Bulletin of Geography. Physical Geography Series, No. 12 (2017): 19-30
http://dx.doi.org/10.1515/bgeo-2017-0002

Changes in lake area as a consequence of plant overgrowth in the South Baltic Lakelands (Northern Poland)

ISSN 2080-7686

Rajmund Skowron[1], Tomasz Jaworski[2]*

[1] Polish Geophysical Society, Pomorski Branch, Toruń, Poland
[2] Nicolaus Copernicus University in Toruń, Poland

* Correspondence: Department of Geomorphology and Palaeogeography of the Quaternary, Nicolaus Copernicus University in Toruń, Poland. E-mail: tomjaw@umk.pl

Abstract. The authors carried out the analysis of changes in the plant overgrowth of the lakes based on cartographic materials. Among 6 793 lakes with the area exceeding 1 ha located in the lakelands of Northern Poland, 893 lakes were selected for the analysis. The lakes were selected on the grounds of the existing bathymetric plans and information on their overgrowth and depth relations. Over the last 50 years lake area declined by 1.9% (from 140 975.0 ha do 138 273.7 ha) and so did the lake area covered with emergent plants, i.e. by 0.27% (from 11 219.0 ha down to 10 637.2 ha). Emergent plants cover on average 7.69% of the lake area. In the case of the lakes of smaller areas (below 80 ha) or medium areas (80÷200 ha) the extent of plant overgrowth was 14.3 and 9.6% respectively. The article presents two indicators which determine plant overgrowth of the lakes. These are the coefficient of overgrowing the lakes (%) and the coefficient of overgrowing the shoreline ($ha \cdot km^{-1}$). These coefficients make it possible to study the extent of lake overgrowing in the South Baltic Lakeland, regardless the direction of these changes.

Key words:
Northern Poland,
lakes,
indicator of plant overgrowth,
shoreline plant overgrowth

Introduction

Lakes are a characteristic element of the landscape in northern Poland. They fill depressions which formed mainly due to erosive activity of subglacial waters, more rarely due to exaration of the Late Weichselian Ice Sheet which retreated from that area in about 13.5 kyr BP. The calculations conducted by Kalinowska (1961) indicate that 2/3 of the area of the lakes in northern Poland have already vanished since the beginning of the Holocene. The lakes located in the lakelands of the northern Poland cover the area of approximately 110 000 km^2, which constitutes 35% of the entire area of Poland. There are 6 793 lakes (of the area of over 1 ha) which cover the area of 2 770 km^2 (Choiński 2006).

The disappearance of lakes is most frequently associated with the decline in their area. This results from the fact that the lakes in Poland are generally small, and shallow in most cases. Two factors are mainly responsible for the disappearance of lakes, namely: sustained reduction of the lake water levels and accumulating deposits in the lake basin. Many researchers indicate the importance of coasts as vital trophic zones, in addition to their barrier functions for materials flowing down from the catchment (Kolada and Ciecierska 2008; Heinsalu and Alliksaar 2009).

Therefore, several evolution stages of the lake basins can be distinguished in the Late Glacial

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and Holocene history of the lakes. According to Niewiarowski (1986, 1987), there were several factors which chiefly influenced these transformations, namely: varied pace of dead ice melt-out, short and long-term climatic changes, and different time when the lakes entered the system of surface runoff. Complex evolution of lake troughs in this time period also have impact on other lakelands located outside of the Baltic, including neighbouring Belarus (Novie et al. 2010), and those located towards the North: Lithuania (Linkevičiené 2009), Latvia (Brižs 2011) and Estonia (Terasmaa 2011; Vainu and Terasmaa 2014).

Severe deforestation has taken place over huge parts of Europe for the last centuries. That process has also led to declining surface and groundwater levels. Besides, anthropopressure has also had a considerable impact upon falling water resources in the lakes. As a result of hydrotechnical and drainage works conducted since the mid-19th century, the water table in many Polish lakes has declined (Niewiarowski 1978; Kaniecki 1997; Błaszkiewicz 2005; Jaworski 2005; Skowron and Piasecki 2012). While analysing bathymetric plans of the lakes in the Masurian and Pomeranian Lakelands, Choiński and Madalińska (2002) conclude that over 60–70 years of the 20th century the lake areas declined by several percent, whereas the lake volume fell by several dozens of percent.

The cartographic materials mainly from the years 1900-1920 and the mid-1970s show that 2215 lakes (of the area >1 ha) disappeared, i.e. 11.2% of their area (Choiński 2007). The changes undergoing in the lake basins in the twentieth century were presented on the examples of Lake Jamno (Choiński 2001), Lake Wikaryjskie (Glazik and Gierszewski 2001), and Lake Miedzno (Kowalewski et al. 2001). The studies indicate that the decline of the water table in many lakes by 0.5–0.7 m resulted in a considerable decrease of their areas, sometimes even by 25–30%. In some lakes the water table lowered by 2.5 m (Lake Miedwie) and by 3.4 m (Lake Gopło), which resulted in the decline of their area by 50% (Kaniecki 1997; Dorożyński and Skowron 2002; Skowron and Piasecki 2012).

The investigations by Choiński et al. (2014) based upon cartographic materials and aerial photographs of the coastal lakes in Poland (Jamno and Bukowo) revealed that in the period of over 100 years there had been considerable decline in their volume by 5.9 and 17.5% respectively. These unfavourable changes occurred mainly in the shallowest parts with the depth up to 1 m. On the other hand, the morphological analysis of the littoral zone in 5 lakes in Poland showed substantial influence of anthropogenic transformation in the littoral upon the number of macrophytes (Jusik and Macioł 2014).

The water table in many lakes in Poland decreased due to hydrotechnical and drainage works (Niewiarowski 1978; Kaniecki 1997; Przybyła 2008; Skowron and Piasecki 2012). Many lakes were found to have their isobaths changed - more towards the middle of the lake from the shore. New peninsulas or islands were formed, and in some cases a lake was found to have divided into several smaller ones (Niewiarowski 1978; Marszelewski 2005). Lake Jamno serves as an example. Over the period 1889–1960 its area decreased by 6.5% and its volume by 22.7% (Choiński 2001). Similar changes were recorded in other regions of the Polish Lowland (Dąbrowski 2002; Nowacka and Ptak 2007; Kunz et al. 2010; Ptak 2010; Ptak and Ławniczak 2012). Linkevičienė (2009) also observes similar processes of lake disappearance with respect to various types of the lakes located in the Lithuanian lakelands.

The analysis of aerial photographs of smaller lakes in the southern part of the Wielkopolskie Lakeland exposed considerable succession of littoral and floating plants (Kijowski 1978). The calculations conducted by Kowalczyk (1993) on nearly 900 lakes located in North Poland show the total overgrowth area equals 9 920 ha, which makes the mean plant overgrowth coefficient of 4.1% (after Choiński 2007). That coefficient was 2.8% in the Pomerania Lakeland, 4.0% in the Masurian Lakeland, and 7.3% in the Wielkopolskie Lakeland. Moreover, the author notices the lack of distinct relations between the rate of plant overgrowth and the mean lake bottom slope, mean depth and lake area. Intensified plant overgrowth takes place in small and shallow lakes, particularly exposed to the inflow of biogenic compounds (Noryśkiewicz 1995; Cieśliński 2015).

Similar changes also occur in the lakes located in Lithuania, Latvia Estonia and Finland. In Lake Luupuvesi (central Finland) the extent of macrophytes increased from 96 ha in 1953 to 355 ha in 1996 (Valta-Hulkkonen et al. 2004). However, the comparison of aerial photographs from the periods of

1947–1963 and 1996–2000 of seven small lakes located in central Finland indicates diversified pace of macrophytes development, from a distinct regression (31–93%) to a considerable succession of plants 49–73%) (Partanen and Hellstenm 2005). The investigations carried out in shallow lakes: Engure (Latvia) and Võrtsjärv (central Estonia) also prove the increase of macrophytes extent in the second half of the twentieth century (Brižs 2011).

The study aims to present changes in the extent of emergent plants in the lakes located in the Polish Lowland (Fig. 1) as an essential element leading to the changes in lake area and the process of lake's gradual disappearance.

Material and methods

The study area constitutes one of the biggest lakeland areas in this part of Europe. It covers the area of over 110 thousand km^2, and comprises three separate lakelands: the Pomeranian Lakeland, the Masurian Lakeland and the Wielkopolskie Lakeland. The altitude of these lakelands only in some places exceeds 300 m a.s.l. (Fig. 1). There are 6 793 lakes of the total area of 276 753.5 ha, and they are located within the range from 0.1 m a.s.l. (coastal lakes) to 290 m a.s.l. (moraine lakes). The landscape is dominated by 5 820 small lakes of the area below 50 ha. There are 496 lakes with the areas ranging from 50 to 100 ha, and only 28 lakes with the area over 1000 ha (Choiński 2007). Relatively small mean depth (7.1 m) is a characteristic feature of the lakes located in the Polish Lowland. The mean depth of the lakes is 6.84 m in the Pomeranian Lakeland, 7.45 m in the Masurian Lakeland, and 5.7 m in the Wielkopolskie Lakeland.

The study is based on the data on plant overgrowth of 893 lakes for which the Inland Fisheries Institute determined the plant overgrowth coefficients. Among these, there are 10 lakes whose maximum depth exceeds 50 m, and 417 with depths bigger than 10 m. The mean depth also indicates a shallow character of the analysed lakes. There are 7 lakes with the mean depth of over 15 m, and as many as 497 lakes with the mean depth below 5 m. 256 lakes are located in the Wielkopolskie Lakeland, 301 lakes in the Pomeranian Lakeland, and 336 lakes are located in the Masurian Lakeland.

While determining the lake outline and area, the ArcGIS software by Eris was used. It allowed for vectorising the raster layer on the screen in the form of the aerial orthophotomap which relates to the national infrastructure of spatial data - geoportal.gov.pl, as the WMS (Web Map Services).

The studies involved defining the outlines of the lakes in a vector file with unique identifiers in the attribute table and calculating automatically the separated areas (Gotlib et al. 2007; Hildebrandt-Radke and Przybycin 2011). The raster layer for which the measurements were carried out (at a scale not lower than 1:1 200),was based upon colour aerial photographs of 0.5-metre pixel size or bigger. The aerial

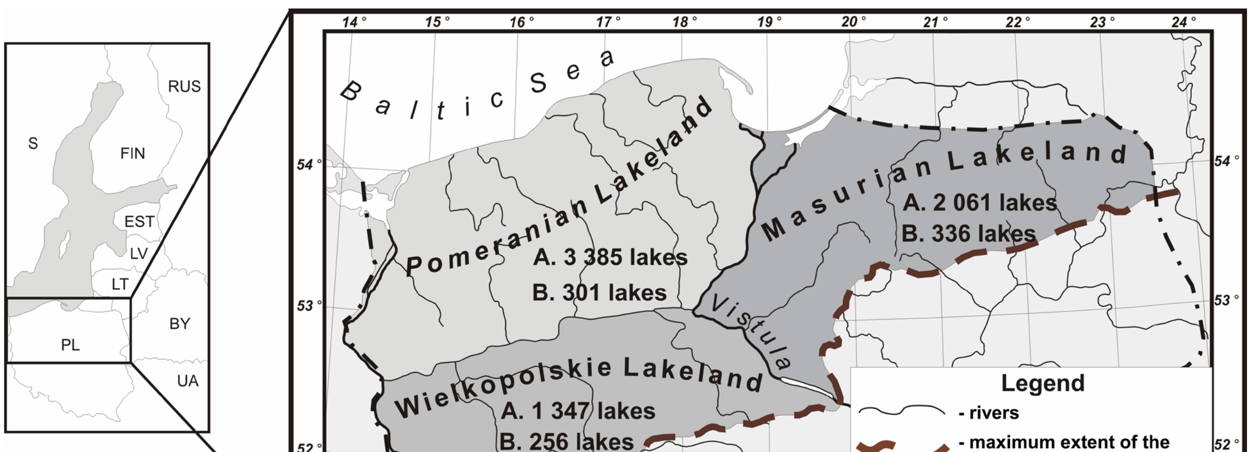

Fig. 1. Main lakelands in northern Poland: A – the total number of lakes, B – the number of analysed lakes

orthophotomaps come from the years 2010–2011. Particular attention was drawn to the littoral zone which was clearly distinct on the colour digital orthophotomap, and which presented the actual condition of macrophytes in the lakes (Fig. 2).

In order to determine the extent of plant overgrowth two indicators were applied. The most important indicator is a plant overgrowth coefficient (%), understood as a percentage share of the area covered by emergent plants in relation to the lake's total area. The other parameter is the shoreline plant overgrowth coefficient which is the ratio of the area covered by emergent plants (excluding the area of islands) to the shoreline length, and is expressed in ha·km^{-1}.

The primary sources for the presented investigation were the measurements conducted by the Inland Fisheries Institute in Olsztyn in the mid-twentieth century and current aerial photographs in a form of an orthophotomap (from the years 2010–2011). The authors prepared the outlines of the lake shorelines, the extent of emergent plants, as well as the outlines of vegetable islands and land islands within the lake basins. Additionally, the parameters included: overlapping of the shoreline zone and overgrowth by the treetops, all the gaps in the reed belt, as well as the development of platforms and concrete quays. Consequently, this provided information pertaining to both the surface of lakes and length of shoreline (Fig. 3).

Results

The results of the analyses of 893 lakes show that regardless of their area, over the analysed period of 50 years the total area covered by emergent plants in the lakes changed slightly. The biggest succession of plants occurred in small lakes with the area of up to 100 ha, whereas noticeable decline can be observed in lakes of over 500 ha.

The depth of water bodies plays a significant role in the process of plant overgrowing. The mean depth of the lakes is an objective parameter influencing this process. While analysing the coefficient of plant overgrowth of the lakes and ranges of the mean depth for the analysed lakes, the authors noticed an interesting fact (Table 1). In the shallowest lakes (with the mean depth of 2.5 m) the plant overgrowth coefficient is 17.7% on average. This coefficient gradually decreases while depth increases. In the deepest lakes (with the mean depth of 10 m)

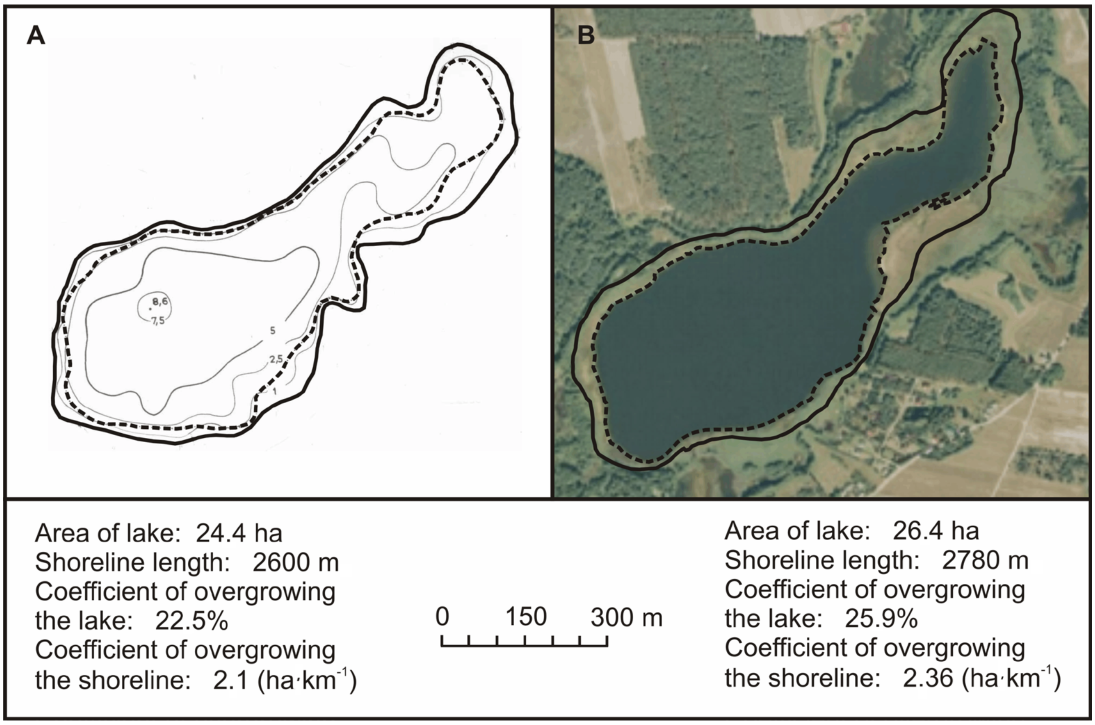

Fig. 2. Differences of lake overgrowth between measurements obtained from the Inland Fisheries Insitute (A) and orthophotomap (B), for example: Lake Czarny Bród (Greater Poland Lakeland); shore line (solid line), and the extent of cover from emerged vegetation (dotted line)

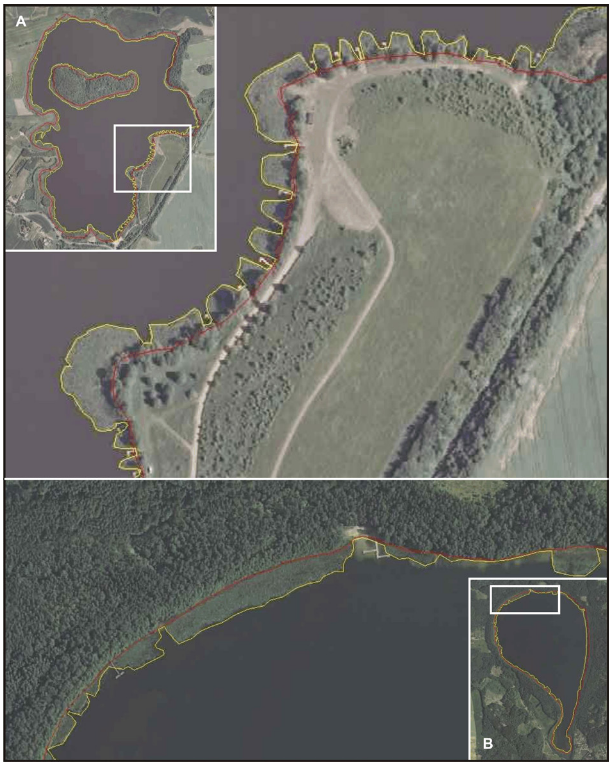

Fig. 3. The course of the shoreline (red line) and a range of emergent vegetation (yellow line) including the gaps in the reed belt, building bridges of orthophotomaps, for example: (A) Choczewskie Lake (Pomeranian Lakeland) and (B) Lake Sowica (Masurian Lakeland)

the coefficient reaches the values below 6.4% on average.

This may be a parameter showing which lakes are more susceptible to the process of plant overgrowing though there is no functional relationship between these elements (Fig. 4). The attempts to establish relationships between the plant overgrowth coefficient and other morphometric parameters and the percentage share of the volume to the depth of 1 m did not prove these relationships (Skowron 2004).

According to the Inland Fisheries Institute, the total area covered by emergent plants equalled 11 219.0 ha for all analysed lakes (total area of lakes 141 250.8 ha), whereas according to the orthophotomap it was 10 637.2 ha (total area of lakes 138 273.7 ha) with the mean coefficient of overgrowing of 7.97 and 7.69% respectively. In the case of the data from the orthophotomap, the biggest values were 30% higher for 35 lakes (Table 2), and were characteristic of small lakes with the area of up to 50 ha. However, the indicator of plant overgrowth of the lakes ranged from 0 to 20% for 784 lakes. On the other hand, the lowest values referred to considerably bigger water bodies, and were below 3.0% for 10 lakes (eg. Niegocin 1.8%, Miedwie 1.7%, Żarnowieckie Lake 1.1%).

Lake disappearance is rightfully associated with the decline of the water table, the accumulation of deposits in the lake basin and progressing eutrophication (Choiński 2007; Skowron and Piasecki 2014). In the process of plant overgrowing whose pace slows down with the distance from the shore, the shoreline plant overgrowth indicator is an important parameter ($ha \cdot km^{-1}$). It determines the area of plant overgrowth of the littoral zone per one kilometre of the shoreline length (Fig. 5).

Increase the mean value of the coefficient of overgrowing the shoreline equals 1.41 $ha \cdot km^{-1}$ at the turn of the 1950s and 1960s (the first bathymetric plans), whereas 50 years later it reaches 1.45 $ha \cdot km^{-1}$. This clearly confirms the presence of plant overgrowth of the lakes and concurrent plant succession. This is due mainly to the reduction in this period the average level of the water in the lakes. Maximum and minimum value of both indicators are shown in Table 3 and 4.

Table 1. Mean values of the area of plant overgrowth of the lakes (ha) and coefficient of overgrowing the lakes (%) at the mean depth ranges of lakes in the Polish Lowland

Mean depth (m)	after Inland Fisheries Institute (1958–1963)		after orhtophotomap (2010–2011)	
	[ha]	[%]	[ha]	[%]
0–2.5	13.7	14.1	11.9	17.7
2.6–5.0	9.9	10.7	9.0	11.8
5.1–7.5	8.9	7.9	9.8	9.1
7.6–10.0	22.0	7.1	20.3	7.8
10.1–12.5	13.1	6.4	13.4	6.7
> 12.5	21.7	5.0	21.2	5.5

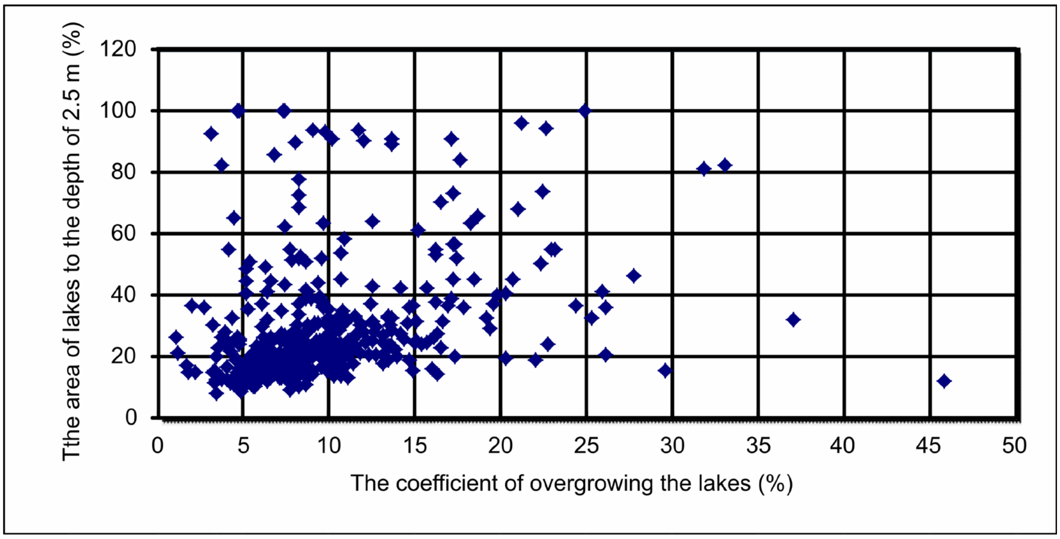

Fig. 4. Relationship between the coefficient of overgrowing the lakes (%) of the lake and the percentage share of the area to the depth of 2.5 m for the analysed lakes in the Polish Lowland

Table 2. Values of the indicator of plant overgrowth of the lakes (emergent plants) with respect to the area of the analysed lakes (893 lakes) according to the Institute of Inland Fisheries and the orthophotomap

Size classes of emergent plants	Plant overgrowth according to the Inland Fisheries Institute (1958–1963)		Plant overgrowth according to an orthophotomap (2010–2011)	
[%]	number lakes	mean area [ha]	number lakes	mean area [ha]
0–10	530	11.5	502	12.8
10.1–20	289	14.5	282	9.7
20.1–30	58	13.6	74	11.8
30.1–40	10	10.1	24	15.5
40.1–50	2	19.0	6	16.8
> 50	4	5.2	5	23.9

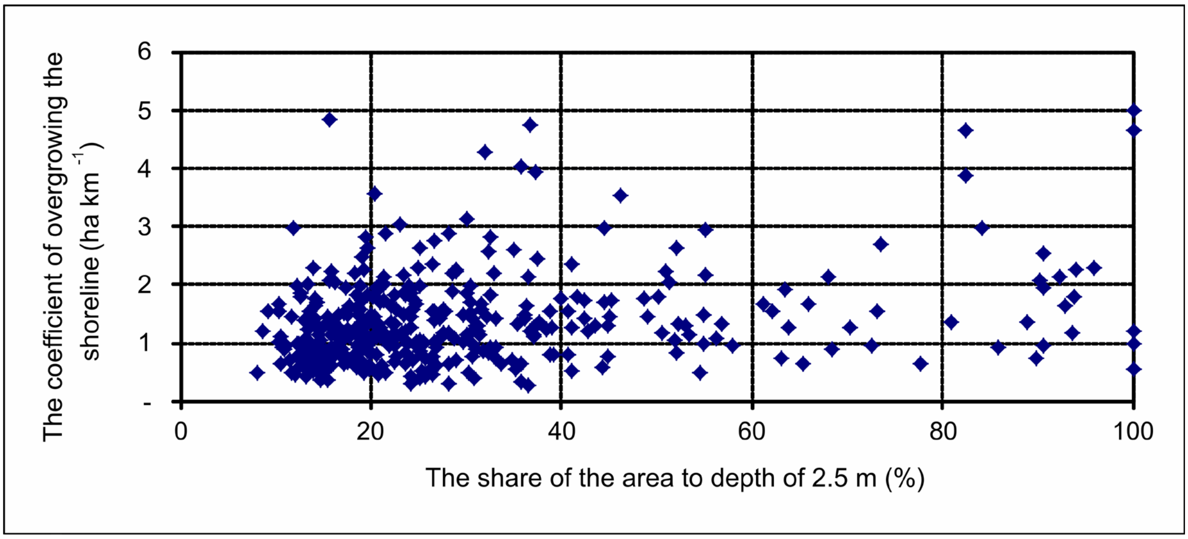

Fig. 5. Relationship between the coefficient of overgrowing the shoreline (ha·km^{-1}) and the percentage share of the area to the depth of 2.5 m for the analysed lakes in the Polish Lowland

Table 3. Maximum and minimum value of the coefficient of overgrowing the lakes (%) in the area of the Polish Lowland on the grounds

Highest values		Lowest values	
Lake[1]	Value	Lake[1]	Value
Sejny (II-19-56)	70.7	Psarskie (III-18-122)	0.6
Trzebidzkie (III-50-03)	69.3	unnamed (III-10-09)	0.9
Brzeźno (III-20-35)	61.4	Żarnowieckie (I-03-08)	1.1
Małe (Łasińskie) (III-50-02)	56.8	Gosławskie (III-45-01)	1.2
unnamed (II-43-47)	56.0	Miedwie (I-60-44)	1.7
Klasztorne (I-78-40)	45.8	Niegocin (II-27-12)	1.8
Brzeźno (II-43-49)	45.0	Warszyn (I-36-89)	2.0
Świerczyńskie (III-56-10)	43.5	Raduńskie Dolne (I-19-49)	2.2
Obrzańskie (III-49-07)	43.4	Kubek (III-08-13)	2.3
unnamed (II-43-48)	42.3	Węgorzyno (I-19-02)	2.4

Symbols: [1] – the number of the lake according to the Catalogue of Polish Lakes (Choiński 2006)

Table 4. Maximum and minimum value of the coefficient of overgrowing the shoreline ($ha \cdot km^{-1}$) in the area of the Polish Lowland on the grounds

Highest values		Lowest values	
Lake[1]	Value	Lake[1]	Value
Trzebidzkie (III-50-3)	15.2	Psarskie (III-18-122)	0.04
Sejny (II-19-56)	12.1	Łęgowskie (III-10-13)	0.14
Wonieść (III-50-4)	9.3	unnamed (III-10-9)	0.19
Tuchlińskie (II-37-9)	7.8	Barlińskie (I-79-38)	0.20
Małe (III-50-2)	7.2	Kubek (III-8-13)	0.21
Jędzelek (II-27-10)	7.1	Mozguć (II-19-17)	0.23
Wielkie (III-50-1)	6.8	Łapińskie (I-20-8)	0.26
Brzeźno (II-43-49)	6.7	Klonek (II-19-19)	0.27
Skomętno (II-29-1)	6.4	Warszyn (I-36-89)	0.28
Kolno (II-39-20)	6.3	Retno (II-49-66)	0.30
Woszczelskie (II-28-29)	6.3	Ostrowite (I-36-34)	0.30
unnamed (II-43-47)	6.2	Nierybno (I-36-75)	0.30

Symbols: [1] – the number of the lake according to the Catalogue of Polish Lakes (Choiński 2006)

Discussion

The article presents two indicators which make it possible to study the extent of lake overgrowing in the South Baltic Lakeland (Northern Poland), regardless the direction of these changes. The study accounts for the data concerning overgrowing of the lakes established by two sources: the Institute of Inland Fisheries, and the authors' calculations on the grounds of the present aerial orthophotomaps.

The analyzed sample of lakes (893 lakes) applies to c. 13.1% of all postglacial lakes in Poland and is c. 50.9% of their area and 49.7% of their water resources. A large number of lakes, including lakes of various sizes (ranging from less than 2 ha to almost 10 000 ha), mean depth (from 0.3 m to 23.4 m) and different relief of littoral zone is a representative statistical sample used to determine the any changes leading to overgrowth in lakes. The analysis was based on 5 basic statistical parameters: the mean value, maximum value, minimum value, standard deviation and the coefficient of variation. The standard deviation values for both the coefficient of overgrowth of the lakes (%) and the coefficient of overgrowth of the shoreline of the particular lakeland showed considerable dispersion: 6.49-9.15 and 0.92-1.13. However, incoporating all lakes, the values were 8.2 i 1.07, respectively. This is confirmed by the coefficient of variability within the limits: 0.92–1.13 and 0.60–0.93, and taking into account all lakes: 1.18 and 0.79. In addition, the average values and extreme values clearly show varrying degrees of significant dispersion of overgrowth within each lakeland. The lowest values of overgrowth of the lake can be seen/observed in, and is characteric of, Pomeranian Lakeland. While the highest values of standard deviation of coefficient of overgrowth the shoreline (ha·km^{-1}) is found in the lakes within the Wielkopolskie Lakeland (1.49). The values of statistical analysis can be observed in Tables 5 and 6. The dispersion of data concerning the overgrowth of lakes in the Polish lakelands results from both the large diversity of their morphometry and the degree of eutrophication of their waters.

During the period of fifty years between the source materials for 893 lakes used in the study there was a general decline in water levels in the lakes. This process was accompanied by overall shallowing of the lakes, i.e. the isobaths moved 1.0 and 2.5 m towards the profundal zone. Alongside the succession of plants in the littoral zone, vegetable islands and also land islands are more frequently formed in the different parts of the lakes. Altogether, out of 893 in analysed lakes 595 vegetable islands of the total area of 585.5 ha and 446 land islands of the total area of 866.6 ha were established. At the same time the inner borderline of emergent plants moved in the same direction. The comparison of the data from the Institute of Inland Fisheries and from the orthophotomap shows prevailing increase of the lake's shoreline length in the particular lakelands: the Masurian by 6%, Pomeranian by 1%, and Wielkopolskie by 0.5% (Table 7). This fact may most probably be related to a more diversified relief of the littoral, where the shoreline processes occur too short.

The relationship between plant overgrowth of the lakes and the altitude above sea level seems interesting. The analysed lakes were assigned to altitude classes in the ranges of 20 m, i.e. from 0 to 200 m a.s.l. and over 200 m a.s.l. The obtained results for the entire study area are presented in Table 8.

In general, the relationship between plant overgrowing and the water table proves the intensity of postglacial relief, and perhaps the influence of an-

Table 5. Statistical features of the coefficient of overgrowth of lakes (%)

Statistical features	Pomerania Lakeland		Masurian Lakeland		Wielkopolskie Lakeland		Total	
	A	B	A	B	A	B	A	B
Numbers of records	301	301	336	336	256	256	893	893
Mean values	6.35	5.73	8.55	8.21	9.45	9.96	7.97	7,69
Maximal	63.6	45.8	66.9	70.7	56.4	69.3	66.9	70.7
Minimal	0.0	1.1	0.5	1.8	0.6	0.6	0.0	0.6
Standard deviation	7.51	6.49	7.49	8.61	7.45	9.15	7.59	8.20
Coefficient of variability	1.18	1.13	0.88	1.05	0.79	0.92	0.95	1.07

Symbols: A – after Inland Fisheries Institute, B – after orthophotomap

Table 6. Statistical features of the coefficient of overgrowth of the shoreline (ha·km^{-1})

Statistical features	Pomerania Lakeland		Masurian Lakeland		Wielkopolskie Lakeland		Total	
	A	B	A	B	A	B	A	B
Numbers of records	301	301	336	336	256	256	893	893
Mean values	1.1	1.2	1.6	1.7	1.4	1.6	1.4	1.5
Maximal	11.7	5.0	10.3	12.1	9.4	15.2	11.7	15.2
Minimal	0.0	0.2	0.0	0.3	0.0	0.0	0.0	0.0
Standard deviation	1.24	0.72	1.26	1.21	1.08	1.49	1.23	1.19
Coefficient of variability	1.12	0.60	0.79	0.71	0.78	0.93	0.88	0.79

Symbols: A – after Inland Fisheries Institute, B – after orthophotomap thropopressure, e.g. the altitude of farming and related anthropogenic denudation (Sinkiewicz 1998; Choiński 2007). Since the lower a lake lies in the catchment the more susceptible it is to degradation and subsequent disappearance. In turn, the higher the lake is located the less matter it receives, thus has better chances for a longer lifespan. Moreover, those lakes located higher have better retention capacity and slower exchange of waters.

This relationship is partially visible in the range 20.1–180 m a.s.l. in the Polish Lowland. With the gradual decline in the water table position above sea level in this range, the plant overgrowth indicator increases from 6.40% (160.1–180 m a.s.l.) to 10.48% (60.1–80 m a.s.l.). The lowest values are recorded in the lakes within the range 0.1–20 m a.s.l. (coastal lakes), which is related to their different, as compared to typical lakeland reservoirs, hydrological regimes (inlets of saline sea waters). In turn, above 180.1 m a.s.l. this indicator rises from 8.48% to 11.23% (Table 8).

Therefore, the following factors determine the faster plant overgrowing rate: quantity and quality of biogenic substances migrating from the catchment to the lake, the slope of the direct catchment, the participation of the littoral zone in the lake's area (the depth of 0–2.5 m), and the lake's age.

The above points are confirmed by the investigations conducted in the postglacial lakes located in the southeast part of the Baltic Sea catchment area. The area of macrophytes increased in the lakes located in central and southern Finland in the second half of the twentieth century (Valta-Hulkonen et al. 2004), and with various course (Partanen and Hellstenm 2005). A similar process occurs in the shallow lakes of Estonia and Latvia (Brižs 2011). Furthermore, according to Linkevičienė (2007), the disappearance of the lakes is a widespread process comprising various types of the lakes.

As already mentioned earlier, this paper presents two indicators which determine plant overgrowth of the lakes. However it must be underlined that the source materials used in the study mainly determine the obtained results. In the case of the topographic maps at the scale 1:50 000, their accuracy amounts to at least 25 metres (0.5 mm in the scale of the map), whereas mapping on the digital layer of the orthophotomap (of 0.5–metre pixel or less)

Table 7. Mean shoreline lengths in the studied lakes in the lakelands and their changes

Lakeland	Shoreline length [m]		Change (%)
	after Inland Fisheries Institute (1958–1963)	after orhtophotomap (2010–2011)	
Pomeranian	6389.0	6451.0	1.0
Masurian	8166.3	8655.1	6.0
Wielkopolskie	6463.9	6498.2	0.5

Table 8. Parameters of plant overgrowth of the lake in the ranges of the altitude of the water table a.s.l.

Ranges of altitude of the water level (m a.s.l.)	Number of lakes	Total area of lakes (ha)	Total area of plant overgrowth (ha)	Area of plant overgrowth (%)
0.1–20	18	22716.2	809.3	3.56
20.1–40	29	2529.8	184.3	7.28
40.1–60	88	9250.8	851.2	9.20
60.1–80	162	15344.3	1608.9	10.48
80.1–100	175	19585.3	1735.3	8.86
100.1–120	129	35127.6	2628.3	7.48
120.1–140	184	22260.9	1977.8	8.88
140.1–160	65	6689.8	511.4	7.64
160.1–180	31	4288.7	274.4	6.40
180.1–200	7	137.9	11.7	8.48
> 200	5	397.0	44.6	11.23

is carried out with the accuracy of at least 1 metre. Surely in the future (in 20–30 years) it will be possible to make comparison on the grounds of teledetection data exclusively.

Conclusions

The analysis of the extent of plant overgrowth of the lakes in the main lakelands refers to 893 lakes, i.e. 13.1% of their total number, which constitutes 50.9% of their entire area and 49.7% of their water resources. These lakes constitute a representative group for the determination of the changes. The calculations and comparison of several parameters referring both to the lake basin and the extent of plant overgrowth of the lake made it possible for the authors to draw a number of conclusions:

- The analysis of the materials for individual lakes proves that there are considerable differences between the areas of the lakes presented in the Inland Fisheries Institute and the data obtained from the orthophotomap 1.5%. This difference mainly results from the accuracy of the base material and the area measurement method itself.
- The changes in the succession of plants involve mainly the shoreline of the lake basin, which is well represented by the coefficient of overgrowing the lakes (%) and the coefficient of overgrowing the shoreline ($ha \cdot km^{-1}$).
- Changes related to succession of emergent plants in the studied lakes primarily result from declining water levels and increasing littoral zone.
- The mean coefficients of the plant overgrowth of the lake determined for 893 lakes on the basis of the orthophotomap equals 7.69%, and is smaller by 0.28% with respect to the data obtained from the bathymetric plans of the Inland Fisheries Institute. Primarily, this indicates that the overall surface of lakes is decreasing.The minimum values are below 2.4% for 10 lakes, whereas the maximum values are higher than 42.3% for 10 lakes.
- The calculated data indicate that in the lakes with the area of up to 50 ha, the coefficients of the plant overgrowth of the lake is higher than 10.0%, whereas it is most frequently below 5% in the lakes with the area exceeding 500 ha.
- The mean coefficient of overgrowing the shoreline of the analysed lakes on the grounds of the orthophotomap equals 1.41 $ha \cdot km^{-1}$, and is bigger by 0.04 $ha \cdot km^{-1}$. While the extreme values ranged from 0.04–15.2 $ha \cdot km^{-1}$.
- The distribution of the indicator of the plant overgrowth of the lakes is typical of the altitude above sea level. It oscillates predominantly between 6.40 and 10.48%, though it equals merely 3.6% in the range from 0.1–20 m a.s.l., while it exceeds 11.23% above 200 m a.s.l.
- The measured statistical parameters for both indices show that the process of lake overgrowth is characterized by vast diversity among its various regions and indicated relationships with the morphometry of lake basins, mainly in the littoral zone.

Acknowledgements

We express our gratitude to Professor Władysław Niewiarowski for inspiration and creative discussion regarding on the changes in lake area on the young glacial areas.

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Received 09 November 2016
Accepted 17 March 2017