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OVERGROWTH OF LAKES AS AN INDICATOR OF THEIR DISAPPEARANCE – ON THE EXAMPLE OF THE LAKES OF NORTH-WESTERN POLAND

Rajmund Skowron, Adam Piasecki
Nicolaus Copernicus University in Toruń, Faculty of Earth Sciences, Department of Hydrology and Water Managemnet, 87-100 Toruń, ul. Lwowska 1, +48 566112611, e-mail: *rskowron@umk.pl*
piasecki@doktorant.umk.pl

Abstract
Lakes in Poland, mainly found in the northern part of the country, occupy about 0.9% of its surface area. Their genesis is related to the last glaciation (Weichselian), which ended approximately 11.5-12.5 ka years ago. They generally have small surface areas and relatively small depths. The transformation of the lake basins has been taking place since their origin. Initially, it was natural in its character; however, since the second half of the eighteenth century, these are mainly anthropogenic changes. One of the manifestations of human impact on lakes has been the lowering of their water level and diminishing of their water resources. On the basis of the cartographic materials of different periods for the 303 lakes the authors analysed the changes in the degree of overgrowth of lakes in the Pomeranian Lake District over the last 60 years. As a result, it was found out the surface area of lakes has decreased by 1.2% (from 49 707.7 ha to 48 996.4 ha). Simultaneously, the area occupied by emergent vegetation has increased by 1.2%.

Keywords*:* Poland, lakes, plant overgrowth,

1 INTRODUCTION

The disappearance of lakes is most often associated with the decrease of their surface area. This is due to the fact that the lakes in northern Poland are generally small and shallow. In such reservoirs the sedimentation and sedentation processes proceeded very quickly, intensified by strong deforestation. The cartographic materials presented in this paper come from different periods; this allows the authors to capture the process of the disappearance of lakes as well as determine its rate.

Several stages (causes) can be distinguished in the evolution of the lake basins in their Holocene history. According to Niewiarowski (1986, 1987) several factors were responsible for these changes, among which the most important role was played by the following: varied pace of melting of dead ice blocks, short- and long-term climate change, different time of the inclusion of lakes into the system of the surface runoff, deforestation of the catchment (both total and direct), conducting hydrotechnical measures (from the mid-eighteenth century), as well as conducting the large-scale reclamation works (Kaniecki 1997,). In the Polish literature on these issues the changes in the water level caused by climate change are confirmed in the works by Niewiarowski (1978, 1987 and 1999) and Churski (1988). According to these authors, the evolution of glacial lakes started as soon as they originated – mostly in Allerød, rarely in Bølling – and showed varying intensity of the processes that caused the changes. The rate of transformation of the lake basin showed large fluctuations from its origin to the present. This was determined by the two main factors, namely: changes in the level (lowering) of the lake water level and filling the lake basin with the accumulating biogenic and terrestrial sediments.

Although the lakes went through several stages of similar transformation they are in various stages of development of their basins. Many authors have expressed the view that in the lake district areas there are different levels of the water in the lakes (Churski 1988). An important role in the development of lake basins was played by the processes associated with melting of the dead ice blocks. It was a very complex process, mainly due to the varying thickness of the sediment deposited therein (Niewiarowski 1987). This led to differences in the rate of their melting at a different level of the water and different depth relationships. Also the Holocene history of the development of many lakes (Biskupińskie, Gościąż, Weneckie, Gąsawskie, Pakoskie, Gopło) showed different levels of water, caused mostly by the climatic factors.

The average level of the disappearance of lakes associated with the Weichselian Glaciation is 67.4% (Kalinowska 1961). Choiński (2006) reports that in the Polish Lowland during the 70 years of the twentieth century as many as 2215 lakes disappeared, i.e. 11.2% of their total surface area. The examples of changes occurring in lake basins in the twentieth century are shown in many studies (Choiński 2001, Glazik & Gierszewski 2001, Kowalewski *et al*. 2001, Drożyński & Skowron 2002, Skowron & Piasecki 2012).

Similarly to other countries, human impact on the formation of the water level in the lakes in Poland began in the Middle Ages and was associated with the construction of water mills. In general, building these hydraulic structures was followed by the damming of lakes, sometimes up to several meters.

This process lasted several hundred years and ended with the liquidation of the mills in the mid-nineteenth century (Niewiarowski 1999, Podgórski 2004). The next stage in the evolution of the lakes was intensified by the drainage works and riverbeds regulation carried out on a large scale since the mid-eighteenth century (Drożyński & Skowron 2002). In the years 1871-1914 a total of approximately 420 000 ha were drained. Lowering the water level in many lakes by 0.5-0.7 m resulted in a significant decrease in their surface areas, sometimes by as much as 25-30% (Kaniecki 1997).

As a result of these measures, the water level in many lakes in Poland lowered (Babiński 1988, Skowron & Piasecki 2012). The analysis of the changes in the lake/land surface area ratio over 100 years in 15 catchments of the Baltic Coastland showed a decrease in the number of lakes by 16.2% and in their area – by 3.9% (Choiński 1997, Choiński & Madalińska 2002, Czaja & Jańczak 2010). Analysing the bathymetry of lakes in the Masurian and Pomeranian Lake Districts Choiński (2002) comes to the conclusion that within 60-70 years of the twentieth century there was a reduction in the lake area by a few percent, while in their capacity – by several tens of percent. As a result of this process the change in the bottom relief was observed: the contours shifted from the banks toward the centre of the lake and new peninsulas and islands emerged; in some cases the original lake was divided into several smaller water bodies (Marszelewski, 2005). An example of this process is Lake Jamno, the volume of which was reduced by 22.7% in the years 1889-1960 (Choiński 2001). Similar situations were observed in other regions of the Polish Lowland (Dąbrowski 2001, Nowacka & Ptak 2007, Kunz *et al.* 2010, Ptak 2010, Ptak & Ławniczak 2012). In turn, the analysis of aerial photographs of small lakes in the southern part of the Wielkopolska Lake District showed a clear succession of the shoreline and floating vegetation (Kijowski 1978).

In the Pomeranian Lake District these changes are also very important. Choiński (2007) reports that one of the effects evidencing the process of shallowing and disappearance of lakes is their overgrowing. The calculations carried out on about 900 lakes in northern Poland by Kowalczyk (1993) showed that the average ratio of the emergent vegetation is 4.1%; for the Pomeranian Lake District this rate is 2.8%. Besides the amount of nutrients the main factor contributing to the overgrowth is a large participation of the littoral zone. Thus it is appropriate to take this research topic after over 60 years since the first measurements and observations of the overgrowth of lakes.

Within the basin of every reservoir there is a littoral zone – extensive or only fragmentary. The littoral zone, in which the influence of the catchment is the clearest, is overgrown with a strip of rooted vegetation. Within the littoral zone several vegetation zones can be distinguished (by Starmach *et al*. 1976):

- zone of rushes, which appears on the border of land and water, with mainly helophyte plants (*carex vesicaria, carem gracilic, juncus, equisetum, acorus calamus*),
- zone of reeds, which includes emergent aquatic plants growing up to 1-2 m water depth (*phragmites communis, schoenoplectus lacustris, typha angustifolia, acorus calamus*),
- zone of floating-leaf vegetation, which includes plants rooted to a depth of 3 m (*potagometon lucens, potagometon perfoliatus, potagometon crispus*),
- zone of submerged flowering and non-flowering vegetation, which are plants rooted at a depth of 3-6 m (*characae, fontinalis*).

The aim of the paper is to show changes in the plant succession in the lakes of the Pomeranian Lake District, as an essential element leading to changes in their surface area and their gradual disappearance.

2 MATERIALS AND METHODS

The area under analysis is situated between the rivers Odra, Vistula, Noteć and the Baltic Sea and is one of the largest lake districts in Poland (Fig. 1). In this region there are 3 385 lakes with a total area of 104 219.4 ha. The landscape is dominated by small lakes with an area of less than 50 ha (3021 lakes). The number of lakes with an area of over 100 ha is 162, while those of more than 1000 hectares – only 12. The average depth of all the lakes in the Pomeranian Lake District is 6.84 m (Choiński 2007).

The size of overgrowth was determined using two indicators. The most important of these is the overgrowth factor, taken as a percentage participation of the surface area taken by the emergent vegetation, relative to the total surface of the lake. The second parameter is the indicator of the shoreline overgrowth, defined as the ratio of the surface area taken by emergent vegetation (excluding islands) to the shoreline length and is expressed in ha/km.

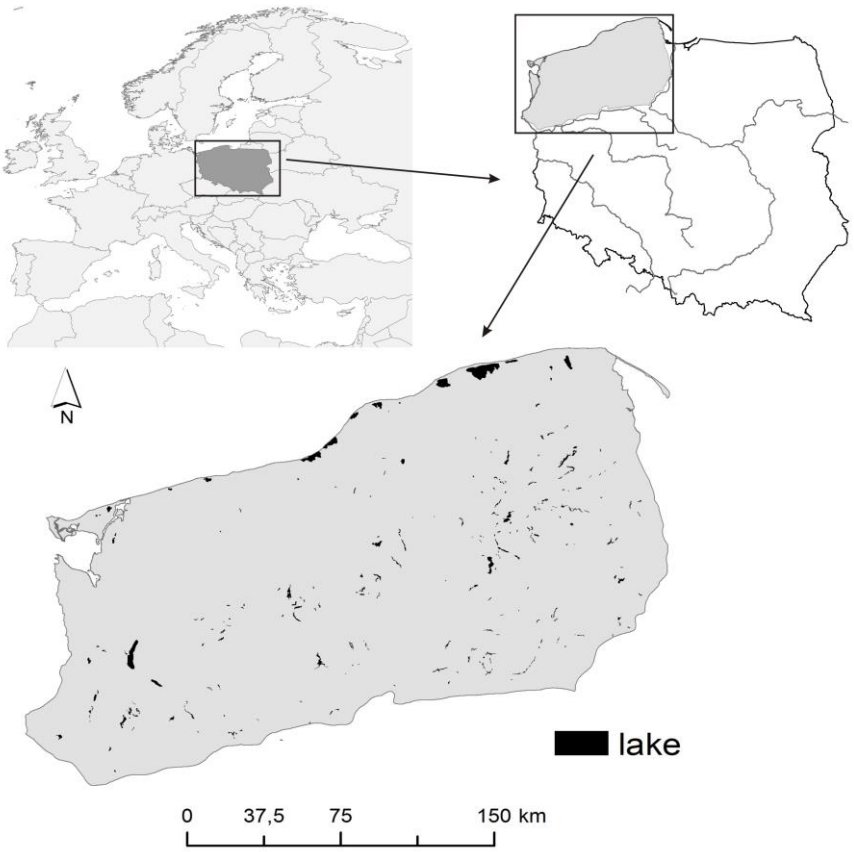

Figure 1 Location of the research area

The main source of the data in the paper were bathymetric plans from the mid-twentieth century made by the Inland Fisheries Institute (IFI) in Olsztyn as well as current aerial photographs as orthophotos from the years 2009-2011. As part of the chamber work the outline of the shoreline of 303 lakes (including their islands) and the emergent vegetation coverage were digitalised. This has provided information on the surface area of open water and emergent vegetation as well as the shoreline length. It should be noted that the scale of the source materials has allowed for more detailed designation of these parameters, taking into account, such elements as individual vegetation patches, gaps in the reed belt, lake platforms and concrete embankments. The process of digitalisation was carried out at a scale 1:1500.

The next step was to collect the information and create a database in a tabular form. As a result, it was possible to carry out further calculations and analyses, and to determine the basic statistical parameters.

3 ANALYSIS OF THE MATERIAL AND DISCUSSION OF THE RESULTS

The area covered by the analysis concerns the Pomeranian Lake District, which occupies approximately 48 770 km^2. In this area there are mainly glacial lakes of various sizes and depths. In total there are 3 385 lakes with an area of 104 219.4 ha. Small lakes with an area of 50 ha predominate – there are 3021 of them. There are 162 lakes larger than 100 ha and just 12 larger than 1000 ha. The largest ones include Lakes Łebsko (7020 ha), Miedwie (3491 ha), Gardno (2337.5 ha) and Jamno (2231.5 ha). The average depth of all the lakes in the Pomeranian Lake District is 6.84 m; the deepest ones include Lakes Drawsko (82.2 m), Wdzydze (69.5 m) and Morzycko (60.7 m). All lakes are flow lakes, with varying degrees of water exchange and slight annual fluctuations in their water levels (for 18 lakes 0.43 m on average).

According to the IFI the total area occupied by emergent vegetation was 3168.2 ha, whereas calculated on the basis of the orthophotos – 2807.1 ha, with an average rate of the overgrowth in the analysed lakes of 8.1 and 10.1%, respectively. According to the updated measurements the highest values were obtained for 13 lakes and were higher than 25%. They were recorded for small lakes with a surface area not exceeding 50 ha (Table 1). In turn, the lowest values refer to the much larger reservoirs and for 10 lakes were

lover than 3.0% (Table 2). For the lakes of up to 50 ha the indicator of the lake overgrowth is greater than 10.0%, while in the lakes of over 500 ha the values lower than 5% are recorded (Table 3).

Table 1 Largest values of the lake overgrowth indicator (emergent vegetation) by orthophotos and the Inland Fisheries Institute (IFI)

Lake	1950 – 1960 years (IFI)		2011 years (orthophotos)	
	ha	%	ha	%
Klasztorne	4,2	25,7	7,1	45,8
bez nazwy	1,4	53,5	0,6	37,5
Czółnów	8,7	30,9	7,7	33,9
Korytowo Małe	1,9	13,1	3,3	32,7
Mnilonka	1,8	37,6	1	32,3
Ząbrowskie	4,4	20,9	5,4	31,0
Strokowo	6,8	12,4	11,7	29,2
Płocice	4,3	24,5	4,4	28,8
Ostrowo	8,3	23,1	9,3	27,8
Gubel	1,9	28,4	1,6	26,7
Runowskie Duże	8,4	15,6	11,4	26,1
Małe Suskie	2,1	9,6	4,3	25,4

Table 2 Lowest values of the lake overgrowth indicator (emergent vegetation) by orthophotos and Inland Fisheries Institute (IFI)

Lake	1950 – 1960 years (IFI)		2011 years (orthophotos)	
	ha	%	ha	%
Żarnowieckie	35	2,5	15,0	1,1
Miedwie	83,7	2,3	60,6	1,7
Warszyn	1,1	3	0,7	2,0
Raduńskie Dolne	2,5	0,3	16,1	2,2
Węgorzyno	2,6	2	3,0	2,4
Koprowo	56,8	11,7	11,1	2,4
Jeleń	0,3	0,3	2,3	2,7
Liwia Łuza	39,4	18,7	4,9	2,7
Zamkowe	0,4	2,2	0,5	2,9
Wielkie	8	15,3	1,6	3,0

Table 3 Emergent vegetation by the surface area of the analysed lakes by different data

Surface (ha)	1950 – 1960 years (IFI)		2011 years (orthophotos)	
	ha	%	ha	%
0-25	129,4	11,8	143,3	14,8
25-50	272,8	7,7	318,7	10,3
50-100	331,8	7,8	399,9	9,4
100-250	404,8	5,4	526,7	7,1
250-500	489,0	7,1	424,0	6,7
500-1000	344,4	5,8	294,8	5,2
> 1000	1 196,0	4,9	700,8	3,4

An important role in the overgrowth of lakes is played by the depth of the water bodies. An objective parameter influencing this process is the average depth of lakes. Although there is no functional correlation between these elements, it may be a good indicator showing which of the lakes are most susceptible to this process (Fig. 2). Moreover, the calculations between the overgrowth indicator, the relative

indicator of the depth (Skowron 2004) and the percentage share of the volume to a depth of 1 m, have not confirmed these correlations.

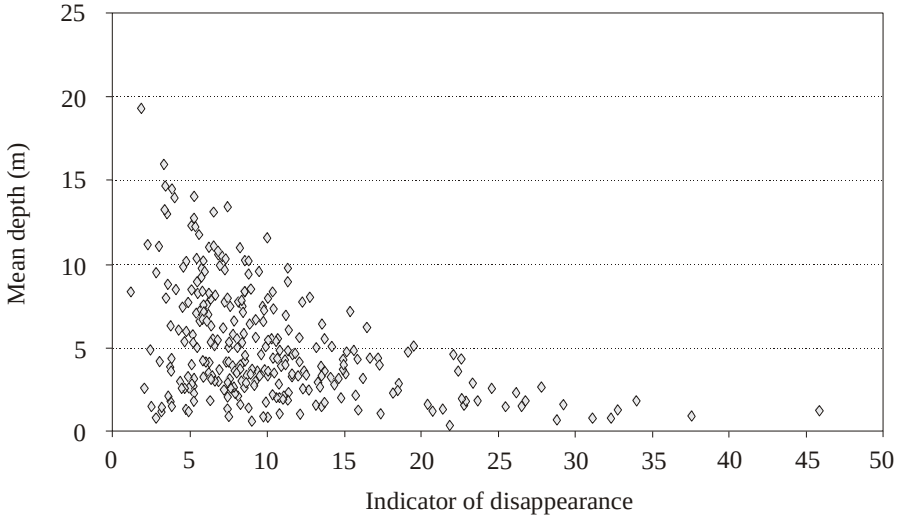

Figure 2 Correlation between the average depth of the lake and an indicator of the lake overgrowth

An interesting material was obtained by analysing the indicator of the lake overgrowth and the separate intervals of the average depth of the analysed lakes (Table 4). For the shallowest lakes (average depth up to 2.5 m) the average indicator of overgrowth is 14.9%, gradually decreasing with the increasing depth. For the deepest lakes (above 10 m of the average depth) it reaches the average of less than 6.2%.

Table 4 Changes in the overgrowth of lakes (emergent vegetation) at the intervals of the average depth of the analysed lakes by different data

Average depth (m)	1950 – 1960 years (IFI)		2011 years (orthophotos)	
	ha	%	ha	%
0-2,5	1 438,7	12,0	968,5	14,9
2,5-5,0	716,6	8,8	676,0	10,5
5,0-7,5	355,2	6,6	428,3	8,4
7,5-10,0	359,3	5,0	409,4	6,8
10,0-12,5	141,4	5,7	168,7	6,2
> 12,5	153,6	3,4	152,7	4,3

In the process of the lakes overgrowth, whose rate decreases with the distance from the shore, an important indicator may be a ratio of the shoreline overgrowth. It defines the surface area of the shoreline overgrowth per one kilometre of the shoreline. The values resulting from this ratio indicate which lakes are most subjected to this process. Of the 303 lakes under analysis the highest values are recorded for large lakes of different shapes: Gardno, Łebsko, Strokowo and Runowskie Duże and amount to over 4.00. The lowest values of less than 0.35 are characteristic for small lakes (up to 300 ha) of different sizes and average depths (Table 5).

Table 5 Maximum and minimum values of the lake shoreline overgrowth ($ha \cdot km^{-1}$) in the Pomeranian Lake District

Highest values		Lowest values	
Lake	Value	Lake	Value
Gardno	5,00	Barlińskie	0,20
Łebsko	4,64	Łapińskie	0,26
Strokowo	4,27	Warszyn	0,28
Runowskie Duże	4,02	Ostrowite	0,30
Michałowo	3,62	Nierybno	0,30
Ostrowo	3,54	Borzęchowskie Wielkie	0,30
Kopań	3,39	Zamkowe	0,31

Czółnów	3,22	Mały Pełcz	0,31
Klasztorne	2,97	Puc	0,32
Wilczkowo	2,63	Łączno	0,33

The decrease in the total surface area of lakes in the Pomeranian Lake District by 9.69% within 40-50 years of the twentieth century points to the process of their disappearance. This also applies to other lake district regions, in which the disappearance is even greater (Choiński 2006). The disappearance of lakes is rightly associated mainly with the lowering of the water level, increasing sedimentation within the lake basin as well as progressive eutrophication. The result of these processes is a visible succession of vegetation in lakes. A good indicator showing increasing plant succession is the shoreline overgrowth index ($ha \cdot km^{-1}$). The index value from the turn of the 1950s and 1960s (development of the bathymetry plans) is 0.98 $ha \cdot km^{-1}$, while at the turn of the first and second decade of the twenty-first century (60 years difference) it reached 1.14 $ha \cdot km^{-1}$. This is a clear evidence of an increase in the lakes overgrowth and plant succession regardless of the kind and type of vegetation.

CONCLUSIONS

The analysis of the degree of overgrowth of lakes in the Pomeranian Lake District referred to 303 lakes, or about 9% of their total number, and accounted for 47.0% of their total surface area (48 996.4 ha). In this respect, the lakes are a representative group for specifying the change. Calculation and comparison of several parameters relating to both the lake basin and the degree of the lakes overgrowth are the basis for the following conclusions:

- changes in plant succession, comprising mainly the coastal zone of the lake basin, are well represented by the overgrowth indicator and the index of the lake shoreline overgrowth,
- the average indicator of the lakes overgrowth, determined on the basis of orthophotos for 303 reservoirs, is 10.1%, which is higher by 2% compared to the bathymetric data plans. The minimum values for the 28 lakes are lower than 4%, while the highest values for the 26 lakes are higher than 20%.
- the average index of the shoreline overgrowth for the analysed lakes is 1.14 $ha \cdot km^{-1}$, while their extreme values are range from 0.2 to 5.0 $ha \cdot km^{-1}$. For the period 1960-2010 this index shows an increase from 0.98 to 1.14 $ha \cdot km^{-1}$.
- the materials derived from the orthophotos indicate that there is no clear correlation between the indicator of overgrowth and morphometric parameters (relative indicator of the depth, the lake volume to 1 m depth). It is best kept between the overgrowth indicator and the average depth of the lake.
- parallel to the succession of vegetation, in the coastal zone of lakes in their different parts there appear vegetation patches and islands, particularly in shallow water bodies. Overall, for the 303 analysed lakes there were 98 islands registered with a surface area of 119.06 ha and 166 vegetation patches with a total surface area of 92.68 ha. The analysis of the material showed that the island ratio is 4.24%, with the average for the whole Pomeranian Lake District of 0.78% (Choiński 2007).
- the analysis of the materials also showed that the surface area of lakes in the Directory of Polish Lakes (Choiński 2006) and the surface area obtained from the orthophoto indicate significant differences, despite the 30-year difference. There was no decrease in the surface area of analysed lakes; on the contrary, the surface area calculated from the orthophoto is higher by 361.1 ha. Certainly, this difference is primarily due to the accuracy of the base material and the very method of measuring the surface area. The average surface area of the 303 lakes from the Directory is 159.2 ha and the overgrowth indicator is 8.1%, while on the basis of the orthophoto the respective values are 161.7 ha and 10.1%.

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