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# THE HISTORY OF COASTAL LAKES STUDIES WITH A SPECIAL REGARD TO LAKE GARDNO

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The South Coast of the Baltic Sea abounds with coastal reservoirs like: the Szczecin Lagoon, the Vistula Lagoon, the Kuroński Lagoon, the Puck Bay (the inner part) and some smaller or bigger lakes of the area of several hectares or from ten to twenty $km^2$ – Lake Łebsko, Lake Gardno, the Dołgie Wielkie Lake, the Dołgie Małe Lake (located on the area of the Słowiński National Park) and Lake Jamno, Lake Sarbsko, Lake Resko, Lake Wicko, the Liwia Duża Lake – situated outside the Park.

The studies of brackish waters were avoided for a long time as they were difficult to define due to the differences in the salinity level. On the beginning, brackish waters were understood as waters of a medium salt content regardless of their origin and character (marine waters, river waters-near outlets, lakes or small, coastal reservoirs).

The Dutch investigator Redeke, on the ground of his research of fauna of Zuidarsee, was first who made an attempt to make it clear in 1922. Consequently, he suggested the classification of waters on salinity zones According to him, brackish waters were regarded as diluted marine waters of chloride ions concentration from 0.1‰ to 17‰ The established categories as follows: oligohaline, mesohaline and polyhaline waters (Sander 1953).

The classification of Redeke was improved by Velikanges on the ground of his research in 1933. As a consequence, the above classification became more clear and accurate.

Ekman and Remane also made an attempt to classify different types of waters. Remane suggested that the classification of fresh and saline waters should be broaden by including waters of a salinity higher than the mean oceanic one (hyperhaline waters). The final, current division into classes according to the salinity level was established during the symposium in Venice in 1958. Accordingly, brackish waters have been regarded as the mixture of fresh and saline water of the salinity lower than 30‰ (excluding inland reservoirs of a high content of salt). The zone above has been called „mixooligohaline" (Mańkowski 1972).

Therefore coastal lakes as well as lagoons should be regarded as mixooligohaline zone (salinity level from ±0.5 to ±5‰).

Among the lakes studied by Szmidt (1972), the highest salinity was recorded in Lake Łebsko (5.7‰) and the lowest in Lake Gardno (1.18‰). Brackish-water reservoirs are regarded as estuaries due to their connection with the Baltic Sea and constant supply of fresh water from a surface flow.

Until quite lately, the estuary used to be defined as a funnel-shaped river outlet widening affected by strong tidal currents preventing river rock-debris from accumulating. However, the definition of estuary has been recently improved and modified. The most often quoted one was supplied by Schubela and Pritchard (1971, according to Mudryk 1994). According to them, an estuary has been understood as semi-closed part of coastal waters, connected with the open sea, where marine water is diluted by fresh water surface flow. Genesis of estuaries is closely related to the history of the Baltic Sea and the last glaciation. The litorina transgression of the Baltic Sea had the principal impact on the present shoreline layout. While some lakes originated from the separation of bays from the sea by sand bars, e.g. Lake Jamno, others were created as a result of frontal moraines depression: the Gardno and Łebsko Lakes (Rosa 1968, Szmidt 1972).

However, the origin of the remaining Baltic coastal lakes is not homogenous. The Żarnowieckie Lake is a typical ribbon lake, Lake Sarbsko is a lagoon whereas Lake Bukowo is a dam reservoir which genesis is a result of the Baltic Sea transgression (Wypych 1965, according to Soszka 198).

All brackish-water lakes differ from marine and fresh waters in hydrology and ecology. What is typical for that lakes is a low mean depth, a low index of a ratio of lake volume to the length of a shoreline , a lack of thermal and oxygen stratification, two-layer vertical layout of water mass as a result of depth differentiation and temporary oxygen depletions sometimes followed by sulphur hydrogen occurrence.

In addition, the lakes above have a complicated water exchange system due to marine- water inflow, the impact of fresh-water surface flow and the influence of rivers, cannals and drainage ditches systems.

Brackish waters, alike sea and fresh water environments, are populated by a limited number of species. Thus that water regions are recognized as a natural selection areas for both fresh -water and marine fauna and flora.

Obviously, water conditions of coastal lakes are strongly affected by different climatic factors: air temperature, precipitation and evaporation.

Up to 1967, the research status of coastal lakes was not impressive. Few, hardly available German papers were the only source of knowledge. The increase of economic and scientific interest generated the need for detailed investigations to explain events and processes running on the verge of marine and continental regimes (Szmidt 1967).

Up to the present, a great deal of research effort has been placed on the biggest lakes: Łebsko, Gardno and Jamno, where investigators worked in the field of bacteriology (Mudryk 1993, 1994), plankton studies (Patalas 1954, Guttowa 1956, Strzelecki and Półtorak 1971, Żmudziński et all 1990, 1992, Paturej 1993, 1999, Paturej and jabłońska 1999, 2001, Paturej et all. 2000), bottom fauna studies (Sandner 1953,

Soszka 1968, Malej 1974, Hajduk et all. 1978, Dyduch and Falniowski 1979, Zmudziński et all. 1992, Dobrowolski 1996, Jabłońska and Paturej 2000); ichtyology (Romański 1972, Ciepielewski 1992, Janta 1997); hydrobiology (Szmidt 1967, 1972, Januszkiewicz and Michalski 1970, Mikulski 1970, Majewski 1972, Balicki 1981, Trojanowski et all. 1990, Cyberski and Jędrasik 1992) and bottom sediments studies (Trojanowski 1991, Trojanowska and Trojanowski 1992, Trojanowska et all. 1993).

The history of research of Lake Gardno has begun in 1618 (1614) when Elihardt Libin presented the map of the shoreline of the reservoir. The verification of changes, from that period up to the present, revealed that the shoreline used to be more complicated, the region of outlet was wider and the amount of small islands situated on the lake was higher.

The area of the reservoir has been remarkably changed during the last centuries. An elongated bay situated in the north-eastern part of the reservoir was separated from it as a result of eolian processes and as a consequence the Dołgie Wielkie and Dołgie Małe Lake appeared (Balicki 1981).

In thirties, many scientists (e.g. Demel 1937, Lucks 1937 according to Hajduk 1978) carried out research on the zooplankton of brackish waters. After the second World War, besides the observations made by the State Hydrology and Meteorology Institute (PIHM), few physical and chemical investigations were carried out by the Department of Water Protection against Pollutants of Water Economy Institute in Gdańsk. However, brackish waters were poorly studied considering their ecology. Sandner (1953) and Patalas (1954) were those who first made that attempt. Sandner concentrated on two lakes connected with the Baltic Sea – Lake Sarbsko and Lake Łebsko. The aim of his study was to determine the fauna of leeches populating both lakes and their distribution affected by different ecological factors (e.g. the salinity level). Whereas Patalas concentrated on the community of pelagic crustaceans of the Pomeranian lakes.

Further investigations of coastal lakes were carried out by Guttowa (1956) who focused on zooplankton and the influence of salt concentration on quantitative and qualitative changes of Cladocera and Copepoda communities. Furthermore, a striking scantiness of species number in the studied reservoirs in comparison with fresh-water lakes, e.g. Lake Wigry, was recorded.

Hitherto existing data were also broadened in field of hydrology. In sixties, the volume on water exchange system between Lake Łebsko and the sea was published by Water-engineering Institute of PAS. Then Szmidt (1967) made an attempt to describe water exchange system of the coastal lakes. On the beginning, he concentrated on Lake Jamno and then on two remaining reservoirs as comparable ones.

Mikulski (1970) and Balicki (1981) were also interested in water-mass dynamics of coastal lakes. As a result, the scientific dissertation of Mikulski was published in 1970. It summarized his investigations on the calculation of the amount of river inflow to the Baltic Sea as well as its impact on hydrological relations in the coastal zone.

Whereas Balicki (1981) concentrated on the analysis of water exchange between the Baltic Sea and Lake Gardno to describe the frequency and duration of Baltic water inflows.

The method he provided to calculate the amount of marine waters inflowing to lakes during a storm period on the Baltic Sea can be used in detailed evaluation of water balance of coastal lakes.

Not only were ecology and hydrology of brackish waters studied but also their paleoecology. Soszka (1968) made an attempt to reconstruct a history of Lake Łebsko of the last four thousand years. The published paper provided the essential knowledge of estuary lakes genesis. According to the author, both, Lake Gardno and Lake Łebsko are parts of the former postglacial reservoirs separated from the sea by moving sand barriers; or reservoirs originated during natural depression filling due to the increase of ground waters level. The above theory was questioned by Hurtwig (according to Rosy 1968) who claimed that some coastal reservoirs might have a different genesis. However, the former theory was proved by the analysis of the faunal composition of pebbles. It revealed that there was a fresh-water postglacial lake on the area of the Gardzieńsko-Łebska Lowland during the boreal period. In addition, the pebbles contained the marine fauna species what proved that during the atlantic period the sea covered an area of the boreal lake and introduced contemporary marine fauna species (Soszka 1968).

The obtained data base concentrated on general characteristics of coastal lakes rather than Lake Gardno. It was poorly investigated until Strzelecki and Półtorak (1971) began detailed biocenotic and hydrologic analysis of Lake Gardno. Then the species composition of the summer zooplankton was studied with a special regard to the influence of the sea on the organisms. The authors made an attempt to relate their studies with the previous one made by Guttowa (1956) and Sandner (1953). The analysis of the algal and animal composition revealed an eutrophic character of the reservoir.

Whereas the research on ecology of parasitic copepods (Grabda 1972) and qualitative and quantitative composition of ichtyofauna (Romański 1972) were carried out from 1960 to 1970.

Further studies of the lakes of the Słowiński National Park concentrated on the fauna of ostracods (Sywula 1974 according to Dyduch and Falniowski 1979) and leeches (Hajduk et all. 1978). The observations showed that the chloride ions concentration - up to 2.5‰ – inhibited the development and eliminated oligohaline species from the environment. Since the slalinity of Lake Gardno is much lower, the species diversity is not high. The increase of the salinity negatively affectes reproduction, development and expansion of particular species.

The benthic fauna, with a special regard to molluscs, were studied in July 1975. The surveys were extended over other lakes: the Dołgie Wielkie Lake, the Dolgie Małe Lake and the Łupawa River. It was recorded that in lakes molluscs avoided muddy sediments and tend to cluster around plants.

The studies of water ecosystems, where transport and sediments accumulation continues, plays undisputed role in investigations of sediments transformation in the basin of a lake.

A series of surveys on benthic fauna populating rivers outlets and cannals (connecting coastal lakes with the sea) have been begun by Janta (1997).

Whereas chemistry of bottom sediments of coastal lakes were reported by Trojanowska (1991), Trojanowska and Trojanowski (1992) and Trojanowska et all. (1993). The work was carried out on Lake Łebsko, Lake Gardno and Lake Sarbsko. What was found was that the lakes were subject to degradation as inflowing rivers brought a great deal of pollutants. The chemical composition of bottom sediments was remarkably affected by periodical supply of marine waters. Marine waters diluted fresh water of lakes and generated the release of many chemical compounds from bottom sediments including biogenic one. In a consequence, the concentration of chemical compounds in bottom sediments was much lower than it might be expected from the size of pollutants load inflowing into the lake with the Łupawa River or other tributaries.

A great deal of research effort has also been placed on obtaining data on water exchange system in lake Gradno. As a result, the mechanisms of water circulation, transformation and unification during the circulation were revealed. However, the problem seems to be more complicated due to the localization of lakes near outlet to the sea (Cyberski and Jędrasik 1992).

During the last years, a steady increase of anthropogenic pollutants input was recorded in estuaries and coastal area of the sea. As a result, an attempt was made to assess sanitation and bacteriological conditions of coastal lakes, including Lake Gardno (Mudryk 1993). The author analyzed multiannual changes of the heterotrophic bacteria abundance populating different ecological zones of the studied lakes concerning their genus composition, physiological and metabolic activity. The research suggested the potential role and the significance of those organisms in degradation and organic matter transformation processes, conservating the homeostasis of the studied lakes (Mudryk 1994).

The series of studies done in years 1986-1989 and 1997-1999 brought the data on the benthic fauna populating Lake Gardno. The determination of the fauna of Chironomidae provided data to calculate the biocenotic index. Accordingly, *Chironomus plumosus, Tanytarsus mancus, Einfeldia carbonana* were reported to show the highest ecological importance among studied group of animals (Dobrowolski 1994, 1996, Paturej and Jabłońska 1999, Jabłońska and Paturej 2000).

Whereas Paturej has made an attempt to determine the systematic compositon of zooplankton. The material for analysis was collected on lakes: Łebsko, Gardno and Jamno from 1986 to 1989. The author concentrated on three zooplankton components: Rotatoria, Cladocera and Copepoda.

The abundance of particular systematic groups as well as dominants and subdominants were determined. Additionally, the data on the mezozooplankton biomass of Lake Gardno where for the first time published.

Complex surveys was also reported which aim was to investigate the impact of abiotic and biotic factors of environment on reservoirs regarding the needs of fishing industry management (Żmudziński et all. 1990, 1992, Paturej et all. 1997).

Further research brought valuable data on the influence of water mass dynamics on the changes of invertebrates number and the similarity of habitats basing on the biocenotic indeces of Jaccard and Renkonen (Paturej and Jabłońska 1999, 2001).

It was concluded, from the multiannual studies of Lake Gardno (1985-1989 and 1993-2000) that rotifers were the main component of zooplankton community (70% of total zooplankton number) while the share of two remaining groups was similar. Simultaneously, the domination of species typical for eutrophicated lakes was recorded (*Keratella cochlearis f. tecta, Brachionus angularis, trichocerca pusilla, Chydorus sphaericus*.).

In addition, a seasonal changes of zooplankton number were reported. Those changes were closely related to the temperature. Zooplankton number was relatively higher in summer than in autumn. The decrease was more evident among crustaceans and copepods – organisms more sensitive to low temperatures.

The salinity level was another factor affecting zooplankton number. The mezozooplankton abundance was remarkably higher at the area subject to a stronger Baltic Sea impact and the lowest in the regions of fresh water influence. A reverse relationship was found considering species number.

The analysis of animals plankton biomass showed a prevailing role of crustaceans while rotifers, due to their small body size, were insignificant. The value of zooplankton production proved high trophy of the reservoir.

Although estuaries has been under a strong anthropopressure lately, they still work as natural filters against different chemical compounds contained in inflowing water. As an effective buffer zone, they hinder toxicants influx into the marine ecosystem. However, estuaries, as receivers of excessive pollutant load, are subject to much faster than inland waters saprophy level increase. The concentration of nutrients often exceeds the level at which they could not all be included in cycling. In a consequence, the surplus of nutrients inhibits the primary production. Furthermore, the nutrient substances easily spread across a shallow, polimictic reservoir and generate a series of typical changes like ichtyofauna and other hydrobionts elimination or the decrease of physical, chemical and biological qualities of water. It irresistably results in a complete economic uselessness of the reservoir due to a low degree of water purity.

To summarize, some precautions should be taken to limit the anthropopressure on estuaries. The precautions, like establishing strict protection over the whole area of Lake Gardno or setting the protective area around the reservoir within which sewage disposal would be prohibited, might help to solve the problem.

Furthermore, the need for systematical, broad-area investigations regarding different groups of hydrobionts seems to be unquestionable.

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