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LAKES IN THE NATURE RESERVES OF THE ZABORSKI LANDSCAPE PARK (NORTHERN POLAND)

Abstract. The aim of the work was to obtain new scientific information about four lakes that are under high legal protection in the form of nature reserves. These are very rare oligotrophic lakes in Poland, located in the Zaborski Landscape Park, which is also the buffer zone of the Bory Tucholskie National Park. These reserves, which belong to the aquatic kind, have unique vegetation. In the context of climate change, and therefore hydrological change, including the development of lake aging processes, data on the characteristics of the physicochemical properties of their basins and the waters within them are necessary. Therefore, bathymetric plans of the lakes and morphometric parameters were developed and selected water features were determined. In addition to the results obtained from field research, the work was enriched with data from the literature.
Key words: lakes, nature reserves, Zaborski Landscape Park, lake morphometry, lakes protection

Блоняж Войцех, Хоїнський Адам, Ільїн Леонід, Маціас Анджей. ОЗЕРА ПРИРОДНИХ ЗАПОВІДНИКІВ ЗАБОРСЬКОГО ЛАНДШАФТНОГО ПАРКУ (ПІВНІЧНА ПОЛЬЩА)
Анотація. Метою роботи було отримання нової наукової інформації про чотири озера, що перебувають під високим рівнем охорони як природні заповідники. Це дуже рідкісні оліготрофні озера в Польщі, роз-

ташовані в Заборському ландшафтному парку, який також є буферною зоною Національного парку Бори Тухольські. Ці заповідники, що належать до водного типу, мають унікальну рослинність. У контексті зміни клімату, отже, і гідрологічних змін, та беручи до уваги розвиток процесів старіння озер, важливими є дані про фізико-хімічні характеристики води та водозборів. Розроблені батиметричні плани озер та визначені морфометричні параметри для окремих водних об'єктів. Окрім результатів, які отримані під час польових досліджень, пропонована праця ґрунтується на аналізі літературних джерел.

Ключові слова: озера, природні заповідники, Заборський ландшафтний парк, морфометрія озер, охорона озер.

Introduction. Before establishing nature reserves, it is necessary to thoroughly research the environment and their immediate surroundings. In the above case, these are nature reserves established to protect lobelia lakes and rare and protected aquatic plants, including water lobelia (*Lobelia dortmanna*), floating water-plantain (*Luronium natans*), and lake quillwort (*Isoetes lacustris*). Of the approximately 7,000 lakes in Poland over 1 ha in size, only about 100 contain the above-mentioned plants. Of course, studies have been carried out on the aquatic environment in which they occur, their range, numbers, etc. However, it seems advisable to define the dynamics of waters, understood as, for example, differences in water level fluctuations, water supply, water balance, etc. This is very important because such findings identify potential threats to protected plants existing at specific depths. This is one of the goals of the following work.

Study area. According to the current physio-geographic regionalisation of Poland [9; 10], the lakes: Długie, Sosnówek and Żabionek are located in the eastern part of the Charzykowska Plain mesoregion (314.67), while the lake Moczadło in the western part of the Bory Tucholskie mesoregion (314.71). Both of the above-mentioned mesoregions belong to the South Pomeranian Lake District macroregion (314.6–7) in the South Baltic Lake District subprovince (314–316) and the Central European Lowland province (31). Both mesoregions are characterized by lowland, fluvioglacial landscapes. All the studied lakes are located on a glaciofluvial plain, within which the lake basins of Żabionek, Moczadło and Sosnówek occupy dead-ice depressions, only Lake Długie is located in a subglacial trough (photos 1–4).

In terms of geological structure, the basins of lakes Żabionek and Sosnówek are located in glaciofluvial sands and gravels, the basin of lake Moczadło – in sands and gravels lying on boulder clay, while most of the basin of Lake Długie is located in the area of glaciofluvial sands and gravels, and only its southern part lies in peat on gyttjas [7]. In the vicinity of the lakes in question, podzolic soils developed from sand and gravel.

Photo 1-A. *Lake Długie – view of the northern shore*

Photo 1-B. *Lake Długie – view of the southern shore*

Photo 2-A. *Sosnówek – view of the northern part of the lake*

Photo 2-B. *Sosnówek – view of the southern part of the lake*

Photo 3-A. *Lake Żabionek – view of its western part*

Photo 3-B. *Lake Żabionek – view of its eastern part*

Photo 4-A. *Moczadło – view of the north-eastern part of the lake*

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Photo 4-B. *Moczadło – view of the western part of the lake*

In terms of natural potential vegetation, according to Matuszkiewicz [6], all the lakes discussed are surrounded by a suboceanic pine forest habitat (*Leucobryo-Pinetum*). In the latest nature and forest regionalization of Poland's according to Zielony and Kliczkowska [11] all the studied lakes are located in the nature and forest land III of Greater Poland-Pomerania in the mesoregion III.1. Bory Tucholskie. The three reservoirs are surrounded by forests with a water-protective function, and only the Moczadło lake is surrounded by reserve forests. A more detailed description of the forests surrounding the analysed lakes is presented in Table 1, and a number of information on monitoring the protection of selected natural habitats in the Natura 2000 "Sandr Brdy" area, where the analysed lakes are located, is included in the work of Ciążyńska and Klimaszyk [4].

The lakes analysed according to the "Atlas of Hydrographic Division of Poland" (2005) are located in the Brda River basin (№ **29** 2). Within the Brda River basin, Lake Długie is in the catchment area of Lake Ostrowite (№ **29** 23161), lakes Sosnówek and Żabionek are in the catchment area of the Tributary from Lake Ostrowite, from Lake Ostrowite to the mouth (№ **29** 23169), and Lake Moczadło is in the Brda river basin from Lake Kosobudno to the separation of the Great Brda Canal (№ **29** 23991).

Table 1

Characteristics of the forests surrounding the analysed lakes

Lake	Forest habitat around the lake	Codominant tree	Age of the codominant tree in the forest stand [years]	Function of the forest stand
Żabionek	– fresh coniferous forest: north-east, east, south-east; – moist mixed coniferous forest: north-west, south-west; – swampy mixed coniferous forest: west.	pine	50–140	water-protection
Sosnówek	– fresh coniferous forest	pine	55–60	water-protection
Moczadło	– fresh coniferous forest	pine	45–135	reserve forest
Jezioro Długie	– fresh coniferous forest: north, north-west, east; – moist mixed coniferous forest: south-west; – swampy mixed coniferous forest – south.	pine	45–90	water-protection

Source: own study based on the Forest Data Bank (https://www.bdl.lasy.gov.pl/portal/mapy)

The analysed lakes are objects with exceptionally small areas, ranging from 4.09 ha (Moczadło) to 6.5 ha (Żabionek). It is worth noting that the average lake area in Poland (determined for 7,081 lakes above 1 ha) is 39.7 ha [3].

All the lakes are drainless, and their basins are located in outwash formations Lakes Sosnówek and Żabionek, in turn, were created as a result of the melting of blocks of dead ice. This is evidenced by their shape and the denivelations in the surrounding terrain. The bowl of Lake Długie is an example of a north-south oriented trough eroded in fluvioglacial formations. The last of the lakes, Moczadło, also has a trough character, but the water fills only the western part of its original range. The axis of the trough runs west-east, which is illustrated by its proximity to the isohypse 130 m above sea level. The earlier larger filling of this trough depression with water may be evidenced by the fact that there are three small kettle lakes (probably former cauldrons) with areas of less than 1 ha.

In addition to the fact that all four studied lakes are protected as nature reserves, they are also located within the Zaborski Landscape Park and two Natura 2 000 areas: "Sandr Brdy" (PLH 220026) and "Wielki Sandr Brdy' (PLB 220001), as well as the buffer zone of the Bory Tucholskie National Park. Before the establishment of nature reserves, these lakes were and still are protected as ecological sites (as they were not deleted from the list of ecological sites of the Pomeranian Voivodeship).

Bathymetry of the studied lakes. Bathymetric measurements of all analysed lakes were made on July 17, 2025 (Photos 5–8). On this day the weather was windless, which, combined with the complete absence of waves, facilitated the measurements. They were made using an echo sounder. Lowrance Elite-3x, and the location of the points was determined by GPS 12, GARMIN Olathe, KS, USA. The results obtained from the echosounder readings were calibrated using a weight probe. Thus, in the case of a "hard", i.e. sandy, bottom, both readings were convergent. In the case of significant hydration of the top layer of bottom sediments, which is affected by the ultrasonic wave, a correction was taken into account for the echosounder readings. The outline of the shores was taken from a topographic map of Poland at a scale of 1:10,000, but was corrected in many places by direct measurement with the above-mentioned device (Fig. 1–4).

Photo. 5. *Transport of equipment for measuring lake bathymetry*

Photo 6. *Preparations for measuring lake bathymetry using the Zodiac pontoon*

Selected morphometric and physicochemical parameters of the analysed lakes. All the lakes are located in distinct depressions in the terrain, and their coastal zones are surrounded by relatively dense forest areas. Even though their maximum lengths coincide with the maximum effective lengths, in small areas the mixing phenomenon has a limited range.

On July 17, 2025, water temperature measurements were also carried out in the studied lakes (Photo 9). Fig. 5A shows examples of thermal stratification of the analysed lakes. Due to their shallow

Photo 7. *Bathymetry measurements of Lake Długie using echosounder and GPS*

Photo. 8. *Depth measurement with a weight probe on Lake Sosnówek*

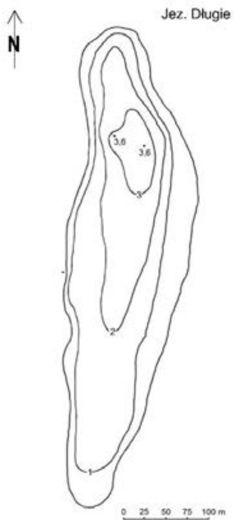

Fig. 1. *Bathymetric plan of Lake Długie*

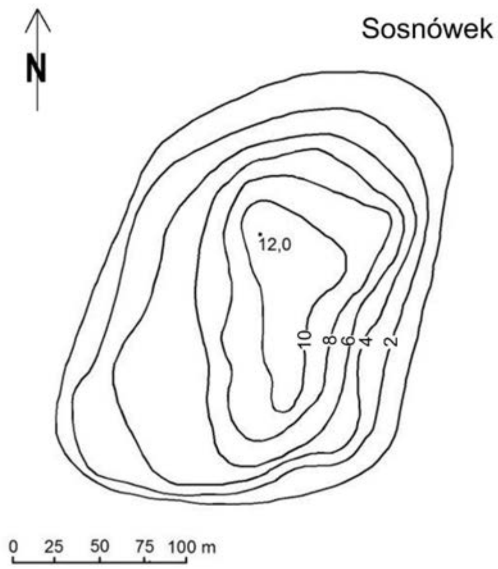

Fig. 2. *Bathymetric plan of Lake Sosnówek*

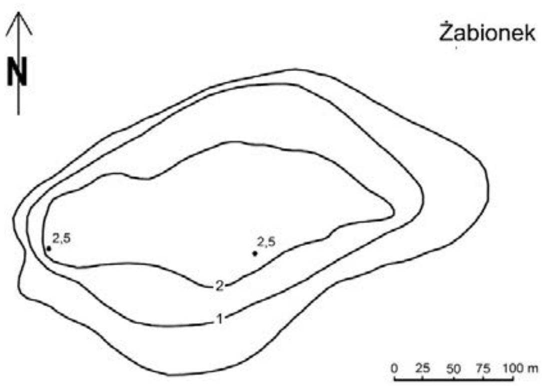

Fig. 3. *Bathymetric plan of Lake Żabionek*

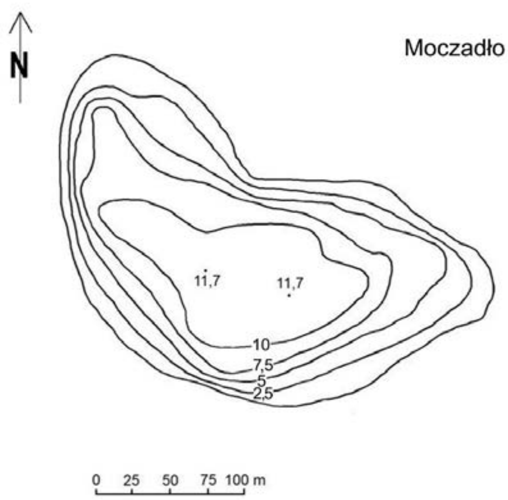

Fig. 4. *Bathymetric plan of Lake Moczadło*

depths, Lake Długie and Lake Żabionek are devoid of the classic summer three-layer stratification. The differences in water temperature between the surface and the bottom are only 1–2 °C. This type of lake can be described as polymictic, in which the water is mixed repeatedly throughout the mass during the summer. When the metalimnion and hypolimnion layers are absent, as in the above case, such lakes are also called epithermal lakes. Lakes Sosnówek and Moczadło, with medium depths, have an epilimnion of 5–6 meters thickness, underlain by a metalimnion layer of 4–5 meters thickness. In these layers the thermal gradient is of the order of 2–2,7 °C x m^{-1}. The above lakes have a reduced hypolimnion. These lakes can be classified as metathermal, as the volume of the epilimnion is close to the sum of the volumes of the metalimnion and hypolimnion. The above measurement results (from 17/07/2025) were compared with the data obtained from earlier studies (third decade of 08/2020; Ciążyńska, Klimaszyk [4] – Fig. 5-B. Although the time between measurements is short on a yearly basis, i.e. about 3 weeks, the thermal curves are varied. This is manifested by a shallower epilimnion range, the presence of a hypolimnion layer in the Moczadło and Sosnówek lakes, and lower water temperatures in all lakes in the later period of measurements. These may include, among others, the consequences of the warmer spring-summer period in 2020, different levels of water mixing, different basin supply or different local conditions.

Photo 9. *Water temperature measurement on Lake Moczadło*

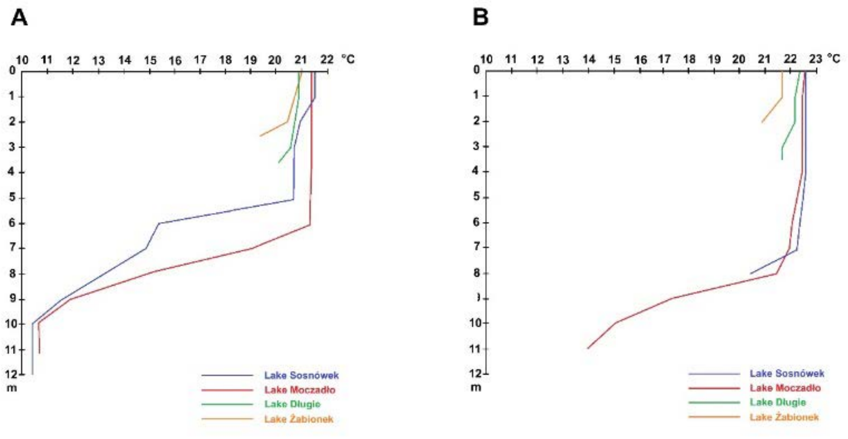

Fig. 5. *Examples of thermal stratification of the analysed lakes:*
A – on 17/07/2025; B – third decade of August 2020

The morphometric parameters of the studied lakes are included in Table 2.

Table 2

Morphometric parameters of the analysed lakes

Parameter/unit	Designation/ formula	Lake Moczadło	Lake Sosnówek	Lake Długie	Lake Żabionek
Area [ha]*	P	4,09	4,13	5,68	6,50
Maximum depth [m]	H_{maks}	11,7	12,0	5,68	2,5
Average depth [m]	$H_{śr}$	6,29	4,97	1,64	1,43
Relative depth	$\frac{H_{maks}}{\sqrt{P}}$	0,0578	0,0590	0,0151	0,0098
Depth gauge	$Wg = \frac{H_{śr}}{H_{maks}}$	0,54	0,41	0,46	0,57
Water volume [thousand m^3]	V	257,24	205,18	93,38	93,16
Maximum length [m]	D	310	294	559	406
Maximum width [m]	S	141	203	147	225
Elongation	D/S	2,20	1,45	3,80	1,80
Medium width [m]	P/D	132	140	102	160
Length of the coastline [m]	L	828	741	1197	1022
Coastline development	$\frac{L}{2\sqrt{\pi P}}$	1,16	1,03	1,42	1,13
Coastline development [m x ha^{-1}]	L/P	202	179	211	157
Volume expansion	$R_v = \frac{3H_{śr}}{H_{maks}}$	1,61	1,03	1,42	1,13
Lake exposure index	$W_o = \frac{P}{H_{śr}}$	0,65	0,83	3,46	4,54
Compactness index	$W_z = \frac{V}{P}$	0,063	0,050	0,016	0,014
Geographic coordinates of the center of the lake	Latitude Longitude	53°48’,872 17°38’,055	53°48’,989 17°36’,980	53°48’,372 17°37’,220	53°49’,908 17°37’,304
Height above sea level [m]	wg NMT*	124,3	124,5	125,7	123,9

*Note: * – according to the Topographic Objects Database (https://www.geoportal.gov.pl/); ** – according to the Digital Terrain Model (https://www.geoportal.gov.pl/)*

Water transparency was measured using a Secchi disk. Deep lakes, i.e. Moczadło and Sosnówek (6.5 and 7.0 m respectively), have waters several times more transparent than shallow lakes, i.e. Długie and Żabionek (2.4 m and 1,4 m respectively). This is due, among other things, to the fact that the base of the waves in shallow lakes reaches the bottom. This often causes resuspension of bottom sediments, which results in a higher content of suspended matter in the water. It is worth emphasizing that the water transparency was measured at the end of August 2020 by Ciążyńska i Klimaszyk [4]. Then the corresponding results obtained to the previous ones were: 6.8 m, 4.5 m, 2.0 m i 1.7 m. Therefore, three of them were highly convergent, and only in the case of Lake Sosnówek there was a significant discrepancy, i.e. 4.5 m in 2020 and 7.0 m in 2025. In the above case, such large differences may result from short-term changes in local conditions.

It should also be added that the obtained results do not correspond at all to the depths of these lakes given on the Topographic Map of Poland at a scale of 1:10,000 (sheets: N-33-84-C-a-2 Leśniczówka-Dębowa Góra, 2002; N-33-84-C-b-1 Męcikał, 2002), or the Hydrogeological Map of Poland on a scale 1:50.000 [8]. The biggest difference occurs in the case of Lake Żabionek – the maps indicate a maximum depth of 10 m, but during measurements only 2.5 m was obtained. The situation is similar in the case of Lake Długie – the maps show 7 m, while measurements show a maximum depth of 3.6 m, and in Lake Moczadło, 14 m and 11.7 m respectively. In turn, Sosnówek has a maximum depth of 8 m, while in reality it is 12.0 m. *In situ* measurements of electrolytic conductivity, oxygen content and pH obtained at the end of August 2020 by Ciążyńska and Klimaszyk should also be taken into account [4] – Fig. 6.

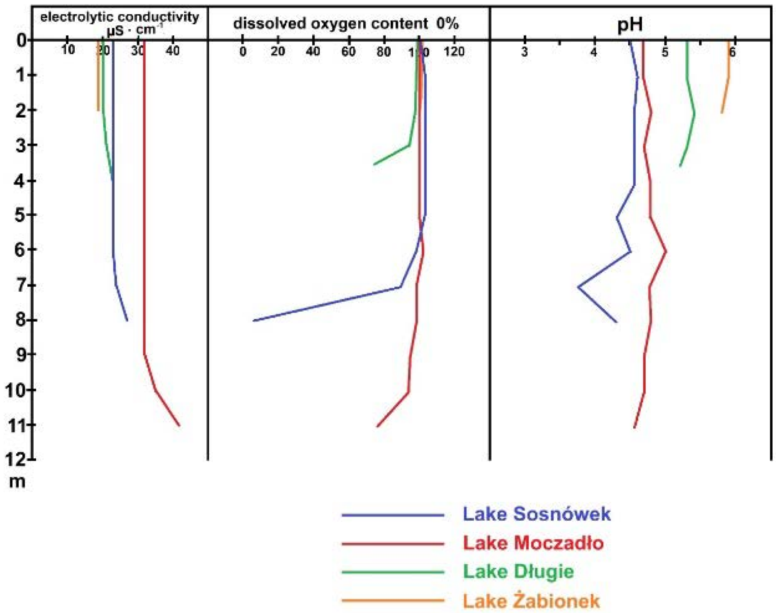

Fig. 6. *Results of in situ measurements of electrolytic conductivity, dissolved oxygen content and pH determined in the cauldrons of the analysed lakes*

As can be seen from the curves illustrating the electrolytic conductivity of water between the surface and the bottom, these are extremely low values on a national scale, oscillating between 19 and 32 $\mu S \cdot cm^{-1}$. Only in the benthic zone do they grow slightly, so where there is close contact between water and sediments. The oxygenation of the waters of all lakes is close to full saturation, i.e. 100%, even reaching a slight state of supersaturation in Lake Sosnówek. About 1 m above the bottom the oxygen content drops rapidly, reaching only 5% in the case of Lake Sosnówek. This is the result of processes occurring in bottom sediments. In terms of pH, the waters of Lake Moczadło and Lake Sosnówek can be classified as acidic, while the waters of Lake Długie and Lake Żabionek are slightly acidic. The acidity of the analysed lakes is mainly the result of inflows of humic substances from the surface of the direct catchment areas.

Similar data were obtained during research on the analysed lakes on July 17, 2025. The pH of the waters of Lake Długie, Żabionek and Sosnówek was ±5.5, so they were slightly acidic. Thus, pH water Lake Długie and Żabionek were the same. Only in the case of the waters of Lake Sosnówek their reaction changed from acidic to slightly acidic. Due to random causes, the pH of the waters of Lake Moczadło was not tested.

Ichthyofauna of the analysed lakes. The ichthyofauna composition studies of Lake Długie, Sosnówek and Żabionek were carried out for the first time for the purpose of including them in a form of nature protection in the form of ecological use. Due to the fact that Lake Moczadło had been a nature reserve since 2011, such research could not be carried out.

The qualitative composition of ichthyofauna in the three analysed lakes was determined on the basis of "catch-and-release" control catches conducted with set nets on September 11–13, 2013. The results of these studies were as follows:

1. Lake Długie – 3 species caught:

a. European perch (*Perca fluviatilis*) – 21 pieces with a total weight of 13.45 kg, the largest specimen weighed 930 g;

b. Prussian carp *(Carasssius auratus gibelio*) – 5 pieces with a total weight of 2.45 kg, the largest of them weighed 620 g,

c. Common roach (*Rutilus rutilus*) – 2 pieces weighing 410 g and 270 g;

2. Lake Sosnówek – 2 species caught:

a. European perch (*Perca fluviatilis*) – 2 pieces weighing 180 g and 175 g,

b. Common roach (*Rutilus rutilus*) – 1 piece weighing 260 g.

3. Lake Żabionek – 4 species caught:

a. Northern pike (*Esox lucius*) – 1 specimen weighing 114 g;

b. Prussian carp (*Carassius auratus gibelio*) – 1 specimen weighing 1480 g;

c. tench (*Tinca tinca*) – 1 specimen weighing 360 g;

d. Common roach (*Rutilus rutilus*) – 12 pieces with a total weight of 3.72 kg, the largest of them weighed 410 g.

The presence of silver crucian carp, tench and pike in the studied lakes may be the result of stocking carried out by individuals leasing Lake Długie and Żabionek in the years preceding their recognition as ecological sites (currently nature reserves).

The poor species composition found in the above-mentioned lakes is characteristic of most lobelia and oligohumus lakes.

Photo 10. *A blooming field of water lobelia (Lobelia dortmanna), strictly protected by law, in the coastal zone of Lake Moczadło*

Conclusions. The research conducted supplements the state of knowledge about the lakes under reserve protection in the Zaborski Landscape Park. The characteristics included in the above text indicate that the analysed lakes, in addition to the fact that they contain numerous sites of the endangered water lobelia (Photo 10), are extremely peculiar objects. They have such distinctive physical and chemical water features that they deserve to be designated as nature reserves.

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