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Water temperature in the lakes of Northern Poland during the bathing season

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Abstract. The study presents characteristics of the bathing season on the basis of stationary daily measurements of surface water temperature in the lakes in the period 1971-2015 conducted by the Institute of Meteorology and Water Management. These measurements were taken in the littoral zone (from bridges) of 28 lakes at 7:00 (6:00 GMT). In order to determine representativeness of these measurements, the author also documents the comparison of water temperature with its values at various points of the lake and its daily course. Stationary surface water temperature measurements provided the basis for the characteristics of the average, the earliest and the latest dates of the beginning and end of the bathing seasons, their duration and mean water temperatures in the summer months. Hence, a new parameter (t_{sum}) is introduced to define the mean surface water temperature for the summer months (June, July and August), and compare water temperature in lakes over a larger area (the Baltic Sea catchment area). The most favorable conditions for bathing in Polish lakes are found in the western part of the Wielkopolskie Lakeland (lakelands: Łagowskie, Poznańskie, Sławskie) from the beginning of July to the end of August, when the surface water temperature in lakes generally exceeds 18°C. Furthermore, the best conditions for bathing in the water are from 10:00 to 18:00. When choosing a place to relax, holidaymakers should also consider bathing locations, infrastructure and safety conditions.

Key words:
Northern Poland,
bathing season,
lakes,
water temperature

Introduction

Pursuant to the Water Law Act of July 18, 2001 (Journal of Laws of 2012, item 145), the bathing season extends from 15 June to 30 September. According to the criterion related to the range of air temperature (mean daytime temperature >15°C), this period is called "thermal summer", and with the range of surface water temperature (>15°C) it is referred to as the "bathing season" (Koźmiński and Michalska 2016).

The European Environment Agency (EEA) reported in 2015 that in Poland there were 115 inland bathing areas for which the average duration of the bathing season amounted to 93 days and 83 percent of which offered good or excellent water quality. In the immediate vicinity of Poland, the largest numbers of bathing areas are found in Germany (1925), Finland (224) and Sweden (199) (www.eea.europa.eu).

The Chief Sanitary Inspectorate in Poland states that according to Directive 2006/7/EC of the

European Parliament, a bathing area is a fragment of surface water area designated and marked by a municipal council decision, and used by a large number of bathers. The official bathing area must be equipped with the full infrastructure necessary for recreation, i.e., appropriate signage, designated zones for swimming for adults and children, bridges, showers, changing rooms, toilets, facilities for the disabled, swimming equipment rental, small catering services, and safety provided by qualified lifeguards. Otherwise, the place becomes unattractive or simply illegal. The attractiveness of recreational areas beyond the mentioned features is also determined by: the natural values of the place, the exposure of the bathing area and the physical and chemical properties of the water (mainly transparency and water temperature). In addition, most lakes in Poland have an advanced trophic level, which limits their use for recreation (Młynarczyk and Borkowski 2015). The exact location of the bathing areas and up-to-date basic information on them can be found in the sanitary-epidemiological bathing service http://sk.gis.gov.pl.

Northern Poland has over seven thousand lakes; this and its landscape diversity are the main factors defining the tourist and recreational attractiveness of the lakelands (Choiński 2006). Additionally, the diversity of postglacial relief, forestation of the region, air purity and favourable bioclimatic conditions are also important factors (Koźmiński et al. 2013).

However, it should be emphasised that the lakes located in the Polish Lowlands are relatively small in surface area. More than half of the lakes cover less than 5 hectares, and only 468 lakes exceed 100 hectares. In general, it is possible to practise sailing and motorboat sports only on lakes over 100 ha, which, with the introduction of limitations on using combustion engines, largely limits the accessibility to many lakes. The number of lakes with an area over 100 hectares is: Pomorskie Lakeland – 150, Masurian Lake District – 222, Wielkopolsko-Kujawskie Lakeland – 96 (Choiński 2006).

Materials, methods and study objective

The study is based on three types of data. The basic analysis was carried out on stationary measurements of surface water temperature in lakes, obtained from the database of the Institute of Meteorology and Water Management. They refer to the surface water temperature measured at a depth of 0.4 m in the littoral zone (mostly from bridges) every day at 07:00 (06:00 GMT). Such data were compiled for 28 lakes in different regions of the Polish Lowland over a period of 45 years (1971–2015) (Fig. 1). In total, over 230,000 measurements were used, covering only the period from April to October inclusive.

The second type of data involved experimental measurements conducted at various terms of the 1971–2015 period. Water temperature measurements carried out in various parts of the lake in the May–September period and the daily courses and vertical distribution of lake water temperature were all used to determine the representativeness of the stationary measurements.

The above-mentioned materials are complemented by air temperature data recorded from April to October and their monthly mean values for the 1971–2015 period. Data were collected for 12 stations in the Polish Lowland. These data were obtained from the web portal of the National Climatic Data Center Global Historical Climate Network version 2; http://www.ncdc.noaa.gov, from the Yearbook of Environmental Protection and Statistical Yearbooks and the publication by Kossowska-Cezak (2005).

All statistical calculations were performed using Microsoft Excel and Corel Quattro Pro 8, while graphing was performed using Corel Draw 9.

The aim of the study is to characterise the course of water temperature during the bathing season in selected lakes of the Polish Lowland in the years 1971–2015. The analysis involved studying surface water temperature and its vertical distribution in the April–September half-year, with particular attention to surface water temperature (in the littoral zone) and epilimnion extent in the summer stagnation (June–August). In addition, water temperature in the daily course was examined in 19 lakes with its vertical distribution, and synchronically at several measurement points.

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Characteristics of the natural environment of lakelands in Poland

The attractiveness of the lakelands in Poland (Pomorskie, Masurian, Wielkopolsko-Kujawskie) is of great interest to the inhabitants of cities and southern Poland. The occurrence of water bodies decreases daily and annual air temperatures, in particular decreasing their amplitudes with respect to land surface temperatures. The positive impact of these areas is also indicated by the condition of the natural environment, high forestation, and better recreational infrastructure.

Meteorological conditioning during the bathing season

Air temperature, in addition to precipitation, is one of the major factors shaping climatic conditions in a given area. Its temporal and spatial variability depends upon general atmospheric circulation, latitude, terrain elevation, and distance from bigger water bodies.

The mean annual air temperatures at selected stations in central and northern Poland in the period 1971–2015 ranged from 6.6°C (Suwałki) to 8.8°C (Szczecin) and 8.9°C (Zielona Góra) and at other stations were from 6.9 to 8.4°C. Their values in each of the analysed years were distinctly different and ranged from 3.9 in 1987 (Suwałki) to 10.1°C in 2000 and 2001 (Zielona Góra and Gorzów Wlkp.).

With respect to the vertical distribution, the western part of the isotherm is 8°C, covering the entire Szczecińskie Lakeland, the Iławskie Lakeland, the eastern part of the Myśliborskie Lakeland, the Choszczeńskie Lakeland and the Dobiegniewskie Lakeland, and most of the Wielkopolskie Lakeland apart from the Chodzieskie Lakeland, is noticeably warmer. The decidedly coolest area is to the east of the Great Masurian Lakes. Only a small part of the Lithuanian Lakeland is covered by an isotherm of 6.5°C. Moreover, the colder regions are the more elevated westernmost parts of the Kashubian Lakeland, the Bytowskie Lakeland, the eastern part of the Drawskie Lakeland, the Wałeckie and Szczecineckie Lakelands and the northern part of the Charzykowska Plain and the Krajeńskie Lakeland.

The warmest months were July and August, which are characterised by a small spatial variation of near-parallel isotherms (Wiszniewski and Chełchowski 1975; Woś 1999). The highest mean monthly air temperatures were recorded in July, and reached 18.7°C in Zielona Góra and 18.7°C in Gorzów Wlkp. The lowest mean values for these two months were recorded in August in Suwałki (16.7°C).

The duration of the thermal summer in the Polish Lowland, i.e. the period in which the mean daily air temperature is higher than 15°C, varies significantly. It is generally accepted that the period begins earliest to the south of the 53°N parallel (before 5 June), slightly later (after 15 June) in the Baltic coast (Woś 1999), and latest (after 25 June) in the Kashubian Lakland. Time differences over the Polish Lowland can be up to 25 days (Table 1).

In Poland the biggest annual sum of hours of sun is for the Central Polish Lowlands, and especially within the Chodzieskie, Gnieźnieńskie and Kujawskie lakelands and in the Trzebiatowski and Słowiński coastal belt, where it exceeds 1,650 hours a year (Kozłowska-Szczęsna et al. 2004; Koźmiński and Michalska 2005). The lowest values of sunshine (below 1,500 hours per year) relate to the Drawsko, Kashubian and Krajeńskie lakelands and the Charzykowska Plain (Atlas of Climate of Poland 2005). Overcast conditions are also an important factor in the bathing season. The lowest levels of cloudiness over Poland in the 1951–2000 period occurred in August (56%), while the greatest were in December (78%). This is significantly related to the North Atlantic Oscillation Index (NAO) from June to October, mainly in July and August. Żmudzka (2007) analysed the effect of atmospheric circulation on the amount of cloudiness over Poland, and concluded that in the period 1951–2000 there was a slight decrease of 0.04% year^{-1}. The influence of the NAO on changes in water temperature in lakes in Poland was noted by Wrzesiński et al. (2015).

The greatest increase in tourist traffic in Poland, especially on the Baltic coast and in the lakelands, is recorded in June–August (Lijewski et al. 2002). The work describes the share of characteristic days in the total number of days from the beginning of April

Table 1. Statistical properties of the thermal summer at selected meteorological stations in the Polish Lowland, 1971–2015

Meteorological station	Date	Average date of ...		Duration of thermal summer days	Average temperature of air (°C)
	Standard deviation **(days)**	**beginning**	**end**		
Szczecin	Date	31 May	4 Sep	96	17.32
	Deviation	*10.48*	*8.67*	*11.5*	
Gorzów Wielkopolski	Date	26 May	5 Sep	102	17.56
	Deviation	*13.24*	*10.52*	*17.9*	
Zielona Góra	Date	27 May	10 Sep	105	17.64
	Deviation	*11.11*	*11.31*	*16.4*	
Koszalin	Date	8 Jun	3 Sep	86	17.07
	Deviation	*15.39*	*8.75*	*16.29*	
Poznań	Date	28 May	6 Sep	101	17.62
	Deviation	*15.37*	*10.14*	*17.03*	
Chojnice	Date	2 Jun	30 Aug	89	16.61
	Deviation	14.62	7.21	*16.6*	
Łeba	Date	17 Jun	2 Sep	76	16.80
	Deviation	*13.67*	*8.49*	*18.91*	
Toruń	Date	28 May	4 Sep	99	17.49
	Deviation	*11.47*	*8.29*	*13.11*	
Olsztyn	Date	3 Jun	30 Aug	88	16.85
	Deviation	*13.83*	*7.25*	*15.53*	
Mikołajki	Date	30 May	1 Sep	81	17.25
	Deviation	*10.84*	*6.91*	*14.88*	
Suwałki	Date	7 Jun	29 Aug	83	16.61
	Deviation	*17.21*	*9.14*	*19.23*	
Białystok	Date	31 May	29 Aug	88	16.92
	Deviation	*14.08*	*7.44*	*19.35*	

to the end of September. The data on the maximum daily air temperature defining the stimulus and the thermal discomfort over the year (Błażejczyk 2004; Koźmiński and Michalska 2011a, 2011b) made it possible to characterise the period from April to October in the years 1971–2015.

Of all the days in the bathing season (April to October), comfortable days (18.1–23.0°C) are most frequent, averaging from 59 to 96 days, followed by moderately hot days (23.1–25.0°C), averaging from 30 to 48 days. In summer, the large share of comfortable days in the total number of days creates good conditions for recreation and tourism in all the lakelands (Pomorskie, Masurian and Wielkopolsko-Kujawskie) (from 40 to 44%), and on the coast (from 45 to 50%). The share of very hot (boiling hot) days (>30.0°C), which are distressing for the human body, is 6–8% in the central-western part of the country, and 2–3% in the coastal zone. In the warm half-year, hot weather (25.1–30.0°C) is observed most often between 26th June and 25th August, and very hot (>30.0°C) from 15th July to 20th August.

Location and morphometric characteristics of the analysed lakes

The analysed lakes are located in northern Poland (φ=51°53'–54°42'N, λ=16°01'–23° 25'E), within the area of the last Weichselian glaciation (Fig. 1). The area of the studied lakes ranged from 154.5 ha (Lake Litygajno) to 7,020 ha (Lake Łebsko), while their mean depths were from 1.6 m (Łebsko) to over 38 m (Hańcza), and their maximal depths range from 6.3 m (Łebsko) to 106.1 m (Hańcza) (Choiński and Skowron 1998).

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Among the many morphometric parameters of lakes, depth relations play a significant role in thermal processes. They also decide on the usage of the littoral zone for bathing and the rate of its overgrowth (Skowron and Jaworski 2017). The deepest of the analysed lakes are: Hańcza (106.1 m), Drawsko (82.2 m) and Wigry (74.4 m) (Choiński and Skowron 1998). The shallowest lakes are water bodies where the maximum depth is less than 5 m: Gardno (2.6 m) and Jamno (3.9 m). One of the most representative morphometric parameters determining depth relations in a lake is its mean depth. In the case of the analysed water bodies the mean depth is over 20 m in four lakes, and less than 5 m in the six shallowest lakes. According to Choiński (2007), the mean depth is 6.62 m in all the lakes in the Pomorskie Lakeland, 7.72 m in the Masurian Lake District, and only 5.53 m in the lakes in the Wielkopolsko-Kujawskie Lakeland.

The percentage share of the lakes' area that does not exceed 1 m in depth confirms the shallow character of the examined lakes. The average share of this indicator is 13.6%, while the biggest share is >20% and they can be found in the shallow lakes of Gardno, Łebsko and Gopło. By contrast, the smallest share (<5%) can be observed in the lakes Ełckie, Mikołajskie and Białe Augustowskie.

Relation between water temperature and air temperature during the bathing season

It is generally known that there is a strong correlation between surface water temperature in lakes and air temperature (Dąbrowski et al. 2004; Skowron 2011; Ptak et al. 2017). It is best noticeable in shallow lakes, where both values are not much different (Szumiec 1984; Skowron 2001; Skowron and Piasecki 2016).

Studies on lakes of varied morphometry have shown that average daily differences between air temperature and surface water temperature may reach 3–3.5°C, but are most commonly at 0.5–1.2°C (Skowron 2011). The greatest differences occur in late spring (mainly in May), and may exceed 8–10°C at midday.

Generally, during the summer months (June–August), the daily air temperature was higher than

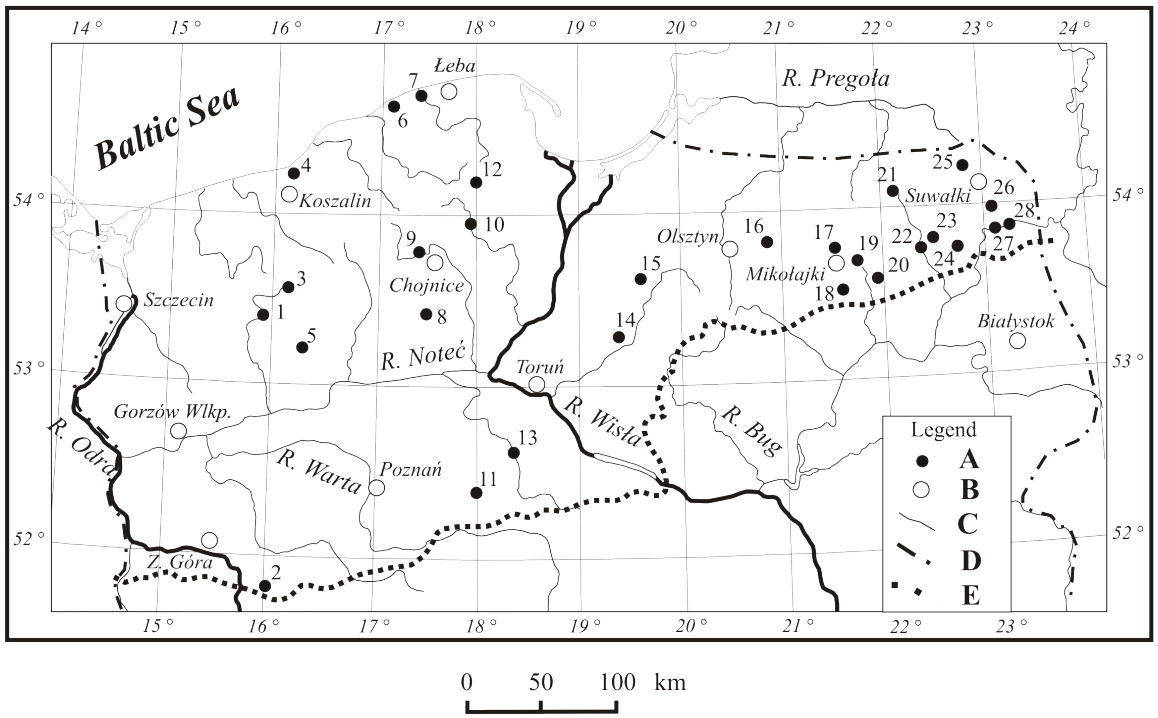

Fig. 1. Location of lakes covered by temperature observations: A lakes: 1-Lubie, 2-Sławskie, 3-Drawsko, 4-Jamno, 5-Nakielno, 6-Gardno, 7-Łebsko, 8-Sępoleńskie, 9-Charzykowskie, 10-Wdzydze Południowe, 11-Powidzkie, 12-Raduńskie Górne, 13-Gopło, 14-Bachotek, 15-Jeziorak, 16-Dadaj, 17-Mikołajskie, 18-Nidzkie, 19-Śniardwy, 20-Roś, 21-Litygajno, 22-Ełckie, 23-Selmęt Wielki, 24-Rajgrodzkie, 25-Hańcza, 26-Wigry, 27-Białe Augustowskie, 28-Studzieniczne, B meteorological stations, C – rivers, D – Polish border, E – maximum extent of the Vistulian Glaciation

the surface water temperature from 10:00 to 18:00 (09:00–17:00 GMT). In the remaining hours, the situation was usually opposite.

Characteristics of water temperature in the lakes during the bathing season

During the bathing season water temperature in lakes in Poland depends not only on climatic conditions and lake morphometry, i.e. the mean and maximum depths of the littoral zone, but also on lake trophic conditions, water transparency, the impact of rivers and the impact of anthropopressure, as well as on the course of the particular phases of the yearly cycle (Kowalska 1972; Jędrasik 1985; Janiec and Turczyński 1988; Skowron 1999, 2001, 2007a, 2011; Kubiak 2003; Sobolewski et al. 2014; Ptak et al. 2016). Therefore, the bathing season only covers a part of the yearly thermal cycle, including mainly the summer warming and summer cooling periods, separated by the date of the occurrence of the maximum surface water temperatures. Since the bathing season in lakes in Poland is most often observed from the end of May to mid-September, the analysis of water temperature in the lakes was carried out from May to October (Koźmiński and Michalska 2016, www.eea.europa.eu). The study examined the course of surface water temperature in lakes in the summer months, i.e. June, July and August, and its vertical and spatial variability and diurnal trends. For better readability of the differences in surface water temperature between the lakes in the Polish Lowland, the author introduced the concept of mean surface water temperature for three summer months (t_{sum}) as an indicator representing the thermal properties of the bathing season.

Temperature of surface water in the lake, its course and changes

The surface layer of a lake is commonly understood to be the most sensitive part of the lake system, which is susceptible to changes in meteorological conditions, and in which the basic processes and mechanisms shaping the dynamics and regime of this system take place (Lange 1978). The surface of water in lakes is a boundary layer, through which energy- and mass-exchange take place between the lake and its surroundings. It is also a zone of solar radiation absorption and water circulation. In this layer, the mechanisms that shape the thermal structures of water are essential to the thermal balance and the hydrological regime (Skowron 2011). In terms of thermal conditions, the "surface layer of water in a lake" is to be understood as a layer of 1 to 1.5 m thick, for which measurements taken at a depth of 0.4 m best represents its characteristics (Skowron 1999, 2000; Sobolewski et al. 2014). The summer water thermals are also influenced by the length of ice phenomena, which affect the initial date of summer temperature (Choiński et al. 2014; Choiński et al. 2015a, b; Wrzesiński et al. 2015b). Therefore, it is important to analyse the heat distribution in the annual course (Choiński et al. 2013).

Based on the mean monthly water temperatures from 15 lakes in the years 2005–2015, Koźmiński and Michalska (2016) concluded that the warmest month was July, with a temperature of 21.0° to 22.0°C. Analysing the mean surface water temperature in 28 lakes in the Polish Lowland in 1971–2010, Skowron (2011) notes that mean yearly temperature values ranged from 8.42°C (Hańcza) to 10.59°C (Sławskie, Powidzkie). The highest values occurred in the years 2001–2005, when in seven lakes they were higher than 10°C, while the lowest temperatures were recorded in the years 1976–1980 when they were lower than 9°C in nine lakes.

The calculations of the mean monthly surface water temperatures for the summer months of 1971–2015 showed that the highest values occurred in July and August, and ranged from 18.49°C (Gardno) to 21.06°C (Bachotek). For the remaining lakes the mean surface water temperatures fluctuated between 19.5 and 20.5°C in July, and 19.3 and 20.3°C in August.

The course of the mean surface water temperature for the summer period (t_{sum}) in 1971–2015 shows a spatial diversity within the Polish Lowland. The lowest water temperature in this period was recorded in the lakes Gardno (17.60°C), Raduńskie Górne (17.81°C) and Lebsko (17.95°C), while the highest temperature was recorded in the lakes

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Sławskie (20.38°C), Bachotek (20.34°C) and Jeziorak (20.22°C).

The highest absolute surface water temperature values were recorded as July turned to August 1994 when in eight lakes they were above 25°C at 07:00. The record high water temperature reached 30.2°C in Lake Nakielno and 29.2°C in Lake Jeziorak (Skowron 2009b, 2011). However, it should be remembered that, in small lakes without stationary temperature measurements, surface water temperature may exceed 31–32°C (Skowron 2011).

The analysis of mean yearly surface water temperature from 1971–2015 showed a significant diversity of course in the Polish Lowland (Table 2). The highest values of mean yearly surface water temperature (TWP) (the limnological isotherm above 10°C) cover the central and southern parts of the Dobrzyńskie Lakeland and the Kujawskie Lakeland and the eastern part of the Wielkopolskie Lakeland (Kowalska 1972). Conversely, the lowest mean yearly surface water temperatures (the limnological isotherm below 9°C) are found in the northern part of the Wschodniosuwalskie Lakeland, the Kashubian Lakeland and the Slowiński coastal area. The remaining areas are within the range of 9–10°C (Skowron 2011; Sobolewski et al. 2014).

Generally, there is a considerable decrease in surface water temperature in the lakes of the Polish Lowland towards the north and northeast, (Skowron 2011; Koźmiński and Michalska 2016). This proves the dependency between latitude and mean surface water temperature during the summer months (t_{sum}) in the selected lakes of the Baltic Sea catchment area (Fig. 2).

There is considerable diversity in the particular ranges of surface water temperature in the lakes and in their durations within individual lakes. The starting dates of the period with temperatures of 15°C and 18°C occurred earliest in the lakes in the Wielkopolskie Lakeland, and the differences between the extreme regions were 4–8 days (Table 2). However, the mean values of surface water temperature for the lakes in different lakelands vary considerably between lakes themselves and between years in the analysed 1971–2015 period.

The analysis of long-term changes in surface water temperature in various lakes in the northern hemisphere shows a noticeable increase in the latter half of the 20th century (Skowron 2011). The conducted calculations show that the mean yearly values of surface water temperature in lakes in Poland in the years 1971–2010 showed a positive trend in all the lakes, at the level of 0.02–0.05°C·year^{-1}

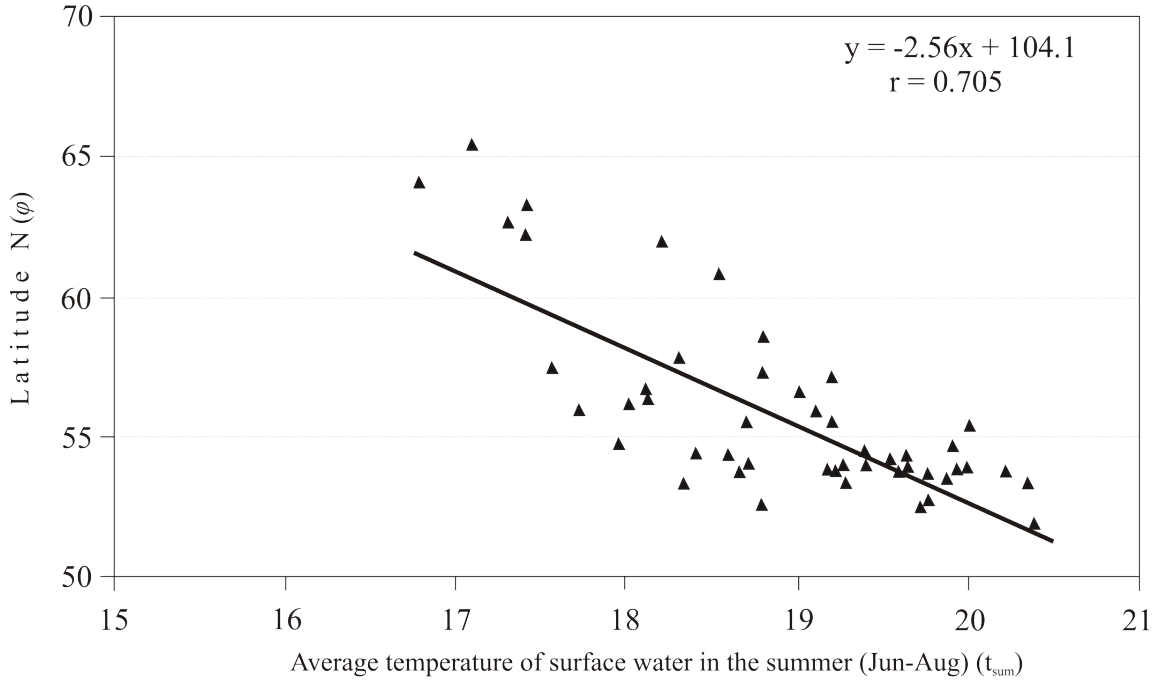

Fig. 2. Dependency between mean summer surface water temperature (t_{sum}) in selected lakes of the Baltic Sea catchment area, and latitude (φ) (after: www.environment.fi; Pernaravičiūtė 2004, modified; Apsīte et al. 2014, modified; and author)

(Skowron 2001; Sobolewski et al. 2014). In the years 1971–2015 there was also a positive trend, which amounted to 0.03–0.06°C·year^{-1}. The surface water temperature in the summer season also had a positive trend: in June – 0.04°C year^{-1}, in July 0.06°C·year^{-1} and August 0.05°C·year^{-1}. All quoted trends were statistically significant at the level of $a<0.01$.

Spatial, temporal and vertical diversity in water temperature in the bathing season

The studies carried out in various lakes in northern Poland show that lakes' surface water layers, which are subject to continuous mixing of water, have only small differences in temperature. Only in large lakes with heavily fragmented shorelines and numerous shallow bays can there be greater differences. The measurements carried out in many lakes of the Polish Lowland show that the largest differences in surface water temperature in the lake occur during spring warming and often reach 4–5°C, while in the other periods of the yearly cycle they rarely exceed 2°C (Skowron 2011).

The differences between the littoral and the profundal zones are rather insignificant and generally do not exceed 3°C (Table 3). Only in sporadic cases can they reach 4–5°C (Skowron 2011).

The differences in surface water temperature between the littoral and open pelagial zones depend on many factors, the most important of which is the nature of both the zones, especially the development and the extent of the littoral zone (Gieysztor 1960). Due to the mixing of water they usually oscillate between 0.8 and 1.5°C. Relatively big surface water temperature differences were observed very often in the summer (e.g. lakes Drawsko, Gopło and Wigry) (Skowron 2000, 2001).

The vast majority of lakes, with the exception of the polymictic water bodies, have fully-developed thermal stratigraphy with epi-, meta- and hypolimnions. This situation applies during the thermal summer (June–August), yet appears most often as early as early May, although in some years there may be significant time differences (Skowron 2011). The thermal stratification of water occurs fastest in bradymictic lakes, whereas in tachymictic lakes the circulation of water is clearly delayed (Starmach et al. 1976; Lampert and Sommer 1996; Kubiak 2003).

During the summer thermal stagnation the Polish lakes mostly developed thermal systems occur on average from mid-July to mid-August. The degree of formation of the individual thermal layers depends on: the depth; the area; the dynamic impact of the wind on the water mass; the shape of the lake and location of the lake's longer axis in relation to the prevailing wind direction; and the vertical distribution of volume. The thickness of individual layers and their thermal gradients are clearly differentiated, and correspond to the parameters characterising the lake basin (Skowron 1990, 2009a). These include mean depth, average slope of the lake bottom, relative depth, and relative depth index (Skowron 2011).

The depth of the occurrence and the temperature gradients of the water in the metalimnion layer (thermocline) (≥1°C·m^{-1}) between the superheated epilimnion and the cold hypolimnion layer are important to underwater diving. Crossing this layer involves the risk of thermal shock, especially for scuba divers who may want to dive without preparation or proper protection. The temperature in the metalimnion layer during the summer can fall by as much as 13–15°C, and sometimes even

Table 2. The mean dates when TSW in lakes crossed the threshold values in the particular Lakelands during the period 1971–2015 (calculated from data from the Institute of Meteorology and Water Management) (number of the lakes representing each Lakeland in brackets)

Region (number of lakes)	15-w	18-w	20-w	Max	20-j	18-j	15-j
Wielkopolskie Lakeland (3)	19-May	6-Jun	15-Jun	24-Jul	27-Aug	7-Sep	27-Sep
Lakes of the Baltic Coast (3)	28-May	14-Jun	24-Jun	26-Jul	12-Aug	22-Aug	9-Sep
Pomeranian Lakeland (7)	28-May	17-Jun	28-Jun	26-Jul	15-Aug	30-Aug	20-Sep
Masurian Lakeland (15)	22-May	9-Jun	16-Jun	25-Jul	21-Aug	1-Sep	20-Sep

Explanations: w – spring temperature, j – autumn temperature, Max – maximal temperature

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Table 3. Mean daily surface water temperature (0.5 m) at the littoral station (L - littoral) and the pelagial station (P - pelagial) on the selected examples (calculated based on measurements carried out every 30 minutes)

Lake (Lake numbers according to the Catalogue of Lakes of Poland after Choiński 2006)	Date	Water temperature (°C)		Difference in temperature (L–P) (°C)
		L - littoral	P – pelagial	
Bachotek (II-49-64)	25.07–02.08.1989	21.8	20.3	1.5
Brzeźno (I-28-10)	14–17.07.2005	23.3	20.6	2.7
Gaładuś (II-19-68)	26–30.06.1997	22.4	19.6	2.8
Gopło (III-23-1)	07–10.07.1998	18.8	17.5	1.3
Hańcza (II-9-20)	16–20.07.1997	22.6	21.6	1.0
Jeziorak (II-32-41)	26–28.07.2005	24.2	22.8	1.5
Wigry (II-19-1)	08–12.08.1995	23.4	21.3	2.1

more. There have been cases when the thermal gradient in the metalimnion layer exceeded 4.0–4.5°C·m^{-1}, which meant a drop in temperature of this layer of up to 3 m thick by as much as 16–17°C (Skowron 2007b). Most often, such places were not observed in bathing areas, where depths are too small to develop that layer. However, several tens of metres from unguarded bathing places in very deep lakes such cases may be recorded.

In the deepest lakes in Poland, the thermocline can be found at an average depth of 5.6 to 10 m, and in extreme cases from 4.8 m (Ełckie, Użewo, Trześniowskie) to 13.3 m (Wdzydze Południowe) (Skowron 2009c). The gradients in this layer in different years were strongly differentiated depending on mixing conditions (effective lengths) and epilimnion temperatures, and they reached 5.8°C·m^{-1}.

For most people bathing in lakes, the water temperature at 07:00 (06:00 GMT) has no practical relevance. Therefore, the time of optimal water temperature is of importance. For this purpose, the author conducted a study on the day trends of water and air temperature at different points of the lake (including in bathing areas). In the years 1971–2015 experimental measurements were conducted on 19 lakes in different parts of the Polish Lowland (Skowron and Piasecki 2016). It should be remembered, however, that experimental research can only be used to thoroughly understand selected processes shaping the thermal regime and to isolate them for detailed study, and therefore, they should be considered as a necessary supplement (Skowron 2011).

The analysis of the diurnal trend of surface water temperature in various lakes of the Lowland indicates that the maximum was recorded on average at 14:00–17:00 (13:00–16:00 GMT), while the minimum was mostly observed at 06:00–07:00 (05:00–06:00 GMT), although it was also recorded after 08:00 (07:00 GMT). Diurnal variations in the vertical distribution of water temperature are clearly noticeable down to a depth of 2.5–3.5 m, and they are also perceived down to a depth of 5.5–7 m (Skowron and Piasecki 2016).

Bathing season in Polish Lowland lakes

It is commonly assumed that the limits of the bathing season are determined by the date when the surface water temperature in the lakes reaches 15°C, at least for the young and healthy, and at least 18°C for the less hardened, the weaker and children (Koźmiński and Michalska 2013). Such conventional limit values suggest that the potential bathing season in Poland should start between 31st May and 25th June, and end between 26th August and 15th September (Lijewski et al. 2002).

For the purpose of this study, the beginning and the end of the bathing season was selected as the date of the earliest and the latest day with a mean surface water temperature higher or equal to – or less than or equal to – 15°C. These began and ended

a cumulative series of mean temperature deviations from 15°C, which for at least one month (31 days) do not reach negative or positive values (Makowiec 1983).

The start and end of the bathing season in the lakes of Poland

The spatial variation of the yearly cycle of surface water temperature in the lakes of the Polish Lowland was examined by analysing the individual thermal seasons of 28 lakes in the 45-year period. Their thermal properties were a function of geographic location (Kowalska 1972) and climatic conditions on the one hand, and individual characteristics of the water bodies on the other, including in particular morphometric, hydrological and trophic conditions, and the height of the water table above sea level (Koczorowska 1974; Skowron 1999, 2001, 2007b; Dąbrowski et al. 2004).

The average date of the beginning of the bathing season (>15°C) in the lakes in the Polish Lowland is between 16th May and 4th June (Table 4). The earliest dates were recorded in lakes Sławskie (15th May), Jeziorak (16th May) and Śniardwy (17th May). By contrast, the latest dates were found in the deep lakes: Raduńskie Górne, Drawsko and Hańcza (4th June). In the remaining lakes, the date of surface water temperature exceeding 15°C was generally between 20th and 25th May. The very earliest start of this season took place in 2000 in Lake Roś (18th April) and Lake Śniardwy (21st April), which resulted from record high air temperatures in mid-April. The latest dates for the start of the bathing season occurred in 1996 in Lake Jamno (16th July) and in 1984 in Lake Hańcza (12th July). In this case the date of the beginning of the bathing season was due to ice phenomena disappearing as late as in mid-April.

By contrast, the bathing season for the less hardened and children (>18°C) began on average between the beginning and the end of June. The earliest date appeared in the shallow lakes Śniardwy (2nd June), Sławskie, Bachotek, Gopło (3rd June) and Łebsko (25th June), but at the latest in lakes Raduńskie Górne (27th June) and Hańcza (26th June). In the remaining lakes these dates ranged between 12th and 15th June. The end of this season is recorded earliest in the coastal lakes Gardno and Łebsko (22nd August), but at the latest in lakes Sławskie (10th September), Powidzkie and Bachotek (7th September).

The end of the bathing season in the lakes of the Polish Lowland was also markedly varied. It ended earliest in the first ten days of September on average: Gardno (6th September), Lebsko (9th September) and Jamno (13th September), and latest at the end of September in the lakes of the Wielkopolskie Lakeland: Sławskie (28th September), Gopło (27th September) and Powidzkie (27th September). The absolute earliest dates of the end of the bathing season are also found in the coastal lakes: Łebsko (20th August), Gardno (21st August) and Jamno (25th August) The last dates with the temperature of 15°C take place as October turns to November: Gopło (2nd November), Studzieniczne (25th October), Slawskie and Lubie (23rd October).

Bathing season duration in Polish Lowland lakes

Due to significant morphometric differences between the lakes, and in particular to varied depths relations, they enter each phase of the yearly cycle at different times. This fact is well documented by the dates on which mean temperatures of 10, 15, 18 and 20°C occur in both spring and autumn, and the maximum temperature (Table 5).

The duration of the bathing season is important to both holidaymakers on lakes and their hosts and the administrative authorities of particular municipalities.

The calculations show that the course of the particular temperature ranges within a year is considerably variable in their time of occurrence. For example, the duration of the "biological summer" (temperature above 10°C) for 28 analysed lakes in the 1971–2015 period ranged from 147 days (Lake Hańcza) to 186 days (Lake Sławskie). Their average duration usually ranged from 168 to 172 days.

The bathing season in the main lakelands in Poland, where the extreme limit is 15°C, lasts from 95 days (Lake Gardno) to 136 days (Lake Sławskie).

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Table 4. Earliest (A), average (B) and latest (C) dates of transition of surface water temperature by selected limit values in the lakes in the Polish Lowland in the years 1971–2015 (based on data collected by the Institute of Meteorology and Water Management-National Research Institute).

No	Lake		15-w	18-w	20-w	Max	20-j	18-j	15-j
1	Lubie	A	2-May	16-May	27-May	10-Jun	18-Jun	26-Jul	25-Aug
		B	28-May	20-Jun	03-Jul	26-Jul	16-Aug	28-Aug	19-Sep
		C	03-Jul	30-Jul	07-Aug	25-Aug	12-Sep	17-Sep	23-Oct
2	Sławskie	A	29-Apr	5-May	12-May	11-Jun	09-Aug	23-Aug	04-Sep
		B	15-May	03-Jun	14-Jun	24-Jul	31-Aug	10-Sep	28-Sep
		C	30-May	24-Jul	26-Jul	23-Aug	17-Sep	29-Sep	23-Oct
3	Drawsko	A	07-May	16-May	24-May	22-Jun	18-Jun	31-Jul	01-Sep
		B	04-Jun	21-Jun	03-Jul	31-Jul	14-Aug	30-Aug	21-Sep
		C	04-Jul	18-Aug	19-Aug	29-Aug	13-Sep	21-Sep	15-Oct
4	Jamno	A	28-Apr	20-May	23-May	02-Jul	08-Jul	29-May	25-Aug
		B	27-May	18-Jun	27-Jun	31-Jul	16-Aug	24-Aug	13-Sep
		C	16-Jul	29-Jul	17-Sep	26-Aug	18-Sep	13-Sep	04-Oct
5	Nakielno	A	03-May	10-May	26-May	24-Jun	11-Jun	11-Aug	28-Aug
		B	24-May	14-Jun	30-Jun	26-Jul	13-Aug	02-Sep	21-Sep
		C	21-Jun	06-Aug	16-Aug	25-Aug	13-Sep	23-Sep	13-Oct
6	Gardno	A	07-May	07-May	28-May	10-Jun	17-Jun	29-Jul	21-Aug
		B	31-May	09-Jun	26-Jun	24-Jul	09-Aug	22-Aug	06-Sep
		C	26-Jun	20-Jul	17-Aug	22-Aug	04-Sep	08-Sep	21-Sep
7	Łebsko	A	28-Apr	22-May	24-May	06-Jun	27-Jun	17-Jul	20-Aug
		B	26-May	15-Jun	20-Jun	23-Jul	13-Aug	22-Aug	09-Sep
		C	16-Jun	08-Aug	17-Aug	22-Aug	01-Sep	13-Sep	04-Oct
8	Sępoleńskie	A	27-Apr	08-May	18-May	13-Jun	14-Jul	21-Aug	03-Sep
		B	19-May	06-Jun	13-Jun	22-Jul	24-Aug	05-Sep	23-Sep
		C	13-Jun	11-Jul	15-Aug	24-Aug	13-Sep	18-Sep	11-Oct
9	Charzykowskie	A	06-May	24-May	30-May	14-Jun	27-Jun	14-Aug	31-Aug
		B	29-May	18-Jun	27-Jun	29-Jul	15-Aug	30-Aug	19-Sep
		C	23-Jun	08-Aug	21-Aug	28-Aug	09-Sep	16-Sep	07-Oct
10	Wdzydze Płd.	A	06-May	25-May	29-May	14-Jun	28-Jun	27-Jul	03-Sep
		B	29-May	19-Jun	29-Jun	28-Jul	16-Aug	30-Aug	21-Sep
		C	24-Jun	09-Aug	15-Aug	01-Sep	12-Sep	17-Sep	16-Oct
11	Powidzkie	A	25-Apr	09-May	15-May	07-Jun	26-Jul	21-Aug	01-Sep
		B	23-May	11-Jun	16-Jun	26-Jul	27-Aug	07-Sep	27-Sep
		C	17-Jun	03-Aug	05-Aug	23-Aug	16-Sep	01-Oct	20-Oct
12	Raduńskie Górne	A	13-May	26-May	28-May	11-Jun	12-Jun	03-Jul	26-Aug
		B	04-Jun	27-Jun	03-Jul	25-Jul	10-Aug	23-Aug	16-Sep
		C	09-Jul	16-Aug	06-Aug	28-Aug	29-Sep	14-Sep	06-Oct
13	Gopło	A	24-Apr	09-May	10-May	07-Jun	19-Jun	28-Jul	30-Aug
		B	20-May	03-Jun	16-Jun	23-Jul	22-Aug	03-Sep	27-Sep
		C	23-Jun	19-Jul	17-Aug	27-Aug	10-Sep	26-Sep	02-Nov
14	Bachotek	A	27-Apr	29-Apr	01-May	11-Jun	15-Aug	21-Aug	29-Aug
		B	18-May	03-Jun	08-Jun	26-Jul	30-Aug	07-Sep	26-Sep
		C	13-Jun	15-Jul	16-Aug	28-Aug	17-Sep	03-Oct	19-Oct
15	Jeziorak	A	26-Apr	30-Apr	11-May	11-Jun	26-Jul	04-Aug	31-Aug
		B	16-May	05-Jun	13-Jun	26-Jul	26-Aug	03-Sep	21-Sep
		C	10-Jun	14-Aug	16-Aug	23-Aug	18-Sep	23-Sep	11-Oct
16	Dadaj	A	27-Apr	13-May	24-May	06-Jun	17-Jun	28-Jul	31-Aug
		B	25-May	14-Jun	16-Jun	26-Jul	18-Aug	01-Sep	21-Sep
		C	22-Jun	15-Aug	18-Aug	24-Aug	12-Sep	17-Sep	12-Oct

		A	27-Apr	24-May	22-May	15-Jun	25-Jul	01-Aug	05-Sep
17	Mikołajskie	B	28-May	15-Jun	20-Jun	29-Jul	24-Aug	04-Sep	25-Sep
		C	26-Jun	14-Aug	16-Aug	31-Aug	14-Sep	23-Sep	16-Oct
		A	24-Apr	13-May	19-May	08-Jun	06-Jul	02-Jul	02-Sep
18	Nidzkie	B	22-May	12-Jun	18-Jun	26-Jul	24-Aug	02-Sep	22-Sep
		C	15-Jun	06-Sep	31-Jul	21-Aug	20-Sep	17-Sep	12-Oct
		A	21-Apr	16-May	19-May	11-Jun	26-Jul	28-Jul	27-Aug
19	Śniardwy	B	17-May	02-Jun	08-Jun	27-Jul	21-Aug	30-Aug	15-Sep
		C	14-Jun	02-Jul	16-Aug	20-Aug	13-Sep	16-Sep	06-Oct
		A	18-Apr	23-May	26-May	10-Jun	30-Jun	02-Aug	28-Aug
20	Roś	B	19-May	12-Jun	22-Jun	27-Jul	20-Aug	31-Aug	18-Sep
		C	29-Jun	16-Jul	16-Aug	27-Aug	13-Sep	17-Sep	07-Oct
		A	25-Apr	11-May	20-May	12-Jun	25-Jul	05-Aug	03-Sep
21	Litygajno	B	24-May	07-Jun	17-Jun	23-Jul	22-Aug	02-Sep	21-Sep
		C	24-Jun	06-Jul	15-Aug	29-Aug	12-Sep	19-Sep	11-Oct
		A	27-Apr	10-May	20-May	11-Jun	28-Jul	05-Aug	02-Sep
22	Elckie	B	20-May	04-Jun	11-Jun	24-Jul	25-Aug	04-Sep	23-Sep
		C	16-Jun	06-Jul	16-Aug	25-Aug	15-Sep	17-Sep	11-Oct
		A	24-Apr	20-May	25-May	11-Jun	01-Jul	14-Aug	31-Aug
23	Selmęt Wielki	B	25-May	13-Jun	20-Jun	22-Jul	17-Aug	01-Sep	20-Sep
		C	26-Jun	04-Aug	03-Aug	21-Aug	12-Sep	16-Sep	11-Oct
		A	24-Apr	16-May	22-May	10-Jun	25-Jul	17-Aug	02-Sep
24	Rajgrodzkie	B	23-May	07-Jun	17-Jun	24-Jul	23-Aug	03-Sep	22-Sep
		C	19-Jun	24-Jul	16-Aug	24-Aug	14-Sep	26-Sep	13-Oct
		A	07-May	29-May	03-Jun	12-Jun	21-Jun	23-Jun	29-Aug
25	Hańcza	B	04-Jun	26-Jun	02-Jul	01-Aug	13-Aug	24-Aug	13-Sep
		C	12-Jul	16-Aug	12-Aug	27-Aug	05-Sep	12-Sep	02-Oct
		A	24-Apr	09-May	14-May	13-Jun	30-Jul	19-Aug	02-Sep
26	Wigry	B	24-May	07-Jun	13-Jun	24-Jul	24-Aug	04-Sep	22-Sep
		C	24-Jun	17-Jul	01-Aug	20-Aug	13-Sep	19-Sep	11-Oct
		A	23-Apr	18-May	21-May	07-Jun	25-Jul	05-Aug	02-Sep
27	Białe Augustowskie	B	24-May	11-Jun	20-Jun	26-Jul	21-Aug	02-Sep	20-Sep
		C	18-Jun	03-Aug	16-Aug	26-Aug	11-Sep	19-Sep	07-Oct
		A	22-Apr	02-May	21-May	04-Jun	22-Jul	29-Jul	02-Sep
28	Studzieniczne	B	23-May	07-Jun	18-Jun	23-Jul	20-Aug	01-Sep	21-Sep
		C	20-Jun	19-Jul	17-Aug	21-Aug	11-Sep	24-Sep	25-Oct

Explanations: w – value of temperature in spring, j – value of temperature in autumn, Max – maximal temperature

In the remaining lakes, it usually varies between 115 and 120 days.

During the 1971–2015 period, the average duration of the bathing season with water temperature ≥18°C ranges from 43 days (Lake Gardno) to 94 days (Lake Sławskie), while the extreme values are within 0 days (lakes Gopło and Hańcza) and 134 days (Lake Bachotek).

There is also considerable spatial variation in the duration of the bathing season with a surface water temperature ≥20°C. It ranges from 16 days for Lake Gardno to 94 days in Lake Sławskie and 93 days in Lake Bachotek, with an average of 70–74 days in the other lakes. There is also large spatial variation in the number of days with a temperature of ≥25°C, which in the analysed 45 years ranged from 0 dys for Lake Raduńskie Górne and 1 for Lake Gardno to 47 in Lake Drawsko and 36 in Lake Jeziorak.

Conclusions

It is generally known that in addition to attractiveness of landscape, water purity and infrastructure, tourists' choice of a holiday resort is also directly influenced by air temperature and water temperature in the lakes. The surface water temperature in the

Table 5. Properties of selected ranges of surface water temperature in Polish Lowland lakes, 1971–2015 (according to data from the Institute of Meteorology and Water Management-National Research Institute).

No	Lake	Number of days above 10°C		Number of days above 15°C		Number of days above 18°C		Number of days above 20°C		Number of days above 25°C – Year
		Average	Min/ Max	Average	Min/ Max	Average	Min/ Max	Average	Min/ Max	Max
1	Lubie	169	141/194	116	76/149	65	17/102	31	0/69	11 - 2010
2	Sławskie	186	169/218	136	103/159	94	45/132	56	13/89	20 - 2006
3	Drawsko	165	140/191	110	75/139	62	14/120	28	0/112	47 - 2003
4	Jamno	170	141/190	109	54/142	58	9/91	26	0/48	21 - 2006
5	Nakielno	173	146/200	118	78/149	69	19/130	36	0/84	27 - 2006
6	Gardno	161	136/181	95	68/130	43	11/75	16	0/54	1 - 1995
7	Łebsko	167	144/192	101	73/127	49	20/79	21	1/48	3 - 1994
8	Sępoleńskie	178	157/203	127	101/152	83	34/125	47	10/80	15 - 1994
9	Charzykowskie	170	152/194	112	77/140	62	26/99	28	1/56	17 - 1994
10	Wdzydze Płd.	169	149/193	112	84/141	63	20/99	29	0/68	10 - 1994
11	Powidzkie	183	159/215	129	96/160	83	31/122	47	6/99	27- 1994
12	Raduńskie Górne	161	142/189	102	68/135	47	11/87	17	0/47	0 -
13	Gopło	185	150/238	131	82/178	85	0/129	47	0/106	22 - 1994
14	Bachotek	182	162/212	133	101/169	93	51/134	55	5/97	17 - 1982
15	Jeziorak	176	156/197	126	99/153	84	30/128	49	3/96	36 - 1994
16	Dadaj	170	148/191	119	85/146	72	19/114	36	0/89	15 - 2010
17	Mikołajskie	171	153/193	120	95/144	71	27/107	38	3/68	13 - 2010
18	Nidzkie	172	152/190	124	88/152	81	27/114	44	0/42	14 - 2010
19	Śniardwy	168	150/188	119	90146	75	31/111	42	5/69	14 - 1994
20	Roś	168	142/188	116	83/140	71	27/110	36	0/80	6 - 2010
21	Litygajno	169	148/189	121	96/144	78	36/128	41	2/76	18 - 2010
22	Ełckie	172	145/192	125	99/144	85	51/126	50	4/90	17 - 1994
23	Selmęt Wielki	168	146/188	118	89/144	69	26/114	35	0/70	11 - 2010
24	Rajgrodzkie	169	147/194	122	96/144	82	42/111	48	7/79	15 - 1994
25	Hańcza	147	108/172	100	77/126	55	0/101	26	0/62	10 - 1994
26	Wigry	168	142/193	120	89/144	77	43/121	43	6/81	17 - 2010
27	Białe Augustowskie	168	147/190	121	95/149	78	27/111	40	2/72	21 - 2010
28	Studzieniczne	168	144/190	121	95/146	78	41/112	42	7/76	22 - 2010

lakes defines its range and daily amplitude and at the same time determines the start and end dates of the bathing season and its duration.

The analyses of the mean monthly and daily surface water temperature trends and their vertical diversity in the lakes of the Polish Lowland during the summer months (June–August) allowed the author to reach the following conclusions:

Surface water temperature in the lakes in the Polish Lowland in July and August ranged from 20 to 24°C.

Differences in surface temperature within the lake ranged from 0.6°C (summer and autumn months) to 3.5°C (spring months). This was confirmed by synchronous measurements conducted in many lakes (Gopło, Jeziorak, Wigry, Hańcza, Brzeźno, Bachotek, Gładuś).

From 11:00 AM to 8:00 PM during the summer months (June–August), surface water temperature in the littoral zone was most often higher than the temperature in the pelagial zone.

From 10:00 AM to 4:00 PM in July and August air temperature was generally higher than surface water temperature, and the maximum differences reached as high as 6–8°C.

In the daily course, the highest values of surface water temperature were recorded between 3:00 PM and 6:00 PM, while the lowest values were usually between 5:00 AM and 7:00 AM, and the mean daily surface water temperature was from 8:00 AM to 11:00 AM, and 8:00–10:00 PM.

Water temperature measurements carried out at 7:00 AM by the Institute of Meteorology and Water Management at a depth of 0.4 m are generally lower than the mean daily value by 2 to 12% (0.5–2.0°C), with an average of approx. 4%. In the period of summer stagnation (the turn of July/August), these differences range from 1.8 to 2.5%. In the period of autumn cooling, they usually fluctuate between 0.8 and 1.1%, and in the periods of homothermy they do not exceed 1%.

The most favourable conditions for bathing in the lakes in Poland occur in the period from the beginning of July to the end of August, when the surface water temperature generally exceeds 18°C. The best conditions for bathing are between 10:00 AM and 6:00 PM.

The location of the bathing areas on the lakes should take into account the bottom relief in the shoreline zone (temperate inclination of the sandy slope), as well as the overgrowing of the littoral zone, accessibility and infrastructure (sanitary and catering facilities), as well as the safety of bathing areas.

References

APSITE E., ELFERTS D., ZUBANICS A. AND LATKOWSKA I., 2014, Long-term changes in hydrological regime of the lakes in Latvia. Hydrology Research, 45(3): 308–321.

ATLAS KLIMATU POLSKI, 2005, H. Lorenc (ed.), Instytut Meteorologii i Gospodarki Wodnej, Warszawa.

BŁAŻEJCZYK K., 2004, Bioklimatyczne uwarunkowania rekreacji i turystyki w Polsce. Prace Geograficzne, IGiPZ PAN, 192, Warszawa.

CHOIŃSKI A., 2006, Katalog jezior Polski, Wyd. Nauk. UAM, Poznań.

CHOIŃSKI A., 2007, Limnologia fizyczna Polski, Wyd. Nauk. UAM, Poznań.

CHOIŃSKI A., Ptak M., Skowron R., 2014, Tendencje zmian zjawisk lodowych jezior Polski w latach 1951–2010. Przegląd Geograficzny, 86(1): 23–40.

CHOIŃSKI A., Ptak M., Strzelczak A., 2015a, Changeability of accumulated heat content in alpine-type lakes. Polish Journal of Environmental Studies, 24(6): 2363–2369.

CHOIŃSKI A., Ptak M., Skowron R., Strzelczak A., 2015b, Changes in ice phenology on Polish lakes from 1961–2010 related to location and morphometry. Limnologica, 53: 42–49.

CHOIŃSKI A., Skowron R., 1998, Najgłębsze jeziora Niżu Polskiego w świetle najnowszych pomiarów głębokościowych. Czasopismo Geograficzne, 60(3–4): 339–343.

DĄBROWSKI M., MARSZELEWSKI W., SKOWRON R., 2004, The trends and dependencies between air and water temperatures in the lakes located in Northern Poland in the years 1961–2000. Hydrology and Earth System Sciences, 8(1): 79–87.

GIEYSZTOR M., 1960, On the thermal conditions of the littoral zone of lakes. Polskie Archiwum Hydrobiologii i Rybactwa, 8, Warszawa: 171–193.

JANIEC B., TURCZYŃSKI M., 1988, Wiosenno-letnia faza cyklu termicznego najgłębszych jezior Pojezierza Łęczyńsko-Włodawskiego. Badania hydrograficzne w poznaniu środowiska, UMCS, Wydz. BiNoZ, Lublin: 59–70.

JĘDRASIK J., 1985, Uwarunkowania cykli termicznych w jeziorach. Zeszyty Naukowe Wydz. Biologii, Geografii

i Oceanologii Uniwersytetu Gdańskiego, Geografia, Gdańsk, 14: 45–56.

KOCZOROWSKA J., 1974, Porównanie termiki powierzchniowej dwóch jezior na Pojezierzu Sławskim. Badania Fizjograficzne nad Polską Zachodnią, t. XXVII, ser. A. Geografia Fizyczna, Poznań: 61–69.

KOSSOWSKA-CEZAK U., 2005, Współczesne ocieplenie a codzienne wartości temperatury średniej dobowej w Warszawie. [in:] E. Bogdanowicz, U. Kossowska-Cezak and J. Szkutnicki (eds), Ekstremalne zjawiska hydrologiczne i meteorologiczne, Polskie Towarzystwo Geofizyczne, IMiGW, Warszawa: 64–69.

KOWALSKA A., 1972, Termika jezior północnej Polski. Czasopismo Geograficzne, 43(4): 371–385.

KOZŁOWSKA-SZCZĘSNA T., KRAWCZYK B., KUCHCIK M., 2004, Wpływ środowiska atmosferycznego na zdrowie i samopoczucie człowieka. IGiZP. PAN, Monografie, Warszawa.

KOŹMIŃSKI C., MICHALSKA B., 2005, Usłonecznienie w Polsce. Wyd. Akademii Rolniczej, Szczecin.

KOŹMIŃSKI C., MICHALSKA B., 2011a, Meteorologiczne uwarunkowania rozwoju turystyki i rekreacji w strefie polskiego wybrzeża Bałtyku. Acta Balneologica, 53(1): 123.

KOŹMIŃSKI C., MICHALSKA B., 2011b, Zmienność dni zimnych, chłodnych, ciepłych, gorących i upalnych w okresie kwiecień-wrzesień w Polsce. Przegląd Geograficzny, 83: 91-107.

KOŹMIŃSKI C., MICHALSKA B., 2016, Ocena temperatury wody w jeziorach i długości sezonu kąpielowego na pojezierzach w Polsce. Przegląd Geograficzny, 88(3): 383–400.

KOŹMIŃSKI C., MICHALSKA B., SZCZEPANOWSKA E., GÓRNIK K., 2013, Zarys turystyki zdrowotnej i uzdrowiskowej. Uniwersytet Szczeciński, Szczecin.

KUBIAK J., 2003, Największe dimiktyczne jeziora Pomorza Zachodniego. Poziom trofii, podatność na degradację oraz warunki siedliskowe ichtiofauny. Szczecin, Rozprawy 214(96).

LAMPERT W., SOMMER U., 1996, Ekologia wód śródlądowych. PWN, Warszawa: 1–290.

LANGE W., 1978, Warunki akumulacji ciepła w jeziorach Pojezierza Kaszubskiego. Zeszyty Naukowe Wydziału Nauk o Ziemi, Geografia 8: 89–108.

LIJEWSKI T., MIKUŁOWSKI B., WYRZYKOWSKI J., 2002, Geograficzna turystyki Polski. Polskie Wydawnictwo Ekonomiczne, Warszawa.

MAKOWIEC M., 1983, Wyznaczanie termicznych pór roku. Przegląd Geofizyczny, 28(2): 209–220.

MŁYNARCZYK Z., BORKOWSKI G., 2015, Limnoturystyka w Polsce Zachodniej na przykładzie Jeziora Zbąszyńskiego. Europa Regionum, Wydawnictwo Uniwersytetu Szczecińskiego, Szczecin, 23: 35–54.

PERNARAVIČIŪTĖ B., 2004, The impact of climate change on thermal regime of Lithuanian lakes. Ekologija, 2: 58–63.

PTAK M., WRZESIŃSKI D., CHOIŃSKI A., 2017, Long-term changes in the hydrological regime of high mountain lake Morskie Oko (Tatra Mountains, Central Europe). Journal of Hydrology and Hydromechanics, 65(2): 146–153.

PTAK M., CHOIŃSKI A., KIRVIEL J., 2016, Long-term water temperature fluctuations in coastal rivers (Southern Baltic) in Poland. Bulletin of Geography. Physical Geography Series, 11: 35–42.

SKOWRON R., 1990, Struktura termiczna wody w okresie letniej stagnacji na przykładzie wybranych jezior z Pojezierza Gnieźnieńskiego i Kujawskiego. Acta Universitatis Nicolai Copernici, Geografia, 22: 45–83.

SKOWRON R., 1999, Letnia stratyfikacja termiczna wody w jeziorze Hańcza. Acta Universitatis Nicolai Copernici, Geografia, 29(103): 247–256.

SKOWRON R., 2000, Zmiany temperatury wody i zasobów ciepła w przebiegu dobowym na przykładzie epitermicznego jeziora Gopło. Acta Universitatis Nicolai Copernici, Geografia, 31(106): 289–306.

SKOWRON R., 2001, Surface water thermal seasons in Polish lakes, their distribution and spatial differentiation. Limnological Review, 1: 251–263.

SKOWRON R., 2007a, Roczny cykl temperatury wody powierzchniowej w jeziorach na Niżu Polskim i jego zmienność. [in:] Z. Michalczyk (ed.), Obieg wody w środowisku naturalnym i przekształconym, Lublin, Badania hydrograficzne w poznaniu środowiska, 8: 452–461.

SKOWRON R., 2007b, The thermocline layer in the thermal water structure of selected Polish lakes. Limnological Review, 7(3): 161–169.

SKOWRON R., 2009a, Kształtowanie się temperatury wody w okresie letniej stagnacji w najgłębszych jeziorach niżowych Polski. [in:] Zasoby wodne i ich ochrona, Obieg wody i materii w zlewniach rzecznych, Fundacja Rozwoju Uniwersytetu Gdańskiego, Gdańsk: 81–95.

SKOWRON R., 2009b, Extreme thermal phenomena of surface water in the lakes of Northern Poland. Limnological Review, 9(2–3): 97–109.

SKOWRON R., 2011, Zróżnicowanie i zmienność wybranych elementów reżimu termicznego w jeziorach na Niżu Polskim. Wydawnictwo Uniwersytetu M. Kopernika, Toruń.

SKOWRON R., JAWORSKI T., 2017, Changes in lake area as a consequence of plant overgrowth in the South Baltic Lakelands (N Poland) resulting from natural and anthropogenic factors. Bulletin of Geography. Physical Geography Series, 12: 19–30.

SKOWRON R., PIASECKI A., 2016, Dynamics of the daily course of water temperature in Polish lakes. Journal of Water and Land Development, 31: 149–156.

SOBOLEWSKI W., BOROWIAK D., BOROWIAK M., SKOWRON R., 2014, Baza danych jezior Polski i jej wykorzystanie w badaniach limnologicznych. „Picador" Komunikacja Graficzna s.c., Lublin.

STARMACH K., WRÓBEL S., PASTERNAK K., 1976, Hydrobiologia. PWN, Warszawa.

SZUMIEC M., 1984, Termika stawów karpiowych.PWN, Warszawa.

WISZNIEWSKI W., CHEŁCHOWSKI W., 1975, Charakterystyka klimatu i regionalizacja klimatologiczna Polski. Wydawnictwo Komunikacji i Łączności, IMGW, Warszawa.

WOŚ A., 1999, Klimat Polski, PWN, Warszawa.

WRZESIŃSKI D., CHOIŃSKI A., PTAK M., 2015a, Effect of the North Atlantic Oscillation on the thermal characteristics of lakes in Poland. Acta Geophysica, 63(3): 863–883.

WRZESIŃSKI D., CHOIŃSKI A., PTAK M., Skowron R., 2015b, Effect of the North Atlantic Oscillation on the Pattern of Lake Ice Phenology in Poland. Acta Geophysica, 63(6): 1664–1684.

ŻMUDZKA E., 2007, Zmienność zachmurzenia nad Polską i jej uwarunkowania cyrkulacyjne (1951–2000). Wydawnictwo Uniwersytetu Warszawskiego, Warszawa.

Electronic sources

NATIONAL CLIMATIC DATA CENTER GLOBAL HISTORICAL CLIMATE NETWORK, version 2; http://www.ncdc.noaa.gov.

EUROPEAN ENVIRONMENT AGENCY, http://eea.europa.eu

ENVIRONMENT, http://environment.fi

SERWIS KĄPIELOWY, http://sk.gis.gov.pl

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