zooplankton communities in 13 coastal lakes, presented here for the first time, may provide valuable information on the structure, densities and biomass of zooplankton as an important link in the food chain and an essential component of the basic foodstuffs of fish. In addition, the above studies allowed to determine the degree of biocenotic diversity in estuaries and to describe long-term changes in zooplankton communities. Estuaries, which today are exposed to increasing anthropopressure, perform a very important role as natural filters for a variety of chemical compounds contained in flowing water. They act as both physical and biological “trophic traps, and form an effective buffer zone that prevents the penetration of toxic biological substances and organic pollutants into the sea” (Paturej 2006b, Paturej 2008).

CONCLUSIONS

Studies of coastal lakes continue to provide valuable information that may be used in various branches of knowledge and research areas. The results of such investigations contribute to a better understanding of the biological structures and functions of biocenoses and help estimate their productivity, as well as support the modeling of the above aquatic ecosystems.

Zooplankton species are important components of the trophic and functional struc-

tures of the biocenoses in estuarine lakes. They play an active role in these ecosystems, particularly in the process of organic matter transformation and energy flow. Zooplankton can be also used as bioindicators of the existing physical and chemical conditions in a given environment. As biotic indicators of thermal properties, salinity and oxygen saturation, zooplankton enable to determine biocenotic changes in coastal lakes, where the functioning of zoocenoses is disturbed by environmental factors of a different range (intrusion of marine waters, inflow of fluvial waters, climate changes).

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ZOOPLANKTONOWE BADANIA JEZIOR PRZYMORSKICH

Streszczenie

Pobrzeża Bałtyku obfitują w liczne zbiorniki słonawowodne o charakterze estuariów. Należą do nich mniejsze lub większe jeziora: Sarbsko, Łebsko, Gardno, Wicko, Kopań, Bukowo, Jamno, Resko Przymorskie, Liwia Łuża, Koprowo i Wicko Wielkie. Mimo niejednokrotnie podobnej genezy i typu geomorfologicznego, jeziora te charakteryzują się bardzo różnym układem stosunków hydrologicznych i hydrochemicznych, ukształtowanych w wyniku przewagi czynnika lądowego lub morskiego. Geneza jezior przymorskich i akwenów transgranicznych na polskim wybrzeżu jest ściśle związana z historią Morza Bałtyckiego i zlodowaceniem skandynawskim. Przybałtyckie wody słonawe zostały zasiedlone zarówno przez organizmy pochodzenia morskiego, jak i słodkowodnego.