The ice regime of Lake Ostrzyckie (Kashubian Lakeland, northern Poland)

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Abstract: The article presents the ice phenology of Lake Ostrzyckie, which is a water body covering an area of 308 ha located in the central part of the Kashubian Lakeland, northern Poland. The analysis presented in the article is based on data from daily ice phenomena monitoring for the period of 1971–2010. Data including forms of lake ice, as well as the thickness of the ice cover were obtained from the Institute of Meteorology and Water. In order to present relations between the ice phenomena and air temperature the meteorological data from the Gdańsk University Limnological Station in Borucino were used. The article presents changes in the duration time of the ice seasons and changes in the ice cover duration time in relation to winter season (November–April) temperatures. The structure of the ice phenomena duration period observed on Lake Ostrzyckie consists of three different stages of ice cover formation. 94% of this time the lake is covered by permanent ice cover, the freezing period takes about 5%, and the break-up takes only 1% of the ice phenomena duration period. In general the ice phenomena in the lake can occur only in the years when the average air temperature in the winter is lower than 5.0°C, whereas the permanent ice cover is created when the average air temperature of the winter season is lower than 4.8°C. The maximum thickness of the ice cover is usually 23 cm, and the average is 14 cm.

Key words: lake ice phenology, long-term ice cover changes, ice cover durability, ice thickness

Introduction

The way in which climate change affects the environment is one of the major challenges for modern science. Continuous monitoring of climate factors is extremely important for a proper understanding of the dynamics and trends of the climate system (Xiao et al. 2018). Gradually increasing air temperature is a good indicator of ongoing changes in climate, it also visibly affects ice phenomena observed on lakes located in the temperate climate zone, including water bodies in the Kashubian Lakeland. Changes in air temperature may also affect economic and leisure activities taking place in areas dependent on ice cover (Murfit et al. 2018). Climate change is reflected by changes in the ice regimes of numerous lakes in other regions of Poland (Borowiak and Barańczuk 2004; Marszelewski and Skowron 2009; Barańczuk et al. 2017; Ptak et al. 2019). Such changes have already been described and analysed by many scholars interested in ice phenomena (Trusewicz et al. 2009; Skowron 2011; Choiński 2016). However, it has to be emphasized that ice cover is a specific

element of the abiotic environment which reflects the influence of both external meteorological conditions and internal water circulation processes (Choiński et al. 2009). One of the most basic physical features of the water environment of lakes, affecting ice phenomena, is variation in surface and subsurface water temperature (Maślanka and Barańczuk 2007), strongly correlated with air temperature.

The latest literature on the Kashubian Lakeland addresses the issue of modelling ice cover emerging on lakes situated in this region (Barańczuk 2018; Barańczuk and Barańczuk 2018; Barańczuk 2019). However, there is only one detailed publication on the ice regime of Lake Raduńskie Górne (Barańczuk et al. 2017) covering such a long data series, and there are no publications addressing other lakes of this district. Usually, the existing publications describe the ice regimes in a very general way or they concern other regions (Barańczuk and Marchlewicz 2003; Borowiak and Barańczuk 2004; Maślanka and Barańczuk 2007; Skowron 2011; Choiński et al. 2015; Ptak et al. 2017). Lake ice cover is considered a vital climate factor and

it has been placed on the Essential Climate Variables (ECV) list (GCOS 2016). The aim of this study was to analyse the ice regime of Lake Ostrzyckie in the period of 1971–2010 against the background of air temperature changes.

Study area

The study area covers Lake Ostrzyckie (54°15'13"N 18°06'16"E), situated in the Polish Lowland region, west of the River Vistula, in the Kashubian Lakeland mesoregion (Fig. 1). The lake is a part of river-lake system of the Upper Radunia River, a tributary of the River Motława which in turn inflow to one of the branches of the Vistula (the so-called Dead Vistula). It is a multi-ribbon lake (Barańczuk 2015), situated at an elevation of 159.0 m above sea level. It is one of the largest lakes (308.0 ha) of this mesoregion as well as in the Kashubian Landscape Park (Borowiak and Barańczuk 2006). The volume of the lake is 20785.2 dam³ (Barańczuk 2018). Lake Ostrzyckie is a flow-through lake (Borowiak and Barańczuk 2005) with a horizontal water exchange rate equalling 4.1 and a retention time 0.24 (Nowiński and Borowiak 2007). According to water exchange criteria (Pasałowski 1975), it is an average hydrological type.

Fig. 1. Location map of the study area

Materials and methods

The data on ice phenomena observed until the end of the first decade of the 21st century, covering a period of thirty years (1971–2010), was received from the Institute of Meteorology and Water Management (IMGW). Measurements of ice phenomena in Lake Ostrzyckie had been performed every five days near the water gauge post, as recommended by the IMGW. The source data on air temperature covering the same period was received from the Limnological Station in Borucino, situated on the shore of the north-western basin of Lake Raduńskie (Barańczuk and Barańczuk 2018). The station is a part of the IMGW climate station network as a 3rd order climate station, and is the nearest climate station located in the vicinity of Lake Ostrzyckie. The data derived from both the Limnological Station and the IMGW water gauge post in Ostrzyce village include

historical data on air temperature and lake ice phenology, such as dates of appearance different forms of ice: bank ice (stranded ice), frazil ice, floating ice, partial ice cover, and permanent ice cover.

Results

During the period of 1971–2010 ice phenomena were observed in Lake Ostrzyckie every year, except for the winter of 2007 (Fig. 2), which was exceptionally warm (the average air temperature in Borucino during the period of November–April 2007 was 4.2°C). The ice phenomena usually occur at the beginning of the third decade of December (the median value is 17th December) but not earlier than on 19th November (the hydrological year of 1989) and not later than on 15th February (the hydrological year of 1975) (Table 1). Most often they start on 24th December. The difference between the initial dates of ice phenomena emergence is 89 days.

The ice phenomena disappear between 13th January (1990) and 22nd April (1996), on 21st March on average (Table 1). Taking the extreme dates of ice phenomena emergence and disappearance under consideration, it may be stated that the total theoretical duration time of the ice season in Lake Ostrzyckie is 156 days. During the analysed 40-year period there was no year in which such a long ice season was observed. The longest duration was recorded in 1996 and it lasted 145 days, and the shortest in 2008 – 18 days (Fig. 2).

Duration time of the ice season calculated for the average year lasted 91 days, including 78 days with ice phenomena (standard deviation s.d. = 32 constitutes 36% of the arithmetic mean). Most often the ice phenomena were observed in the lake for 88 days while the median was 83 days. The total number of days with ice phenomena correlates with average air temperature calculated for the whole winter half-year (November–April) (Fig. 3). Theoretically, therefore, the ice phenomena could appear in the lake only when the average air temperature during the winter season (XI–IV) at Borucino is lower than 5.0°C.

The ice season in Lake Ostrzyckie usually begins on the day that bank ice appears (21 such cases) or, what is less common, on the day of the appearance of a permanent ice cover (continuous ice coat) (18 such cases), whereas it finishes with the emergence of ice floe (6 cases), but yet more often with bank ice (21 cases). There were also twelve winters when the ice season ended with a permanent thin ice coat covering all the lake.

Bank ice is the form of ice that most often begins and ends ice phenomena in the lake. It also often appears in the middle of the ice season, starting or ending short episodes of permanent ice cover occurrence (Fig. 2).

ice season was on average 5%. The years 1989 and 2008 were extraordinary in this respect because in these winters the share of bank ice accounted for 26 and 33% of the duration of the ice season, respectively.

It is not unusual for Lake Ostrzyckie to start the ice season with permanent ice cover. Permanent ice cover occurred on the lake surface on 20th November 1989 at the earliest, and on 15th February 1975 at the latest. Most often it appeared on around 9th December, the median of its emergence is 18th December; but during the average winter conditions it forms on 12th December. The period of permanent ice cover finishes between

12th January (1990) and 22nd April (1996) (Fig. 2), and on 17th March on average.

Extreme values of the permanent ice cover duration time were between 12 and 136 days, respectively, in 2008 and 1996. The average duration of this period was 73 days (Table 1). The winters of 1979, 1980, 1982, 1984–1987, 2003 and 2006 were cold enough for the permanent ice cover phase to exceed 100 days (Fig. 2, Table 1).

Table 1. Duration of the ice season, the ice phenomena and various forms of ice at Lake Ostrzyckie in the period 1971–2010 (data provided by the IMGW)

Winter season	Duration [in days]					Ice season beginning	Ice season end
	Ice season ¹	Ice phenomena ²	Freeze-up	Ice cover	Break-up		
1971	88	88	–	87	1	24 DEC	21 MAR
1972	71	71	–	71	–	10 JAN	20 MAR
1973	86	70	–	69	1	21 DEC	15 MAR
1974	109	109	–	109	–	27 NOV	15 MAR
1975	20	20	–	20	–	15 FEB	06 MAR
1976	119	95	–	88	7	10 DEC	06 APR
1977	81	81	–	77	4	27 DEC	17 MAR
1978	76	76	4	72	–	14 JAN	30 MAR
1979	123	123	5	112	6	10 DEC	11 APR
1980	107	107	4	103	–	04 DEC	19 APR
1981	106	82	–	82	–	05 DEC	20 MAR
1982	109	109	–	109	–	09 DEC	27 MAR
1983	81	40	–	40	–	24 DEC	14 MAR
1984	130	109	1	108	–	02 DEC	09 MAR
1985	112	112	6	106	–	12 DEC	02 APR
1986	125	102	–	102	–	28 NOV	01 APR
1987	107	107	–	107	–	25 DEC	10 APR
1988	75	71	8	62	1	18 JAN	01 APR
1989	93	38	10	28	–	19 NOV	19 FEB
1990	37	23	4	19	–	08 DEC	13 JAN
1991	110	83	13	70	–	01 DEC	20 MAR
1992	86	60	9	51	–	09 DEC	03 MAR
1993	90	88	7	81	–	18 DEC	17 MAR
1994	116	91	7	84	–	29 NOV	24 MAR
1995	78	48	1	45	2	02 DEC	17 FEB
1996	145	145	9	136	–	30 NOV	22 APR
1997	196	88	5	83	–	13 DEC	28 MAR
1998	91	41	7	34	–	17 DEC	17 MAR
1999	120	105	9	96	–	20 NOV	19 MAR
2000	72	57	4	53	–	18 DEC	27 FEB
2001	66	53	8	45	–	20 JAN	27 MAR
2002	49	49	3	46	–	12 DEC	29 JAN
2003	112	112	4	108	–	08 DEC	29 MAR
2004	79	79	3	76	–	30 DEC	17 MAR
2005	69	69	3	66	–	24 JAN	02 APR
2006	103	103	3	100	–	01 JAN	13 APR
2007	–	–	–	–	–	–	–
2008	18	18	6	12	–	01 JAN	18 JAN
2009	83	83	6	77	–	27 DEC	19 MAR
2010	98	98	–	98	–	19 DEC	26 MAR
Mean	91	78	4	73	1	19 DEC	21 MAR

¹Ice season: number of days between the earliest freeze-onset and the latest ice-off dates. Ice season includes days without ice if they occurred between these two dates; ²Ice phenomena: number of days on which any form of ice was observed.

When permanent ice cover forms on the surface of a lake it often remains uninterrupted until the end of the ice season. However, in some years it happens that first ice cover is interrupted or totally disappears. In these years, two, three or even four most frequently short phases of permanent ice were observed. The extent of time between consecutive periods of the permanent ice forming on the lake surface was from 5 (1988, 1993, 1999) to 38 days (1983).

Permanent ice cover is the main ice phenomenon observed at Lake Ostrzyckie. It constitutes from 67 up to 100% of the ice phenomena duration time, 94% on average (Fig. 2).

The duration of the permanent ice cover strongly affects the thickness of the ice. The relationship between the maximum ice thickness (MIT) and the duration of permanent ice cover (PIC) can be described by the following equation: $MIT = 0.302(PIC)$, $R^2 = 0.770$, p

Fig. 3. Relationship between the mean air temperature in the winter half-year (November–April) in Borucino Limnological Station and duration of the ice phenomena at Lake Ostrzyckie in the period 1971–2010

Fig. 4. Inter-annual changes of the ice cover at Lake Ostrzyckie

<0.05 . In turn, the relationship between the average thickness of the ice cover (AIT) and the number of days with permanent ice cover (PIC) describes the following equation: $AIT = 0.185(PIC)$, $R^2 = 0.661$, $p < 0.05$.

From the day when permanent ice cover was already completely formed on the lake surface its thickness ranged from 1 to 6 cm, and 2 cm on average (most often 1 cm). Permanent ice cover takes three months to fully develop. The ice cover usually reaches its maximum thickness in the last decade of March. The phase of ice cover break-up is almost three times shorter (Fig. 4). On the last day of permanent ice cover presence its thickness ranged from 1 to 23 cm, 9 cm on average, and most often 8 cm.

The maximum thickness of the permanent ice cover in the lake varied between 4 (1990) and 45 cm (1996), and most often 12 cm (Fig. 5). The average ice thickness was between 3 (1990, 2008) and 30 cm (1996), and most often 6 cm. In average winter conditions the average thickness of the ice cover was 14 cm, and the maximum was 23 cm. The relationship between the maximum (MIT) and the average (AIT) ice thickness during the

Fig. 5. Mean and maximum thickness of the ice cover at Lake Ostrzyckie during the winter seasons in the period 1971–2010

Fig. 6. Relationship between the mean air temperature in the winter half-year (November–April) in Borucino and the number of days with the permanent ice cover at Lake Ostrzyckie in the period 1971–2010

ice phase can be described by the following equation: $MIT = -0.026(AIT)^2 + 2.103(AIT)$, $R^2 = 0.903$, $p < 0.05$.

A strong statistical dependence was also found between the number of days with ice cover and the average air temperature of the winter season (XI–IV). This relationship indicates that permanent ice cover on the surface of Lake Ostrzyckie can form if the average air temperature during the winter season (XI–IV) is lower than 4.8°C (Fig. 6).

The breaking-up phase (ice floe) at Lake Ostrzyckie constituted only 1% of the whole period of ice phenomena at the lake. Ice floe ended the ice season at this lake in 1971, 1976, 1977, 1979, 1980 and 1995 (Fig. 2). In 1976 this phase took 7%, and in 1977 and 1979 approximately 5% of the ice phenomena duration time. The longest period with ice floe covering Lake Ostrzyckie lasted 7 days (1976) (Table 1).

Discussion

Nowadays, climate change and global warming are two phenomena affecting the natural environment. That is why it is so important to constantly monitor climate parameters (Xiao and al. 2018). Ice phenomena constitute a significant group of such parameters and the most important one is ice cover. Usually, data on ice cover are analysed in long time periods, with special attention paid to a proper dataset with the same end dates. It seems that the best end dates for analysing ice regimes of lakes are the decade end ones (Choiński et al. 2014; Choiński et al. 2015; Weyhenmeyer et al. 2012; Barańczuk et al. 2017; Surdu and al. 2014). However, in the case of a lack of such data, other long-term periods are used (Barańczuk and Borowiak 2005; Ptak et al. 2019; Nowak et al. 2018; Kainz et al. 2017; Lei et al. 2012; Soja et al. 2014) in order to determine the ice regimes of selected lakes, which are largely affected by climate change (Smekhtin 2017).

Data on ice regimes collected in situ are considered especially important and interesting as this method of data collection is now being replaced by satellite monitoring (Chang 2014). However, the quality of satellite data is sometimes insufficient (Pour et al. 2017; Surdu et al. 2014; Dorofy 2016; Gabre et al. 2014; Engram et al. 2018).

Lake Ostrzyckie and Lake Raduńskie Górne are two water bodies, situated in the Kashubian Lake Districts, that are under constant in situ monitoring. The data analysis indicates that although those two lakes are located in close proximity to each other, the duration of the ice cover on Lake Ostrzyckie is on average 9 days longer than in Lake Raduńskie Górne (Barańczuk et al. 2017). The example of the Gniezno Lakeland, situated in the central part of Poland, shows that the more southern the location, the shorter the duration of ice cover. Here, the average duration of ice cover fluctuated between 43 days (Lake Powidzkie), through 60 days (Lake Lednica) to 63 days on Lake Biskupskie (Nowak et al. 2018). Nonetheless, the more eastern the location, the longer the duration of ice cover: 76 days in Lake Mikołajskie (Choiński et al. 2014), 78 days on Lake Jagodne (Ptak et al. 2019) and more than 96 days on Lake Studziennicze, situated near the border with Belarus (Choiński et al. 2015). In western Poland we can observe the opposite situation. Here, the average duration of ice cover is a little more than 66 days (Lake Osiek; Choiński et al. 2015). In the south, in the mountains, ice cover is present for 159 days (Lake Morskie Oko; Pawłowski 2018). A similar situation is observed in Austria where the ice covers the surface of Lake Lunz for a very long period. However, there were winters (in 2006 and 2013) without any ice cover observed there. The ice regime of Lake Lunz has mainly been modified by a rise in air temperature that has been recorded in the last few years (Kainz et al. 2017). This is also agrees with the research by Franssena and Sherrer (2008) who analysed the ice regimes of 11 lakes situated in the Swiss plateau and stated that ice cover duration has changed as the air temperature in winter is higher than it used to be. The research team studying Lake Balaton (Hungary) and Lake Neusiedl (Austria/Hungary) observed a very similar situation, and the average duration of ice cover was 44 and 73 days respectively, with a large interim variability (Soja et al. 2014). Obviously, the ice cover duration is longer in the northern part of Europe – ice covers the surface of Lake Kilpisjärvi for 222 days, yet even here we can observe some modifications resulting from global warming (Lei et al. 2012).

Weyhenmeyer et al. (2012) suggest that the expected further rise in the air temperature in the northern hemisphere will increase the sensitivity of lake ice regimes, in particular, the time of ice cover emergence and du-

ration will change. As a result, we may expect an increased variability in physical, chemical and biological processes taking place in lakes.

Conclusions

The analysis performed as well as the data investigation allowed the ice regime of Lake Ostrzyckie to be determined. The results are as follows:

The permanent ice cover is the main form of the ice regime of Lake Ostrzyckie, situated in northern Poland in the Kashubian Lakeland. During the winter seasons of 1971–2010, it constituted 94% of all the observed ice phenomena on average. Floating ice in the form of bank ice and partial ice cover was observed on Lake Ostrzyckie for 5% of the ice period and ice floe for 1%.

Ice phenomena form on the surface of Lake Ostrzyckie when the average air temperature during the winter season (XI–IV) in Borucino is lower than 5.0°C, while permanent ice cover starts forming when the temperature is not higher than 4.8°C.

The ice cover usually increases for three months, reaching its maximum in the last decade of March. The thickness of the ice is 14 cm on average, and the maximum thickness is 23 cm. The phase of ice cover growth is three times longer than the phase of its break-up.

The frequency of ice phenomena in the analysed lake shows an upward trend from the fourth pentad of November to the penultimate pentad of January. Then, until the fourth pentad of February, the frequency of ice phenomena is relatively stabilized at 80–85%, and from the first pentad of March gradually decreases until the last pentad of April, when the ice season ends. However, some disorders of this pattern are observed. The largest ones are visible in the sixth pentad of November, the fourth pentad of December and the third pentad of March.

References

- Barańczuk J., 2015, Przebieg zjawisk lodowych na wybranych jeziorach Pojezierza Kaszubskiego (The course of ice phenomena on the selected lakes of the Kashubian Lakeland) [Dissertation], Gdańsk University – Department of Limnology, Gdańsk, 231 pp (in Polish).
- Barańczuk J., 2018, The statistical relation/coherence between ice regimes of Lake Raduńskie Górne and Lake Ostrzyckie, *Limnol. Rev.* 18(3): 103–108.
- Barańczuk J., 2019, Ice cover thickness formulas for the selected flow-through lakes of the upper Łeba River (Kashubian Lakeland, northern Poland) and the overview of GIS methods, models for determining the thickness of the ice cover on the selected examples, *Limnol. Rev.* 19(2): 49–55.
- Barańczuk J., Bajkiewicz–Grabowska E., Barańczuk K., Staszek W., 2017, The ice regime of Lake Raduńskie Górne (Kashubian Lakeland, northern Poland), *Limnol. Rev.* 17(2): 61–70.
- Barańczuk J., Barańczuk K., 2018, Models for calculating ice cover thickness on selected endorheic lakes of the upper Radunia (Kashubian Lakeland, northern Poland), *Limnol. Rev.* 18(4): 129–135.
- Barańczuk J., Borowiak D., 2005, Zjawiska lodowe jezior (Lakes ice cover), [in:] Lange W. (ed.), Jeziora górnej Raduni i jej zlewnia w badaniach z udziałem Stacji Limnologicznej w Borucinie (Lakes of the upper Radunia River and its catchment in research with the participation of the Limnological Station in Borucino), Ser. Bad. Limnol. 3, Wydaw. KLUG, Gdańsk: 251–260 (in Polish, English summary).
- Barańczuk J., Marchlewicz R., 2003, Diversity of development of ice phenomena in chosen lakes of Kaszubskie Lakeland in winter 2003, *Limnol. Rev.* 3: 25–30.
- Borowiak D., Barańczuk J., 2004, Secular fluctuations of ice phenomena in Lake Raduńskie Górne, Kashubian Lakeland, *Limnol. Rev.* 4: 17–24.
- Borowiak D., Barańczuk J., 2005, Funkcje hydrologiczne jezior (Hydrological functions of lakes), [in:] Lange W. (ed.), Jeziora górnej Raduni i jej zlewnia w badaniach z udziałem Stacji Limnologicznej w Borucinie (Lakes of the upper Radunia River and its catchment in research with the participation of the Limnological Station in Borucino), Ser. Bad. Limnol. 3, Wydaw. KLUG, Gdańsk: 215–231 (in Polish, English summary).
- Borowiak D., Barańczuk J., 2006, Diversity of surface outflow from lakes which perform different hydrological functions, *Limnol. Rev.* 6: 13–20.
- Cheng B., Vihma T., Rontu L., Kontu A., Pour H. K., Duguay C., Pulliainen J., 2014, Evolution of snow and ice temperature, thickness and energy balance in Lake Orajärvi, northern Finland, *Tellus A* 66(1): 1–20.
- Choiński A., 2016, Ice phenomena on Lake Czarny Staw pod Rysami, *Limnol. Rev.* 16(3): 165–169.
- Choiński A., Kalendowicz L., Pociask–Karteczka J., Sobkowiak L., 2010, Changes in lake ice cover on the Morskie Oko Lake in Poland (1971–2007), *Adv. Clim. Change Res.* 1(2): 71–75.
- Choiński A., Ptak M., Skowron M., 2014, Tendencje zmian zjawisk lodowych jezior Polski w latach 1951–2010 (Tendencies of changes of the ice phenomena in Polish lakes in the period 1951–2010), *Prz. Geogr.* 86(1): 23–40 (in Polish, English summary).
- Choiński A., Ptak M., Skowron R., Strzelczak A., 2015, Changes in ice on Polish lakes from 1961 to 2010 related to location and morphometry, *Limnologica* 53: 42–49.
- Dorofy P., Nazari R., Romanov P., Key J., 2016, Development of a Mid-Infrared Sea and lake ice index (MISI) using the GOES Imager, *Remote Sens.* 8(12): 1015.
- Engram M., Arp C.D., Jones B.M., Ajadi O.A., Meyer F.J., 2018, Analyzing floating and bedfast lake ice regimes

- across Arctic Alaska using 25 years of space-borne SAR imagery, *Remote Sens. Environ.* 209: 660–676.
- Franssen K.J., Scherrer S.C., 2008, Freezing of lakes on the Swiss plateau in the period 1901–2006, *Int. J. Climatol.* 28: 421–433.
- [GCOS] Global Climate Observing System, 2016, The global observing system for climate: Implementation needs, Tech. Rep. 200, WMO, Geneva, 315 pp.
- Gebre S., Boissy T., Alfredsen K., 2014, Sensitivity of lake ice regimes to climate change in the Nordic region, *Cryosphere* 8: 1589–1605.
- Kainz M.J., Ptacnik R., Rasconi S., Hager H.H., 2017, Irregular changes in lake surface water temperature and ice cover in subalpine Lake Lunz, Austria, *Inland Waters* 7(1): 27–33.
- Lei R., Leppäranta M., Cheng B., Heil P., Li Z., 2012, Changes in ice-season characteristics of a European Arctic lake from 1964 to 2008, *Climatic Change* 115: 725–739.
- Marszelewski W., Skowron R., 2009, Extreme ice phenomena on the lakes of Northern Poland, *Limnol. Rev.* 9(2–3): 81–89.
- Maślanka W., Barańczuk J., 2007, Termika i dynamika wód (Thermics and water dynamics), [in:] Borowiak D. (ed.), Jeziora Kaszubskiego Parku Krajobrazowego (Lakes of the Kashubian Landscape Park), Ser. Bad. Limnol. 5, Wydaw. KLUG, Gdańsk: 67–86 (in Polish, English summary).
- Murfitt J.C., Brown L.C., Howell S.E.L., 2018, Estimating lake ice thickness in Central Ontario, *PLoS ONE* 13(12): 1–20.
- Nowak B., Nowak D., Ptak M., 2018, Variability and course of occurrence of ice cover on selected lakes of the Gnieźnieńskie Lakeland (Central Poland) in the period 1976–2015, *E3S Web of Conferences* 44, 00126.
- Nowiński K., Borowiak D., 2007, Jezioro Ostrzyckie (Lake Ostrzyckie), [in:] Borowiak D. (ed.), Jeziora Kaszubskiego Parku Krajobrazowego (Lakes of the Kashubian Landscape Park), Ser. Bad. Limnol. 5, Wydaw. KLUG, Gdańsk: 225–231 (in Polish, English summary).
- Pasławski Z., 1975, Typologia hydrologiczna jezior Pojezierza Wielkopolskiego (Hydrological typology of lakes of the Wielkopolskie Lake District), *Prz. Geofiz.* 20(4): 271–280 (in Polish, English summary).
- Pawłowski B., 2017, Changes in the course of ice phenomena on Morskie Oko in the Tatra Mountains from 1963 to 2012 and the implications for tourism, *Limnol. Rev.* 18(4): 167–173.
- Pour H.K., Duguay C.R., Scott K.A., Kang K.-K., 2017, Improvement of Lake Ice Thickness Retrieval From MODIS Satellite Data Using a Thermodynamic Model, *IEEE Trans. Geosci. Remote Sens.* 55(10): 5956–5965.
- Ptak M., Wrzesiński D., Choiński A., 2017, Long-term changes in the hydrological regime of high mountain Lake Morskie Oko (Tatra Mountains, Central Europe), *J. Hydrol. Hydromech.* 65(2): 146–153.
- Ptak M., Sojka M., Nowak B., 2019, Changes in ice regime of Jagodne Lake (north-eastern Poland), *Acta Sci. Pol. Formatio Circumictus* 18(1): 89–100.
- Skowron R., 2011, Zróżnicowanie i zmienność wybranych elementów reżimu termicznego wody w jeziorach na Niżu Polskim (Diversity and variability of selected elements of the thermal regime of water in lakes in the Polish Lowlands), Wydaw. Nauk. UMK, Toruń, 345 pp (in Polish, English summary).
- Smakhtin V.K., 2018, Ledovyi rezhim ozer Zabaikala v usloviakh sovremennogo poteplenia (Ice regime of Transbaikalia lakes in the present-day warming), *Led i Sneg, Ice and Snow* 58(2): 225–230 [in Russian, English summary].
- Soja A.-M., Kutics K., Maracek K., Molnár G., Soja G., 2014, Changes in ice phenology characteristics of two Central European steppe lakes from 1926 to 2012 – influences of local weather and large scale oscillation patterns, *Clim. Change* 126: 119–133.
- Surdu C.M., Duguay C.R., Brown L.C., Prieto D.F., 2014, Response of ice cover on shallow lakes of the North Slope of Alaska to contemporary climate conditions (1950–2011): radar remote-sensing and numerical modeling data analysis, *Cryosphere* 8: 167–180.
- Trusewicz Z., Markowski M., Barańczuk J., 2009, The influence of the North Atlantic Oscillation on variability of surface temperature of Lake Raduńskie Górne, *Limnol. Rev.* 9(2–3): 55–62.
- Weyhenmeyer G.A., Livingstone D.M., Meilis M., Jensen O., Benson B., Magnuson J.J., 2011, Large geographical differences in the sensitivity of ice-covered lakes and rivers in the Northern Hemisphere to temperature changes, *Global Change Biol.* 17(1): 268–275.
- Xiao M., Rothermel M., Tom M., Galliani S., Baltsavias E., Schindler K., 2018, Lake ice monitoring with webcams, *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.* IV(2): 311–315.