Limnological Review 4 (2004) 167–176

Changes in the area of the Mazurian Lakes in the light of the cartographic materials at the scale 1:25000

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Abstract: The article presents the result of comparative investigations of the areas of the Great Mazurian Lakes. Water decrease was found at the level of 3.1% in the period of approximately seventy years of the twentieth century. Similar tendency was documented with respect to several cases from the latter half of the nineteenth century. The authors draw attention to the role of hydrotechnical build-up (canals, sluices, weirs) constructed to slow down the pace of lake area decline. Several examples of lake area increase and renaturalisation are demonstrated. Most frequent physiographic consequences caused by changes in the lake area include: decrease of bay areas, growth of the extent and number of wetlands, and expansion of islands. The results of the authors' investigations are compared with other materials and data.

Key words: lakes, changes in the area, tendency, consequences, the Great Mazurian Lakes Region.

Introduction

Changes in the area constitute one of the indicators of the lake evolution. They occur faster in postglacial lakes located in the areas, which are characterised by high biomass production. Up to the sixteenth century these changes involved the lake decrease due to natural processes, including among others: lowering of the erosion bed, overgrowing, and accumulation of bottom sediments. For the last two hundred years these have been intensified by anthropogenic activity, and have involved not only the decrease but also the increase of the lake area.

The specialist literature most frequently discusses the changes in the area and number of the lakes, as well as the pace of their decline. Researchers are primarily interested in the postglacial lowland lakes, where these processes occur faster than in the lakes of a different genesis. Most frequently the results of the investigations documenting the decrease of the lake area have been published (on a physical-geographic scale these were publications by among others: Srokowski, 1930; Glazik, 1988; Jańczak, 1991; Lossow, 1996; Dąbrowski, 2001; Choiński, Madalińska, 2002 and the entire country: Choiński, Jańczak, 1988; Choiński, 1991, as well as with respect to particular lakes: Jureko, 1969; Babiński, 1988, among others). The review of the works dedicated to these problems was presented by Choiński (1995). The analyses of the changes in the lake areas conducted on the grounds of the bathymetric plans of the nineteenth and twentieth centuries have been rarely conducted (Choiński, 2002).

The main objective of this work is to define the directions and size of changes in the lake areas in the Great Mazurian Lakes Region in the twentieth century, as well as their physiographic consequences, including those related primarily to the land layout. The study area was selected because of three reasons, at least:

— the biggest lake density in Poland (24,1%);
— the availability of cartographic materials from the beginning and the end of the twentieth century at the same scale 1:25000;

— considerable importance of water resources to the region for municipal management, farming and tourism purposes.

The study area covers approximately 1730 km^2. There are 201 lakes bigger than 1 ha, which cover 416,56 km^2 altogether (Lossow, 1996).

Methods and extent of investigations

The work includes cartographic materials at the scale 1:25000 from two different periods: Prussian topographic maps Kőnigl. Preußische Landesaufnahme, Reichsamt fűr Landesaufnahme made in the years 1909–1919 and the Polish topographic maps from 1984, made on the grounds of the maps at the scale 1:10000 from 1981 and 1982. The use of maps in a uniform and detailed scale and the software MapInfo 4.0 made it possible to increase the accuracy of measurements required for this type of compilations. The time interval, when the studied changes of the lake area occurred, amounts from 62 to 73 years (67 years on average).

The accuracy of the maps was checked with respect to potential paper deformations (shrinkage). The measurements along the lines of a kilometre grid were conducted on several representative map sheets. Polish topographic maps from the 1980s were found to have good carthometry where surface deformation coefficient did not exceed 0.2%. On the other hand, the surface shrinkage of the archival maps amounted from 0.25 to 0.82%, which for the accuracy of the conducted graphic works of the 0.2– 0.3 mm order offers the imprecision of approximately 5%. It is generally accepted to assume that the error amounting from 3 to 8 % gives reliable results and allows for defining the tendencies of the changes.

All the lakes bigger than 1 ha in the Great Mazurian Lakes Region were subject to the analysis. Their areas were calculated in the years 1909–1919 and 1981–1982 (Fig. 1). When the difference in the area of a given lake did not exceed 1% in the two terms, they were assumed not to have changed their areas. Minor changes could have been caused by periodical fluctuations of water levels, and hence, a different course of the lake shorelines.

Changes of water networks and their influence upon the lake areas

Anthropogenic interference in the hydrological network of the Great Mazurian Lakes Region dates back to the sixteenth century, and has been related to economic development and population increase (Dąbrowski, 2001). Three directions dominated water network transformations:

— rises of the lake levels with a view to building water mills, among others;
— wetland drainage and lake levels lowering with a view to obtaining new lands for meadows and pastures;
— constructions of canals to join lakes and make water routes for transportation.

As early as in the seventeenth and eighteenth centuries hydrotechnical works in the vicinity of Węgorzów (construction of mill-ponds and moats) resulted in the water level increase by 2.8 m, and the merger of several lakes into one reservoir. Thus, a big complex of Lake Mamry developed in the northern part of the discussed region (the total area of approx. 99 km^2). It has retained its shape until the present time (Toeppen, 1998). The construction of the water routes also began to allow for the transportation of wood from the south to the north. Up to 1765 five canals had been completed which joined the biggest lakes in the central and northern parts of the region. Their water levels were determined at various heights and maintained by sluices. Slightly later, in the years 1845–1849 the 98-kilometre long Jagiellonian Canal was dug to join the lakes located in the southern part of the Great Mazurian Lakes Region.

Since the beginning of the nineteenth century melioration works were carried out with a view to lowering the water levels. Lakes Kruklińskie and Wąż serve as a good example here, being decreased by 6.3 and 2.0 m respectively. The area of nearly 9 km^2 obtained in such a way was managed for farming purposes: meadows and pastures (Srokowski, 1930). Melioration works and canals constructions also continued in the twentieth century. The completion of a project to join the Great Mazurian Lakes and Pregoła was, however, interrupted due to the war. The Mazurian Canal (in the direction of Lake Rydzówka) remained uncompleted, similarly to other related hydrotechnical constructions.

Fig. 1. Location of the lakes in the Great Mazurian Lakes Region. The lakes with area changes marked with numbers (as in Table 1) Symbols: 1 – region border; 2 – major towns

Anthropogenic changes of the water network in the Great Mazurian Lakes Region were multidirectional. Sub-damming of lakes resulted in the increase of their areas, and numerous weirs and sluices stabilized the water level at particular heights. The changes of this type occurred predominantly in the biggest lakes. On the other hand, water levels in many single and minor lakes decreased, mainly due to melioration works.

Results

The changes in the area exceeding 1% were recorded in 116 lakes out of 203 located in the Great Mazurian Lakes Region (Fig.1, Tab.1). They constitute 57%, and as much as 83.2% of the total area of all the lakes. The remaining 85 lakes (42.3%) were found to have undergone insignificant changes (below 1%), or there were no changes at all. These were the lakes located most frequently in deep sub-glacial channels, such as: Bełdany, Buwełno and Tałty-Ryńskie, among others. There were merely minimal divergences in the course of shorelines in some bays, which correlates to the morphometric properties of these lakes. They are characterised by big depths, considerable bed gradient and the steep slopes of subglacial channels. Their demise occurred mainly through the shallowing of the lake basin, and not through the change of the course of the lake shoreline or its area, which was visible on the maps.

The analysis of 116 lakes, whose areas underwent changes, indicated that they had covered 32956.8 ha in the early twentieth century (1909–1919). Whereas, in the years 1981–1982 its total area diminished by 1236.4 ha (3.8%) and amounted to 31720.4 ha. In this group as many as 98 lakes (84.5%) showed a tendency of the area decrease (31428.1 down to 29904.3 ha, i.e. by 4.9%). Two lakes totally vanished, and they were open lakes: Wąż and Ornet, located in the swampy areas. These lakes disappeared due to the intensive melioration works conducted in their catchments. The biggest area declines (even above 80%) were recorded in a group of the smaller lakes (from some to dozen or so hectares). On the other hand, the areas of the biggest lakes decreased faintly: Śniardwy by 2.4%, and the entire complex of Lake Mamry by 3.5% (Tab. 1). Located in the complex of Lake Mamry, Kirsajty, a shallow lake, whose area decreased by 14.2%, illustrated the most significant changes. In the northern and southern parts of this lake there was a considerable narrowing caused by transformation of the isles into peninsulas. Besides, the area of these isles increased, and in two cases the neighbouring isles merged. The changes in the course of the shorelines of the remaining reservoirs of the Mamry complex were minor. Only the areas of most isles grew from some to dozen or so percent.

Eighteen lakes (15.5%) showed another tendency. Their areas expanded from 1528.7 up to 1816.1 ha, i.e. by 18.8%. Lake Guber increased most from 35.6 ha in 1916 up to 204.9 ha in 1982. This fact deserves particular attention, as it is an interesting and unique renaturalisation example of a big lake. At the beginning of the twentieth century there used to be only shallow floodwaters there, surrounded by a system of melioration ditches, which implied an anthropogenic character of the land drainage. In the 1930s the development of sugar industry in the vicinity of Kętrzyn caused the increase of water demand for technological purposes. This resulted in the construction of weirs at the outflow from the lake (the River Guber) and reformation of the lake. With time the lake expanded. It got inhabited by rare species of birds and became a symbol of cooperation between the man and nature. The examples of the changes of certain lake areas are presented in Fig. 2.

Apart from the area the size structure also changed. The most significant changes occurred in a group of the lakes whose area reached 50 ha. They involved the rise and decline of the number of lakes in particular size classes (Tab. 2). The number of the smallest lakes (≤ 5.0 ha) rose by half, and declined by approx. 25% in the class from 20,1 do 50 ha. The number of lakes did not change in the class of the biggest lakes, i.e. 100.1–500.0 ha and above 500 ha, however, their areas decreased (altogether by 886.9 ha).

The changes in the lake area can also be expressed in percentages. In such an assessment the biggest group comprises the lakes whose area decreased from 10 to 50% (37) and from 5 do 10% (23). Only in four cases did the lake area rose above 10%, including 2 by over 50% (Tab. 3). It is worth emphasising that nearly 27% of the lakes are characterised by insignificant area changes which fall into the error limits of the conducted measurements and calculations.

Table 1. Changes in the areas of the lakes in the Great Mazurian Lakes Region (the numbers of the lakes as in Fig. 1)

No.	Lake	Area (ha)		Difference		No.	Lake	Area (ha)		Difference	
		1909–1919	1981–1982	(ha)	(%)			1909–1919	1981–1982	(ha)	(%)
1	Babka	33.4	50.5	17.1	51.2	59	Mierzejewskie	145.5	139.9	-5.6	-3.8
2	unnamed lake	13.5	2.1	-11.4	-84.4	60	Mikołajskie	498.3	488.5	-9.8	-2.0
3	unnamed lake	9.8	5.9	-3.9	-39.8	61	Miłkowskie (Wobel)	21.1	22.6	1.5	7.1
4	unnamed lake	1.4	1.5	0.1	7.1	62	Mój	127.2	110.6	-16.6	-13.1
5	unnamed lake	12.1	13.3	1.2	9.9	63	Okrągłe	36.4	35.9	-0.5	-1.4
6	unnamed lake	14.1	12.5	-1.6	-11.3	64	Orło	111.7	118.1	6.4	5.7
7	unnamed lake	6.3	1.9	-4.4	-69.8	65	Ornet	21.4	0.0	-21.4	-100.0
8	unnamed lake	3.8	3.3	-0.5	-13.2	66	Orzysz	1066.4	1041.6	-24.8	-2.3
9	unnamed lake	4.0	1.8	-2.2	-55.0	67	Osiołek	1.6	1.3	-0.3	-18.8
10	Biała Kuta	126.4	124.1	-2.3	-1.8	68	Pamer	64.0	61.9	-2.1	-3.3
11	Białe	8.0	7.0	-1.0	-12.5	69	Pamerek	15.1	13.8	-1.3	-8.6
12	Borkowskie	3.1	2.7	0.4	-12.9	70	Paproteckie	24.2	24.5	0.3	1.2
13	Brożówka	57.4	62.1	4.7	8.2	71	Patelka (Patelnia)	11.1	12.2	1.1	9.9
14	Czarne	2.9	3.3	0.4	13.8	72	Piecek	22.7	23.1	0.4	1.8
15	Dargin	3059.1	2968.7	-90.4	-3.0	73	Pierwos	23.6	3.3	-20.3	-86.0
16	Dejguny	846.4	820.7	-25.7	-3.0	74	Płociczne	30.9	29.1	-1.8	-5.8
17	Dgał Mały	19.4	14.1	-5.3	-27.3	75	Płociczne II	10.6	1.8	-8.8	-83.0
18	Dgał Wielki	100.6	86.4	-14.2	-14.1	76	Pniewskie	45.4	41.5	-3.9	-8.6
19	Długie	38.8	36.0	-2.8	-7.2	77	Pozezdrze	131.4	122.9	-8.5	-6.5
20	Długie II	24.5	23.4	-1.1	-4.5	78	Przykop	13.8	10.6	-3,2	-23.2
21	Dłużec	11.6	9.2	-2.4	-20.7	79	Romint	29.9	11.5	-18,4	-61.5
22	Dobskie	1797.5	1738.1	-59.4	-3.3	80	Rudzienko	2.6	1.9	-0,7	-26.9
23	Dziewiszewskie	24.5	17.1	-7.4	-30.2	81	Rudzkie	24.5	20.3	-4,2	-17.1
24	Fryd	48.9	35.2	-13.7	-28.0	82	Sajno	32.1	21.2	-10,9	-34.0
25	Gardyńskie	90.1	68.1	-22.0	-24.4	83	Siersze	62.6	50.4	-12,2	-19.5
26	Głęboka Kuta	15.8	16.4	0.6	3.8	84	Silickie	118.1	122.8	4,7	4.0
27	Głębokie	45.3	44.1	-1.2	-2.6	85	Skarż	58.5	45.3	-13,2	-22.6
28	Gołdapiwo	923.2	961.3	38.1	4.1	86	Skok	12.6	11.0	-1,6	-12.7
29	Grajewko	43.6	41.0	-2.6	-6.0	87	Smolak	9,4	8.7	-0,7	-7.4
30	Gryżewskie	4.7	3.8	-0.9	-19.1	88	Smolak Mały	3.7	2.5	-1,2	-32.4
31	Grzybek	4.5	0.7	-3.8	-84.4	89	Stręgiel	403.1	396.6	-6,5	-1.6
32	Guber	0.0	190.8	190.8	100.0	90	Stręgielek	36.7	34.5	-2,2	-6.0
33	Harsz	219.5	192.7	-26.8	-12.2	91	Sztynorskie	48.6	45.7	-2,9	-6.0
34	Iławki	120.4	114.4	-6.0	-5.0	92	Szymon	164.0	129.6	-34.4	-21.0
35	Inulec	169.5	163.2	-6.3	-3.7	93	Śniardwy	11636.0	11351.7	-284.3	-2.4
36	Jagodne	946.9	912.5	-34.4	-3.6	94	Święcajty	845.1	817.5	-27.6	-3.3
37	Jagodzienko	7.2	5.6	-1.6	-22.2	95	Tajty	249.4	241.0	-8.4	-3.4
38	Jaśkowskie (Małe)	5.1	1.1	-4.0	-78.4	96	Talki	1.1	1.0	-0.1	-9.1
39	Jeziorka	11.5	6.1	-5.4	-47.0	97	Tałtowisko	339.7	302.7	-37.0	-10.9
40	Jędzelek	87.7	46.1	-41.6	-47.4	98	Tuchel	42.4	38.9	-3.5	-8.3
41	Jorzec	43.9	37.2	-6.7	-15.3	99	Tuchlińskie	230.8	214.8	-16.0	-6.9
42	Kąpskie	19.4	18.2	-1.2	-6.2	100	Tyrkło	227.2	219.1	-8.1	-3.6
43	Kęczek	4.0	3.5	-0.5	-12.5	101	Upinek	10.3	9.7	-0.6	-5.8
44	Kirsajty	221.2	189.8	-31.4	-14.2	102	Upłackie Małe	10.9	11.6	0.7	6.4
45	Kisajno	1987.1	1941.5	-45.6	-2.3	103	Warniak Duży	40.3	35.9	-4.4	-10.9
46	Kotek	37.4	16.2	-21.2	-56.7	104	Wąż	45.9	0.0	-45.9	-100.0
47	Kruklin	361.4	354.9	-6.5	-1.8	105	Wejsunek	38.3	32.0	-6.3	-16.4
48	Kuchenka	15.4	14.1	-1.3	-8.4	106	Wersminia	97.7	87.7	-10.0	-10.2
49	Kwiedzińskie	33.3	42.0	8.7	26.1	107	Wesołek	1.5	1.4	-0.1	-6.7
50	Lemięt	73.3	68.7	-4.6	-6.3	108	Węgielsztyńskie	81.4	78.6	-2.8	-3.4
51	Lisunie	12.9	11.7	-1.2	-9.3	109	Wigrynki	38.4	17.3	-21.1	-54.9
52	Ławki	67.7	66.2	-1.5	-2.2	110	Wilkasy Duże	40.9	33.1	-7.8	-19.1
53	Ławki Małe	29.3	23.4	-5.9	-20.1	111	Wilkasy Małe	5.2	4.7	-0.5	-9.6
54	Łuknajno	697.3	599.1	-98.2	-14.1	112	Wilkus	122.8	133.2	10.4	8.5
55	Małe (Bębenek)	6.6	6.8	0.2	3.0	113	Wojnowo	169.6	165.4	-4.2	-2.5
56	Mamry Północne	2560.1	2448.2	-111.9	-4.4	114	Wojsak	56.7	19.2	-37.5	-66.1
57	Mażańskie	20.3	13.1	-7.2	-35.5	115	Zełwążek	11.3	10.7	-0.6	-5.3
58	Miałkie	10.5	7.4	-3.1	-29.5	116	Żywki	21.5	17.2	-4.3	-20.0

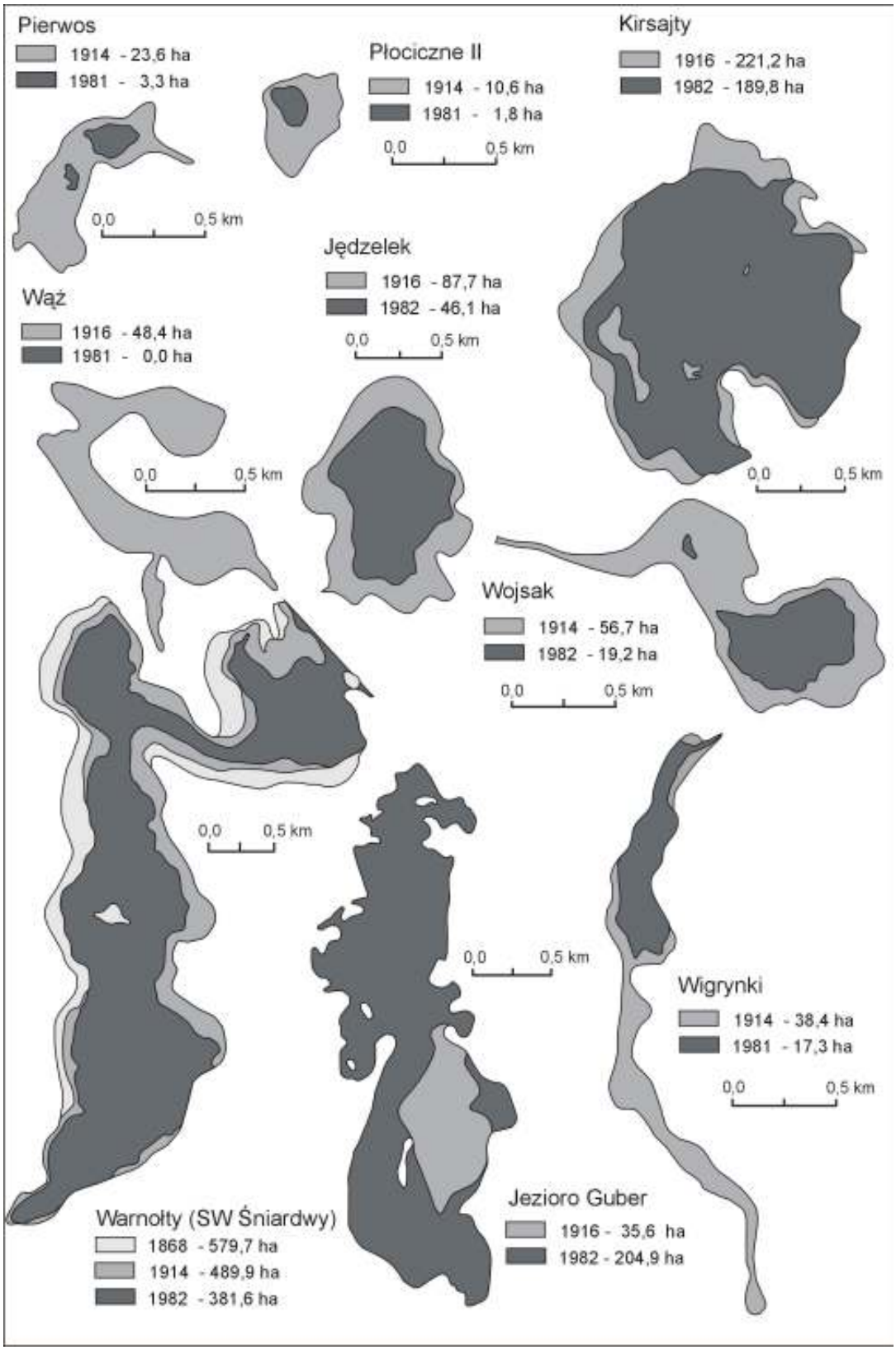

Fig. 2. Examples of the lake area changes in the Great Mazurian Lakes Region

In a longer time interval (over 110 years) the lake area changes can be documented using the maps at the scale 1:25000 made in the years 1868–1873, and published after 1875. These are the oldest maps at this scale, and at the same time they are topographic maps of good quality (Topographische Über-sichtskarte des Deutschen Reiches/Königl. Preu-ßische Landesaufnahme; Reichsamt für Landesauf-nahme). The authors were granted access to them in the City Library in Berlin, Germany. Despite the fact that these maps were prepared after the completion of the biggest hydrotechnical works in the Great Mazurian Lakes Region, they make it possible to indicate the continuity of the changes in the lake areas and the course of the shorelines. The pace of the changes varied in particular cases, which may prove the diverse intensity of anthropopressure. Several selected examples are quoted in Tab. 4.

Table 2. Division of the lakes with the recorded area changes according to the size classes

Size classes (ha)	1909–1919		1981–1982	
	N	% NT	N	% NT
	S (ha)	% ST	S (ha)	% ST
≤ 5.0	14	12.1	21	18.1
	38.9	0.1	43.6	0.1
5,1 – 10.0	11	9.5	9	7.7
	89.4	0.3	66.4	0.2
10,1 – 20.0	17	14.6	20	17.3
	241.2	0.7	281.8	0.9
20,1 – 50.0	31	26.7	24	20.7
	1067.3	3.2	812.0	2.7
50,1 – 100.0	11	9.5	10	8.6
	797.1	2.4	680.6	2.1
100,1 – 500.0	21	18.1	21	19.0
	4357.8	13.2	4235.1	13.3
> 500	11	9.5	11	8.6
	26365.1	80.1	25600.9	80.7
Total	116	100.0	116	100.0
	32956.8	100.0	31720.4	100.0

Symbols: N – number of lakes, S – area, % NT – percentage of the total number of lakes, % ST – percentage of the total area

The changes of the lake area bring about various natural and economic consequences. The former can be subdivided into hydrologic and physiographic. The hydrologic effects include the changes of lake density, water retention size, the course of small circulation of water and water balance. Hydrologic consequences do not always predominate in lake area changes. The decline of water retention in a lake may go several times faster (Choiński, 2001). However, in the case of a big group of the lakes it is difficult to document this type of dependency, as it is indispensable to have the archival and contemporary bathymetric plans.

Table 3. Tendencies of the lake area changes

Tendencies		Number of cases	%
Area decrease	> 50%	13	11.2
	50.0 – 10.1	37	31.9
	10.0 – 5.1	23	19.9
Changes in the measurement error limits	0.0 – 5.0	31	26.7
Area increase	5.1 – 10.0	8	6.9
	10.1 – 50.0	2	1.7
	> 50%	2	1.7

It is considerably easier to define physiographic consequences of the changes in the lake area. They depend upon the type of the lake area decrease or increase. The physiographic effects are fewer with respect to lake area decrease, as the shape and the course of the shoreline alter evenly along the entire circumference (compare: Lake Jędzelek, Fig. 2). On the other hand, the fragmentary decrease of the lake area produces various physiographic results (compare: Lake Kirsajty, Fig. 2). Twelve types of such results were distinguished in the Great Mazurian Lakes Region (Tab. 5). Most frequently these were decreases of the bay areas (72 cases) and increases in the area and number of wetlands (61 cases). The changes of this type occurred in the lakes that are extremely different with respect to the covered areas (from some up to several thousand hectares).

Table 4. Changes in the areas of the selected lakes in the years 1868–1982

Lake	Lake area in ha			Difference					
	1868	1919	1982	1868–1919		1919–1982		1862–1982	
				ha	%	ha	%	ha	%
Jeziorka	13.7	11.5	6.1	2.2	16.1	5.4	46.9	7.6	55.5
Dziewiszewskie	39.9	24.5	17.1	15.4	38.6	7.4	30.2	22.8	57.1
Iławki	158.6	120.4	114.4	38.2	24.1	5.0	4.1	44.2	27.9
Warnołty (SW Śniardwy)	579.7	489.9*	381.6	89.8	15.5	108.3	22.1	198.1	34.2
Wersminia	107.1	97.7	87.7	9.4	8.8	10.0	10.2	19.4	18.1

*lake area in 1914

Table 5. Physiographic consequences caused by the changes in the areas of the Great Mazurian Lakes in the twentieth century

No.	Consequences of the changes in the lake area	Examples of the lakes	Number of cases
1	Decrease of bay areas	Dejguny, Dgał, Fryd, Grzybek, Iławka, Inulec, Jeziorka, Jędzelek, Jorzec, Kotek, Kruklin, Krzywa Kuta, Lemięt, Ławki, Mój, Pamer, Pozezdrze, Romnit, Siersze, Szymon, Tałtowisko, Tuchlińskie, Warnołty, Wejsunek, Wersminia, Wilkus	72
2	Increase of the area and number of wetlands	Brożówka, Czarne, Gardyńskie, Jędzelek, Łuknajno, Sajno, Warnołty, Wigrynki, Wilkasy Duże, Wojsak,	61
3	Increase of isles area	Kisajno, Siersze, Święcajty, Kruklin, Dargin	17
4	Formation of isles	Kwiedzińskie, Krzywa Kuta, Święcajty, Tajty, Gołdapiwo, Kruklin, Kirsajty, Tuchlińskie, Dobskie	10
5	Disappearance of isles	Babka, Wersminia, Iławka, Inulec, Łuknajno, Dargin	9
6	Formation of peninsulas due to the merger of the isles with the land	Krzywa Kuta, Kirsajty, Tuchlińskie, Dobskie, Warnołty	7
7	Narrowing of connections between the lakes	Harsz, Kruklin, Kirsajty, Skarż	6
8	Division of the lake into several parts (reservoirs)	Wersminia, Smolak Mały, Wojsak, unnamed lake (37)	5
9	Increase of bay areas	Babka, Orło, unnamed lake (9)	6
10	Formation of bays	Kwiedzińskie, Brożówka, Gołdapiwo, Upłackie Małe, Patelma	5
11	Lake demise	Wąż, Ornet	2
12	Lake formation	Guber	1

The isles were the most frequently changing elements. Three types of these changes were differentiated: area increase, demise, or formation of the new ones. The increase of the isle areas, which was recorded in dozen or so locations, concurred with the lake area decrease. Whereas, the isles demise or formation was spotted in the case of the lake area increase and decrease. Sometimes, these isles developed into peninsulas, and a part of the lake basin between the isle and the shore became a land.

In some bigger lakes there was narrowing of the connections between particular reservoirs. Lake Kirsajty serves a good illustration of such a phenomenon. It constitutes a connection of Northern Mamry and Lake Dargin. The subsequent stage of the changes may involve the division of the lake into several reservoirs.

The results of the analysis of the cartographic map at the scale 1:25000 confirm a general tendency of the lake area decrease. A fuller picture of this phenomenon can be obtained through the comparison with other materials: the bathymetric plans of the lakes from the 1960s, conducted at the Inland Fisheries Institute in Olsztyn and the data from the maps at the scale 1:50000 coming from the 1970 (Choiński, 1991). Such a comparison may be performed with respect to 84 out of 116 lakes with area changes, as there is not a complete set of the required data for all the lakes, the smallest ones m ainly (Tab. 6). The particular comparative periods were marked with the following names: period 1 (1909–1919), period 2 (the early 1960s), period 3 (the mid-1970s), and period 4 (1981–1982).

Table 6. Changes in the area of 84 lakes in the Great Mazurian Lakes Region in the twentieth century in the light of the available data

Period	1	2	3	4
Source of data	Königl. Preußische Landesaufnahme Maps, scale 1:25 000 (1909–1919)	Bathymetric plans of the Inland Fisheries Institute in Olsztyn (1960s)	Topographic maps scale 1:50000 (according to A.Choiński 1991) (mid-1970s)	Topographic maps scale 1:25000 (1981–1982)
Ha	32573.7	31913.0	30912.3	31361.1
%	100.0	98.0	94.9	96.3

In the period 2 – as compared to the period 1 – there were 45 cases of the lake area decreases, and 39 cases of the lake area increases. At the same time there was a general tendency of the total area decline of the lakes from 32573.7 down to 31913.0 ha, i.e. by 2.0% (Tab. 6). This tendency accelerated between the periods 2 and 3, when the area of 69 lakes decreased, and the area of only 15 lakes expanded. The total area of the lakes declined in this period by 1000.7 ha, i.e. by 3.1%. However, the results of the measurements conducted on the maps at the scale of 1:25000 from the years 1981–

1982 did not indicate a further decline tendency. With comparison to the period 3, the total area of the lakes turned out bigger by 448.8 ha, and thus, was lower by 551.9 ha from the value recorded in the period 2. These differences may be related to the varied map scales and bathymetric plans applied in the calculations. Therefore, it seems that the investigations into area changes of a big number of lakes over a longer period of time should be conducted on the grounds of the maps at the same scale.

Considering the total area of all the lakes located in the Great Mazurian Lakes Region within the limits as presented in Fig. 1 over the period 1 (39361.9 ha) and over the period 4 (38125.5 ha), the authors found that the area had decreased by 1236.4 ha, i.e. by 3.1%. Thus, the average annual decrease of the lake areas amounts to approx. 0.05%.

Final remarks

With comparison to other big regions, the demise of the lake areas in the Great Mazurian Lakes Region ran slower in the twentieth century. The total lake area decreased by 10.0% in Northeast Poland (the Mazurian Lakeland approx. 30000 km^2), whereas, by 9.6% in Northwest Poland (the Pomeranian Lakeland) (Choiński, 1991). These considerable regional differences should be justified by anthropogenic factors mainly.

A part of the discussed lakes – as mentioned beforehand – was connected by canals as early as in the first half of the twentieth century. The water level was regulated by means of sluices and weirs. Owing to this, the pace of the lake demise slowed down in the system of the Great Mazurian Lakes. Moreover, due to restraining the outflow of some rivers, the water level rose in particular lakes located outside the system of the Mazurian lakes, which resulted in their area increase.

The biggest lake area demise occurred in the meliorated regions located outside the main system of the Great Mazurian Lakes. The melioration works led to water level lowering not only in the lakes but also in the wetlands. Many of them disappeared, particularly in the central part of the region (for instance the Nietlickie Swamps).

The lake area decrease may probably be higher in other regions. This assumption concerns those areas where the water level in the lakes has not been regulated and where melioration has been the only hydrotechnical and dominant procedure. The above thesis should be investigated on the grounds of an agricultural region with a dominance of farming lands.

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Streszczenie

W artykule przedstawiono wyniki badań na temat kierunków i wielkości zmian powierzchni jezior w Krainie Wielkich Jezior Mazurskich w XX wieku, a także ich skutków fizjograficznych. Analiza materiałów kartograficznych w skali 1:25000 obejmowała identyfikację ilościową i przestrzenną jezior w dwóch okresach: 1909–1919 oraz 1981–1982. Zastosowanie map w jednolitej i szczegółowej skali oraz programu komputerowego MapInfo 4.0 zwiększyło dokładności pomiarów wymaganą przy tego typu opracowaniach.

Zmiany powierzchni przekraczające 1% stwierdzono w 116 spośród 203 jezior (ryc. 1, tab. 1), które stanowią 83.2% łącznej powierzchni wszystkich jezior. Powierzchnie 98 jezior uległy zmniejszeniu (o 1523 ha), a 18. zwiększeniu (o 287.4 ha). Najczęstsze zmiany nastąpiły w grupie jezior małych o powierzchni do 50 ha (tab. 2). Z kolei największą grupę stanowią jeziora, których powierzchnia zmniejszyła się od 10 do 50% (37) oraz od 5 do 10% (23). Jeziora wielkie (Śniardwy, Mamry, Niegocin) zmniejszyły się nieznacznie (do 2.4–3.5%). Tylko w 4 przypadkach powierzchnia jeziora wzrosła ponad 10%, w tym w 2. o ponad 50% (tab. 3). Przykłady zmian powierzchni jezior w XX wieku, a także w okresie dłuższym przedstawia ryc. 2 i tab. 4.

Wśród 12. wyróżnionych skutków fizjograficznych spowodowanych zmianami powierzchni jezior (tab. 5), najwięcej przypadków związanych było ze zmniejszaniem powierzchni zatok (72) oraz wzrostem powierzchni i liczby mokradeł (61). Do najbardziej zmiennych elementów należały wyspy. Wykazano większe zróżnicowanie skutków fizjograficznych w przypadku fragmentarycznego zmniejszania powierzchni jeziora w porównaniu do arealnego.

Biorąc pod uwagę powierzchnię łączną wszystkich jezior położonych w Krainie Wielkich Jezior Mazurskich w granicach przedstawionych na ryc.1 stwierdzono, że uległa ona zmniejszeniu o 1236.4 ha, czyli o 3.1%. Średni roczny ubytek powierzchni jezior wynosi ok. 0.05%. Zmniejszanie powierzchni jezior na tym obszarze w XX wieku przebiegało więc wolniej w porównaniu z innymi regionami. Wydaje się, że jest to skutek przede wszystkim połączenia wielu jezior kanałami i regulacji poziomu wody śluzami oraz jazami. Dzięki temu spowolniono tempo zaniku jezior wchodzących w skład systemu jezior mazurskich. Ponadto – w wyniku zahamowania odpływu niektórych rzek – podniesiono poziom wody w pojedynczych jeziorach położonych poza systemem jezior mazurskich, co spowodowało wzrost ich powierzchni.