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A Review of Biological Research in the Vistula Lagoon

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Abstract

The Vistula Lagoon, a brackish water body that offers unique living conditions to aquatic organisms, is an interesting object of hydrobiological investigations. This paper presents a review of biological research conducted on the Vistula Lagoon, from simple floristic and faunistic analyses to satellite-based comprehensive environmental analyses. Changes that occurred in the studied aquatic ecosystem due to human pressure over the last century are discussed. Innovative research technologies determined what measures should be taken to preserve the unique biocenoses in the Vistula Lagoon.

INTRODUCTION

In terms of Poland's physical and geographic regions (Kondracki 2002), the Vistula Lagoon is situated in the South Baltic Coastland, in the macroregion of the Gdańsk Coastland, and in the mesoregion of the Vistula Spit (Kondracki 2002). This brackish water body is a lagoon on the Baltic Sea, separated from the Gdańsk Bay by the Vistula Spit. The Strait of Baltiysk connects it to Gdańsk Bay. Poland and Russia share the Vistula Lagoon (Kaliningrad Oblast). In Poland, it is located east of the mouth of the Vistula River flowing into the Gdańsk Bay, whereas in Russia it stretches beyond the city of Kaliningrad. With respect to its biological and hydrographic conditions, the Polish part of the Vistula Lagoon is divided into two regions: a region close to the river mouth and a central region. The area near the river mouth comprises the south-western part of the lagoon dominated by fresh water (Western Basin), whereas the central region encompasses the north-eastern part of the water body dominated by saline water, referred to as the Vistula Lagoon proper (Central Basin).

The catchment basin of the Vistula Lagoon has a total surface area of 23.870 km², whereas the Lagoon covers 838 km², including 328 km² in the Polish part. The total length of the Vistula Lagoon is 85 km, 35.1 km of which are in Poland, and its width ranges from 8 to 10 km. On the Polish side, the Lagoon has an average depth of 2.4 m and a maximum depth of 5.1 m (Kondracki 2002).

Brackish waters differ from marine and inland waters in terms of salinity levels and hydrological and ecological conditions, which is why they continue to arouse interest among researchers. The mixing of saline water from the Baltic Sea with freshwater inflows from rivers that feed into the lagoon leads to salinity and temperature changes, which affect the

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biotic and abiotic components in the water body. The biological and ecological specificity of brackish waters results from their hydrological distinctness. Brackish waters provide habitat for a lower number of species than marine and fresh waters. Remane (1934) and Remane, Schlieper (1971) identified a species minimum in the Baltic Sea at 5 – 8 PSU salinity. The number of species increased both below and above this range. In the Vistula Lagoon, average salinity ranges from 0.5 PSU at the mouth of the Nogat River to around 7 PSU near the Strait of Baltiysk. The coastal brackish water bodies, including the Vistula Lagoon, have been colonized by marine and freshwater organisms, such as freshwater and seawater euryhaline species, whereas typical brackish water species remain relatively rare (Paturej 2005).

The origins of biological research in the Vistula Lagoon

The first biological reports regarding the Vistula Lagoon date back to the early 1800s. According to Majewski, Prokofiewa (1975), faunistic studies of the area were conducted in 1828 by Kleeberg, who described four bivalve species in an extensive dissertation. In the late 1800s, Schoedler (1866), Zaddach (1878), Mendthal (1889), and Seligo (1895) launched successive research projects (after Majewski, Prokofiewa 1975).

In-depth biological investigations carried out in 1911 – 1917 by Vanhöffen (1917) compiled a list of zooplankton species in the Vistula Lagoon. In the early 1900s the hydrological conditions of the Vistula Lagoon changed considerably due to flow regulation in the Lower Vistula system (1916 – cutting off the Nogat River), and the process of widening and deepening the Strait of Baltyisk (1923). The freshwater Vistula Lagoon system became subject to salt water intrusion leading to increased salinity. The inflow of seawater through the Strait of Baltiysk caused more environmental changes in the Vistula Lagoon than the inflow of fresh water. Salinity levels were highest in the Baltiysk region (10 PSU), and they decreased with increasing distance from the Strait (towards the Vistula deltas), and east towards the mouth of the Pregola River. The following rivers fed into the Vistula Lagoon: Pregola (44%), Nogat (17%), Pasłęka (14%) and Elbląg (6%). Willer (1925) and Seligo (1926) initiated much-needed new hydrological and biological studies.

Studies conducted in the 1950s and 1960s

Polish researchers started their investigations in 1950, and their results were presented in numerous valuable floristic and faunistic reports. Phytoplankton studies conducted by Szarejko-Łukaszewicz (1957) showed the domination of Cyanobacteria over diatoms in phytoplankton communities. The communities of aquatic vegetation were described in detail by Szarejko (1955), who distinguished several floristic regions in the Vistula Lagoon. Biernacka (1956) pioneered investigations into the protozoa of the Vistula Lagoon. Fragmentary data on the abundance of zooplankton (Cladocera and Rotifera) were collected by Gieysztor et al. (1958), who found that Rotifera were the predominant group. Benthic organisms living at the bottom of the Vistula Lagoon were also characterized in the 1950s. Żmudziński (1957) studied zoobenthos in the Polish part of the water body, and reported a high number of species typical of brackish waters, such as *Balanus improvisus*, *Jaera marina*, *Gammarus zaddachi*, and *Crangon crangon*. The most abundant benthic fauna was noted in the central regions of the Vistula Lagoon, with a muddy bottom. Klimowicz (1958) focused on mollusks in the Polish section of the Lagoon. The author distinguished four areas of mollusks (from the mouth of the Vistula River to the Polish-Russian border) based on their sensitivity to salinity, and demonstrated that freshwater bivalves are more sensitive to salinity than gastropods, and therefore the former disappear first with an increase in salinity. Filuk (1955, 1957, 1961, 1963, 1964, 1965), and Filuk & Żmudziński (1966) carried out observations of the ichthyofauna in the Vistula Lagoon, and reported that freshwater species (pikeperch, common bream, common roach, and European eel) were of greatest significance, while marine species were not abundant.

The works of Wiktor J., Wiktor K. (1959), Różańska (1962, 1963, 1964, 1967) and Wiktor (1967) paved the way for further research into the species composition and distribution patterns of zooplankton communities in the Vistula Lagoon. According to Różańska (1962), Rotifera accounted for 80% of total zooplankton, with *Keratella cochlearis* as the predominant species. The author divided the Polish part of the Lagoon into α-oligohaline and β-oligohaline zones. Another extensive monograph, entitled "Hydro-meteorological Conditions of the Vistula Lagoon" (1975), was the result of seven years (1958-1965) of Polish-Russian research in the fields of hydrology, meteorology, geomorphology, and

geology.

Studies conducted in the 1970s

After a several-year break, intensive studies (1974-1978) were undertaken to determine changes in the hydrological and biological structure of the Vistula Lagoon ecosystem. The studies were commissioned by the "Man and the Environment" Committee of the Polish Academy of Sciences, within the framework of Key Problem 09.1.7. The biocenotic components of the Vistula Lagoon that had been previously investigated, including phytoplankton, zooplankton, benthic fauna, and vascular plants, were analyzed first. The studies provided new, important information regarding chlorophyll concentrations in water (Latała 1978), petroleum hydrocarbon concentrations and the abundance of saprophytic bacteria (Maciejowska, Macur 1978), the rate of primary production (Niedoszytko, Wiktor 1978), the abundance and biomass of phytoplankton and directions of their changes (Pliński, Simm 1978, Pliński 1979), and the dynamics and abundance of zooplankton (Adamkiewicz-Chojnacka 1978).

Physicochemical properties of the water were also thoroughly analyzed (Różańska, Więcławski 1978, 1981; Różańska 1984), and samples were collected from the same sites as biological samples, which supported a reliable interpretation of the observed interactions.

Large-scale investigations revealed the acceleration of the eutrophication process in the Vistula Lagoon, as manifested by a dramatic increase in biogenic element accumulation and a high organic matter content (Różańska, Więcławski 1978, 1981; Różańska 1984). Hydrochemical changes were noted in the biocenoses of the studied water body. The species composition of zoocenoses was limited, and the number of both freshwater and marine species decreased. The elimination of rare species was followed by the domination of leading taxa. A distinguishing feature of phytoplankton were summer blooms of Cyanobacteria and the domination of Cyanobacteria over diatoms – the trend was stronger than in 1953 (Pliński, Simm 1978). Chlorophyll concentrations in water (Latała 1978) and the rate of primary production (Niedoszytko, Wiktor 1978) were characteristic of highly eutrophicated water bodies. Particularly high levels of primary and secondary production were observed in the littoral zone. Research results showed that environmental conditions varied widely across the Vistula Lagoon. The distinct southwestern section was characterized by the lowest salinity levels, an abundance of phosphorus and nitrogen salts, and periodically the highest counts of saprophytic bacteria (Maciejowska, Macur 1978). This is where freshwater zooplankton species and euryhaline seawater species ended their range. Therefore, despite the richness of zooplankton species able to tolerate low salinities, many of the taxa were rare or sporadic, and they did not form large populations (Adamkiewicz-Chojnacka 1978; Adamkiewicz-Chojnacka, Majerski 1980). A survey of vascular plants pointed to a decrease in the surface area of underwater meadows, accompanied by reed expansion (Pliński et al. 1978). The species composition of dominant zoobenthos communities did not change, and Oligochaeta continued to be the most abundant group of invertebrates, suggesting the environmental effect of pollutants (Cywińska, Różańska 1978). Some of the species recorded previously by Żmudziński (1957), such as *Aselus aquaticus*, *Jaera marina*, *Corophium volutator* and *C. lacustris*, were not reported in the cited study. Further investigations into the local ichthyofauna were carried out by Filuk (1973, 1974), who discussed the results of stocking the Vistula Lagoon with imported eels, which enabled an increase in the catch rates in the Polish part of the water body.

Studies conducted from the late 1970s to the present

No biological analyses of bacteria, phytoplankton, vegetation, zoobenthos, and fish have been performed in the Vistula Lagoon from the end of the 1970s to today. Only a few publications appeared during that period in Poland, while many reports on zooplankton were published. Adamkiewicz-Chojnacka has made significant contributions to this field. Since 1978 she has authored and co-authored many papers on the dynamics and abundance of zooplankton (Adamkiewicz-Chojnacka 1978; Adamkiewicz-Chojnacka, Majerski 1980) and the spatial distribution of zooplankton communities in response to environmental factors (Adamkiewicz-Chojnacka et al. 1985a; Adamkiewicz-Chojnacka, Radwan 1989). The role of zooplankton species as bioindicators in the brackish water ecosystem of the Vistula Lagoon has also been stressed (Adamkiewicz-Chojnacka 1983a; Adamkiewicz-Chojnacka, Heerkloss 1995). The effects of eutrophication and pollution on zooplankton taxa, abundance, and

biomass were studied (Adamkiewicz-Chojnacka, Leśniak 1985; Adamkiewicz-Chojnacka et al. 1985b; Adamkiewicz-Chojnacka, Fait 1987; Adamkiewicz-Chojnacka, Różańska 1990; Heerkloss et al. 1991; Adamkiewicz-Chojnacka, Heerkloss 1995). Some publications addressed the spatial distribution and changes in the abundance of selected species, such as *Eurytemora affinis* (Różańska, Adamkiewicz-Chojnacka 1988), and taxa of the genera Brachionus (Różańska et al. 1985a, 1985b) and Euchlanis (Adamkiewicz-Chojnacka 1988). In addition, Adamkiewicz-Chojnacka examined trends in zooplankton aggregation (Adamkiewicz-Chojnacka 1983b, Adamkiewicz-Chojnacka, Mrozowska 1983, 1984), and compared the effectiveness of sampling devices in zooplankton studies (Adamkiewicz-Chojnacka, Różańska 1985).

Grawiński et al. (1998) focused on bacterial communities in water and bottom deposits in the Vistula Lagoon. They analyzed infectious agents in the Lagoon, including pathogenic bacteria harmful to fish and humans, and viruses posing a risk to human health.

Phytoplankton were analyzed in a broader context, with special emphasis on Cyanobacteria responsible for massive toxic water blooms (Rybicka 2005). Several potentially toxic species were recorded, including *Anabaena flos-aquae*, *Anabaena spiroides, Anabaena lemmermannii, Anabaena mendotae, Anabaena* cf. *circinalis, Anabaena crassa, Aphanizomenon sp.*, *Microcystis botrys, Microcystis wesenbergii*, and *Nodularia spumigena,* whose occurrence could pose a serious problem in the future, due to the specific environmental conditions in the Vistula Lagoon and global warming. Mazur-Marzec et al. (2010) determined the morphological, chemical, genetic, and physiological characteristics of two *Microcystis aeruginosa* strains isolated in the Lagoon. The obtained results validated the suitability of selected morphological traits for estimating the potential toxicity of *Microcystis aeruginosa* blooms.

Phytoplankton communities have also been studied in the Russian part of the Vistula Lagoon. Semenova, Smyslov (2009) noted modifications of phytoplankton community structure resulting from adverse changes in the Lagoon ecosystem. The effect of environmental factors on primary production in the Vistula Lagoon was also determined (Renk et al. 2001). Phytoplankton, vegetation, and primary production were discussed by Pliński (2005) as part of the hydrobiological characteristics of the Vistula Lagoon.

Considerable changes were observed in zoobenthos communities in the Vistula Lagoon, mostly due to human pressure. Many once-common species of benthic invertebrates, including four leech species, 21 mollusk species, and two crustacean species, disappeared or were found within a reduced area of their former ranges. Several new, alien species appeared, such as *Marenzelleria viridis, Potamopyrgus antipodarum*, *Gammarus tigrinus*, and *Rhithropanopeus harrisii*, which exerted a profound effect on habitat conditions in the Vistula Lagoon (Ezhova et al. 2005). Kocheshkova & Matviy (2009) also studied new zoobenthos species in the Lagoon. The authors focused on two polychaete species, *Streblospio benedicti* and *Manayunkia aestuarina*, which were discovered in the Vistula Lagoon in the 1990s, and analyzed how their spatial distribution was affected by salinity and necrozooplankton concentrations.

Numerous papers on ichthyofaunal communities in the Vistula Lagoon have been published since the mid-1990s. These papers discussed fish species present in the Lagoon (Stolarski 1995), their growth rate (Fey 2001, Trella 2003), spawning (Krasovskaya 2002), fry development (Maciejewska et al. 2004), production effectiveness (Psuty, Draganik 2008), and fish culture (Psuty, Borowski 1997; Draganik et al. 2004; Psuty-Lipska, Draganik 2005; Bzoma et al. 2008; Wilkońska, Psuty 2008). The impact of environmental factors on fish was also researched (Goździejewska et al. 2006; Psuty, Wilkońska 2009).

Another problem addressed by researchers during the 1990s and early 2000s was the invasion of alien species, which significantly affected the qualitative and quantitative structure of hydrobionts. The first reports, published in the mid-1990s, were devoted to zoobenthos. The North American polychaete *Marenzelleria viridis,* which dominated the zoobenthos biomass in the sandy and muddy habitats of the Vistula Lagoon, has been investigated in detail to date (Żmudziński 1996; Olenin, Leppäkoski 1999). A preliminary analysis of the morphometric parameters of the North American crayfish *Orconectes limosus* was performed (Szaniawska et al. 2005), and alien *Gammarus* species were studied (Grabowski et al. 2006). Alien zooplankton species have not been extensively researched. A few papers on the invasive cladoceran species *Cercopagis pengoi* were published in the late 1990s (Hornatkiewicz-Żbik 1999, Polunina 2005). New alien fish species have also been discovered, including the invasive Ponto-Caspian round goby *Neogobius melanostomus*, whose juvenile forms appeared for the first time in July 2004, near

the northern coast of the Sambia Peninsula. Due to its specific development cycle, the species could relatively easily form stable populations in the Vistula Lagoon. The invasion of *Neogobius melanostomus* led to a decrease in the abundance of the local viviparous eelpout *Zoarces viviparous* (Karasiova, Naumenko 2005).

A comprehensive hydrobiological study of the Vistula Lagoon was conducted within the framework of the INTERREG IIIA/TACIS Lithuania, Poland, and Kaliningrad Region of the Russian Federation Neighbourhood Programme (2006 – 2007), as part of the MONTRANSAT research project "The use of satellite remote sensing for water quality monitoring in the Vistula Lagoon", and the VISLA research project 'System of the environmental and spatial information as the background for the sustainable management of the Vistula Lagoon ecosystem", financed by the Polish-Norwegian Research Fund (2008 - 2011).

Under the INTERREG program, water quality parameters in the Vistula Lagoon were determined based on physical, chemical, and hydrobiological measurements and satellite monitoring data. It was found that water quality assessed based on the values of the Trophic Status Index (TSI) (Carlson 1977), oscillated between eutrophy and hypertrophy. Water transparency did not exceed 1m on average. High total phosphorus concentrations were noted, and phytoplankton biocenoses were dominated by Cyanobacteria of the genera *Microcystis*, *Aphanocapsa*, *Woronichinia*, *Anabaena*, *Gloeocapsa*, *Aphanothece*, *Gomphosphaeria*, and *Merismopedia*. Bacillariophyceae and Chlorophyta were also recorded, but their abundance was low (Kruk et al. 2008). In zooplankton communities, a higher number of species were reported from the saltwater intrusion section of the Vistula Lagoon (Central Basin) than from the area of freshwater inflow (Western Basin). The average density of the analyzed zooplankton in the western part of the Vistula Lagoon reached 654 indiv. dm^{-3}, three-fold higher than in the central part (224 indiv. dm^{-3}). Differences in zooplankton biomass were even more pronounced (13.43 mg dm^{-3} vs. 2.33 mg dm^{-3}). Copepoda, mostly of the genus Acartia, dominated the Central Basin of the Vistula Lagoon. Cladocera, mainly *Chydorus sphaericus,* predominated in the Western Basin. The significant differences in zooplankton biomass and abundance resulted not only from salinity and temperature conditions, but also from dissolved oxygen concentrations, the trophic state of the investigated water body, and the existing biocenotic relationships (Paturej, Kruk 2011).

Water quality monitoring initiated under the MONTRANSAT program continued within the framework of the VISLA research project. Water quality was assessed based on satellite data (MERIS) and *in situ* analyses. The following parameters were determined: concentrations of chlorophyll *a*, total suspended solids, and colored dissolved organic matter (CDOM) expressed as dissolved organic carbon (DOC). A preliminary analysis of data showed that periodic changes in the above parameters could result from the combined effect of phytoplankton seasonal dynamics, including water blooms, irregular wind-induced water mixing, and hydrodynamic factors. However, the suitability of MERIS data for water quality monitoring in shallow, highly eutrophic, brackish estuarine water bodies, such as the Vistula lagoon, is limited due to very high values of the studied parameters and their interrelations (Kruk et al. 2010).

The obtained results will provide a basis for developing a mathematical model for the prediction of environmental effects of human interference into the spatial system of the Vistula Lagoon, as well as long-term scenarios of climate change. The model will be developed using satellite remote sensing and data provided by the Global Environment Monitoring System (GEMS) Water Programme (Kosakowski et al. 2010).

SUMMARY AND CONCLUSIONS

The Vistula Lagoon is a unique ecosystem that has been attracting the interest of researchers for years. The water body has been thoroughly studied since the late 1800s. Simple floristic and faunistic analyses were followed by in-depth investigations into biocenoses and environmental relationships, and water quality parameters were determined with the use of modern technologies. Many adverse changes were documented in the Vistula Lagoon over that period. Water quality deteriorated considerably. Between 1950 and the late 1990s, the Lagoon was transformed from a naturally nutrient-rich water body to a highly eutrophicated water body, which reduced the biodiversity of several groups of organisms (Andrulewicz 1997). Many native species disappeared or their ranges diminished, and several invasive alien species were discovered.

Today all available measures are used (including marine research, satellite remote sensing, and

mathematical modeling) to regularly and accurately monitor the Vistula Lagoon ecosystem and to provide adequate environmental safety control in the area.

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