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THERMAL-OXYGEN CONDITIONS IN LAKES ROŚ AND ROSPUDA FILIPOWSKA (NORTH-EASTERN POLAND) IN THE SUMMER HALF-YEAR 2005–2014

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Key words: thermal profile, oxygen, lakes, wind, Mazurian Lakeland.

Abstract

Thermal and oxygen conditions of lake ecosystems are important for their functioning. The availability of detailed information is of particular importance in the context of the observed environmental changes. The paper presents thermal-oxygen conditions in Lakes Roś and Rospuda Filipowska in north-eastern Poland in the years 2005–2014 for the summer half-year (May – October). Both of the lakes are classified as stratified lakes. The mean water temperature throughout the water column in Lake Roś was 11.3°C, and in Lake Rospuda 9.4°C. The temperature distribution was evidently affected by wind. In the case of Lake Roś with better conditions for water mixing due to the orientation of the lake's axis in relation to the direction of dominant winds, the epilimnion covered approximately 25% of the water column (in July), whereas in the case of Lake Rospuda (with axis not aligned with the direction of dominant winds), the zone covered approximately 18%. In both of the lakes, a correlation was recorded between oxygen dissolved in water and water temperature. It was more evident in the case of Lake Roś, where the oxygen curve in all months was similar to that of temperature. In Lake Rospuda, no such situation was recorded for May and June. No statistically significant changes in both of the parameters were recorded in the analysed multiannual.

WARUNKI TERMICZNO-TLENOWE JEZIORA ROŚ I ROSPUDA FILIPOWSKA (PÓŁNOCNO-WSCHODNIA POLSKA) W PÓŁROCZU LETNIM 2005–2014

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Słowa kluczowe: profile termiczne, tlen, jeziora, wiatr, Pojezierze Mazurskie.

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A b s t r a k t

Istotne dla funkcjonowania ekosystemów jeziornych są warunki termiczne i tlenowe w nich panujące. Posiadanie szczegółowych informacji na ten temat jest ważne w kontekście obserwowanych zmian środowiska. W pracy przeanalizowano warunki termiczno-tlenowe jeziora Roś i Rospuda Filipowska w północno-wschodniej Polsce w latach 2005–2014 dla półrocza letniego (maj – październik). Oba jeziora należą do stratyfikowanych. Średnia temperatura wody całego pionu jeziora Roś wyniosła 11,3°C, a jeziora Rospuda 9,4°C. Na rozkład temperatury widoczny był wpływ wiatru. W przypadku jeziora Roś, w którym występują lepsze warunki do mieszania wody z uwagi na orientację osi jeziora w stosunku do kierunku dominujących wiatrów, epilimnion obejmował ok. 25% (w lipcu), podczas gdy w przypadku jeziora Rospuda (niezorientowanego osią do kierunku przeważających wiatrów) strefa ta wyniosła ok. 18%. W obu jeziorach odnotowano związek rozkładu tlenu rozpuszczonego w wodzie z jej temperaturą. Był on bardziej wyraźny w przypadku jeziora Roś, gdzie krzywa tlenowa była we wszystkich miesiącach współkształtna z krzywą temperatury. W Rospudzie takiej sytuacji nie odnotowano dla maja i czerwca. W analizowanym wieloleciu nie wykryto istotnych statystycznie zmian obu parametrów.

Introduction

Water is one of the basic elements of the natural environment. Its accessibility and appropriate quality are of key importance for the course of life processes. Moreover, water is important for the broadly defined human economic activity, determining industrial and agricultural production etc. Due to its properties, water rapidly responds to any changes in the environment, both of natural e.g. climate changes (CHOIŃSKI et al. 2015) and artificial origin, e.g. melioration works (PTAK et al. 2013). A special role in the hydrosphere is played by lakes which constitute an easily accessible reservoir of drinking water at the global scale. The strongest relations between the environment and lakes occur in lakelands, where high density of lakes influences the water circulation conditions, topoclimate, tourism development, etc. In Poland, areas of the type are particularly located in the northern part of the country, corresponding to the range of the last glaciation.

The basic parameters of lake waters include temperature and dissolved oxygen. Water temperature is of high importance both in biological (HÖÖK et al. 2007, DUPUIS and HANN 2009, PEŁECHATA et al. 2015) and physical-chemical terms (NONAKA et al. 2007, XU et al. 2012, LI et al. 2013). Oxygen is necessary for the transformations of all aerobic organisms, and is of key importance in biogeochemical processes (WITEK and JAROSZEWICZ 2010). Oxygen dissolved in water is one of the primary parameters determining its quality (TERZHEVIK et al. 2009). In extreme cases, lack of oxygen can lead to death of organisms; such cases are quite common (MHLANGA et al. 2006, JONIAK et al. 2013, RAO et al. 2014).

In view of the above, the detailed determination of the distribution of both of the parameters constitutes an elementary set of information on a given lake ecosystem. Such information is not only important from the scientific point of view. It can provide the basis for undertaking potential reclamation works for degraded lakes. The objective of the paper is to characterise the thermal-oxygen conditions of two lakes: Roś and Rospuda Filipowska (Rospuda) and assessment of their correlations with meteorological conditions.

Research Area, Materials and Methods

The analysed lakes are located in the Masurian Lakeland in north-eastern Poland (Figure 1).

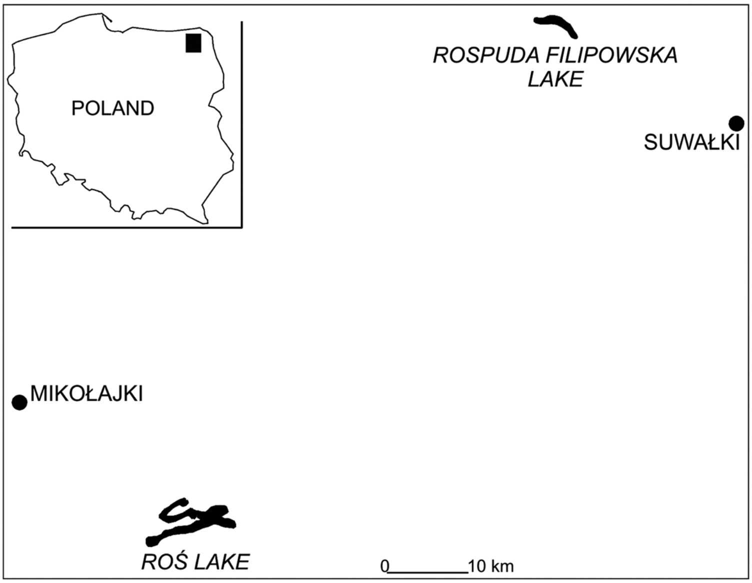

Fig. 1. Location of the studied lakes

Lake Roś with an area of 1,808 ha has a maximum depth of 31.8 m. Its mean depth is 8.1 m. The lake belongs to the land of Great Masurian Lakes, closing their sequence to the south-east (KONDRACKI 2002). It is connected with Lake Śniardwy (the largest lake in Poland) with the Jegliński Channel. The Pisa River (river of III degree), a right tributary of the Narew River, takes its beginning in Lake Roś. Lake Rospuda has an area of 323 ha, maximum depth of 38.9 m. and mean depth of 14.5 m. The Rospuda River flows through the lake. The Area of Protected Landscape "Rospuda Valley" with a total area of 25 250 ha was established for the river in 1991. According to the climatic division of Poland (WOŚ 2010), Lake Roś is located in region 11 – where mean air temperature amounts to 7°C, the coldest month is January (-3.5°C), and the warmest month is July (17.5°C). The mean annual precipitation total amounts to 552 mm. Lake Rospuda is located in region 12, where mean air temperature amounts to 6.7°C, the coldest month is January (-4.2°C), and the warmest month is July (17.3°C). Mean annual precipitation total amounts to 576 mm.

The paper is based on data collected by the Institute of Meteorology and Water Management – National Research Institute (IMGW-PIB). The data cover measurements of temperature and oxygen dissolved in water in both lakes. The measurements were performed with monthly frequency in the deepest place of each of the lakes every 1 m. This involved the application of a thermal-oxygen sonde YSI Proffesional and YSI ProOdo. The observations concern the summer half-year (May – October) in the years 2005–2014. Data on air temperatures (daily means) and wind direction for the Suwałki and Mikołajki stations (hourly values) from the years 2005–2014 were also used. The analysis of trends of changes in water temperature, oxygen dissolved in water, and air temperature was performed by means of linear regression in Microsoft Excel software, adopting the significance level of $p = 0.05$.

Results and Discussion

The distribution of water temperature and oxygen dissolved in water in the monthly course is presented in Figure 2.

Due to their considerable depths, Lakes Roś and Rospuda are both stratified lakes. After the period of spring homothermy, thermal layering occurs, and three characteristic zones develop, namely epi-, meta-, and hypolimnion. In both of the cases, such a situation is recorded from the first to the last of the analysed months. The mean water temperature (entire profile) in the analysed multiannual for Lake Roś amounted to 11.3°C, and for Lake Rospuda 9.4°C. The highest difference in temperature in a profile occurs in July for both of the lakes. In the case of Lake Roś, it amounts to 15.6°C, and 15.8°C for Lake Rospuda. The lowest difference in water temperature was recorded in October, and amounted to 2.4°C and 3.7°C, respectively. More evident development of particular zones in the case of Lake Rospuda in all months draws attention. Such a situation should be associated with individual parameters of lakes. Water mixing, generated by wind, is of key importance for heat distribution from the surface zone of water into its deeper sectors. The depth in the lake reached by the wave base is determined not only by the aforementioned individual parameters, but also climatic factors – impact of wind. The analysis of the mean effective length of lake D_e (determining the average route of wind

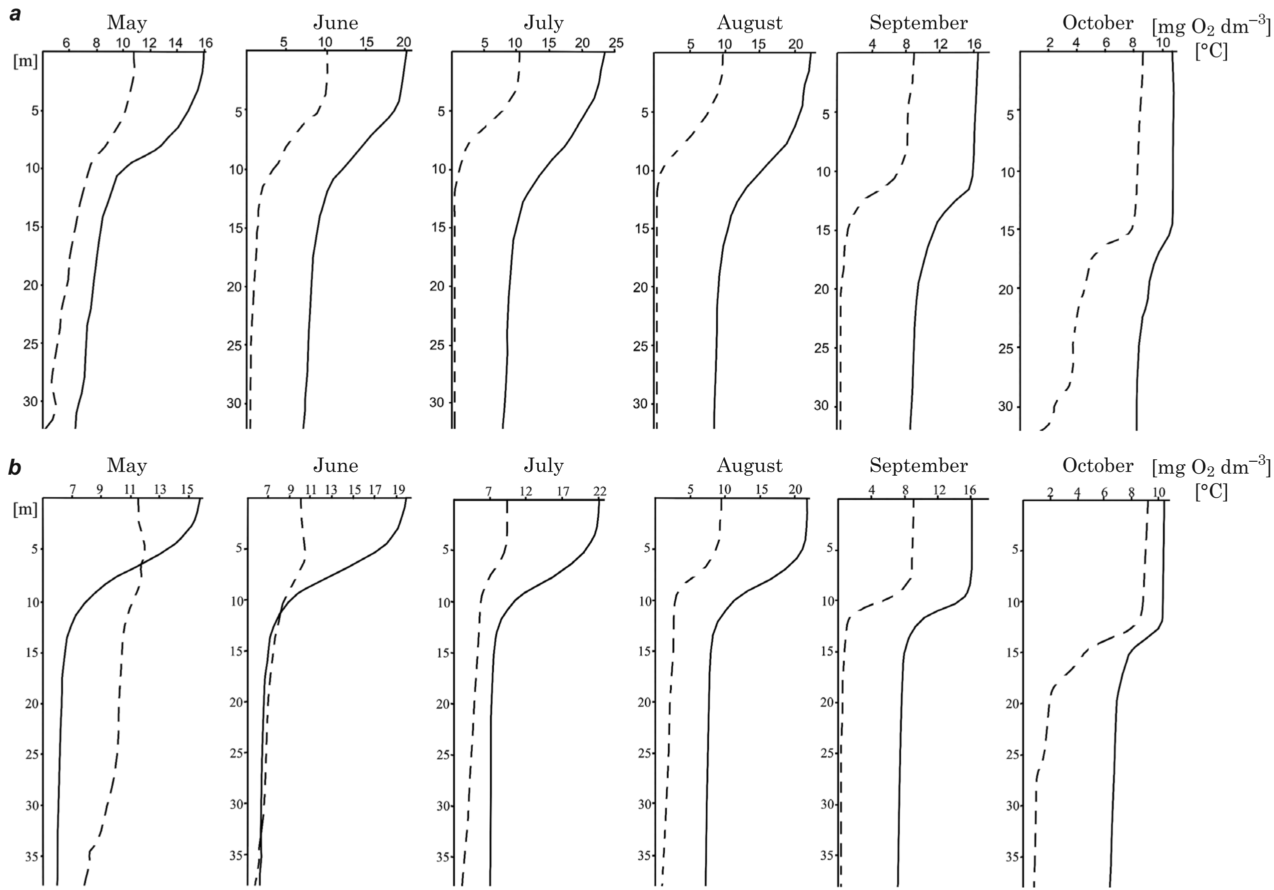

Fig. 2. The distribution of temperatures and oxygen dissolved in water in the analysed profiles (monthly means from the years 2005–2014): *a* – Roś Lake; *b* – Rospuda Lake; dotted line – oxygen, continuous line – temperature

over the water surface on which wind encounters no obstacles) suggests that in the context of mixing of limnic waters, Lake Rość shows better conditions, with the value equalling 6.7 km. For Lake Rospuda, the value amounts to 3.3 km. Therefore, a longer route of wind impact influences the possibility of water mixing in deeper parts of the lake. Moreover, the axis of Lake Rość is parallel to the direction of winds dominant in the region of its location. The performed analysis of the frequency of occurrence of winds from a particular direction (Figure 3) suggests that for the Suwałki station, winds from the western sector were recorded the most frequently (9.6%), and in the case of the Mikołajki station, wind from the south-western direction was dominant (9.1%). In the case of stations Mikołajki and Suwałki, the highest contribution was reached by winds with strength from 1 to 5 m s^{-1}. They constituted respectively 85% and 80% of all of the recorded measurements.

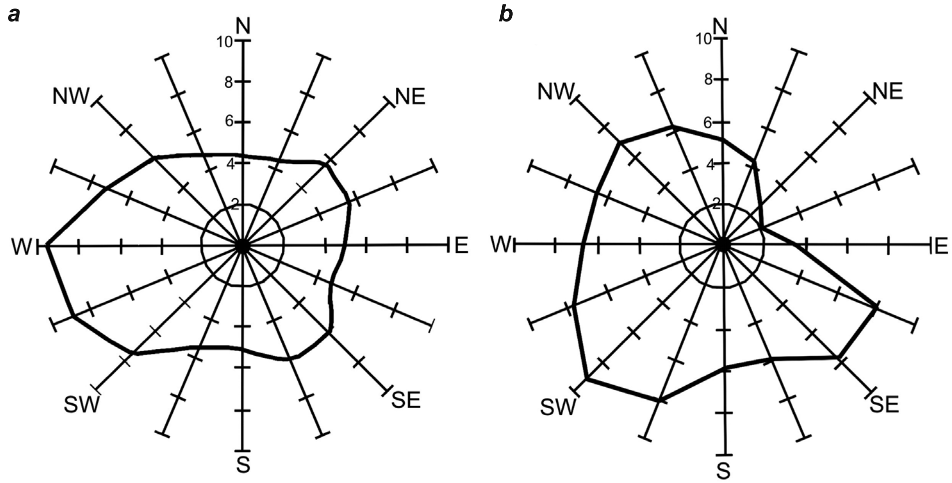

Fig. 3. Wind rose for the Suwałki (*a*) and Mikołajki (*b*) stations in the years 2005–2014

In the analysed cases, the above situation is reflected in the distribution of temperature curves taking a milder shape for Lake Rość at the moment of transition of particular zones during thermal stratification. SKOWRON and PIASECKI (2014) point out that the thickness of the epilimnion largely depends on wind. In the case of Lake Rość with better conditions for water mixing in July (complete thermal stratification), the zone covered approximately 25% of the analysed profile, whereas in the case of Lake Rospuda, the zone covered approximately 18%.

Considering the distribution of oxygen dissolved in water, an evident correlation with temperature curves occurs for Lake Rość. In all of the analysed months, they took the form of a clinograde. Monthly means from the analysed multiannual for the entire profile were variable, and ranged from 2.1 mg O_2 dm^{-3} in July to 6.9 mg O_2 dm^{-3} in May. In reference to those values, saturation of water with oxygen was variable. The analysis of the parameter at a level of 50% suggests that in May, water with such (and lower) saturation stagnated at a depth of approximately18 m. In June and July, the zone expanded reaching a depth of 9 and 7 m, respectively, to decrease again (depths of 8, 12, and 17 m) in the next three analysed months (August, September, October). The anaerobic zone was recorded from June to September, and its range in particular months of the period developed at depths of 21, 12, 11, and 17 m.

The analysis of the distribution of oxygen dissolved in water for Lake Rospuda suggests that it also depends on water temperature, although the correlation is not as evident as in the other lake. In May and June, oxygen curves take the form approximate to an orthograde, whereas temperature curves correspond with a form typical of summer stratification. In the remaining months, the oxygen curve changes shape to clinograde, and is similar to temperature distribution in the profile. Monthly means from the analysed multiannual for the entire profile were variable, and ranged from 2.6 mg O_2 dm^{-3} in September to 10.2 mg O_2 dm^{-3} in May. In reference to the values, saturation of water with oxygen was variable. The analysis of the parameter at a level of 50% and higher covered the entire studied profile. In June and July, the zone with water saturation with oxygen below 50% stagnated at a depth below 36 m. In two subsequent months, the zone with such saturation expanded, reaching a depth of 12 m in July, and 9 m in August. The last two months were distinguished by an improvement of oxygen conditions, and the depth at which water was oxygenated at a level of 50% and more reached 11 and 14 m. An anaerobic zone (oxygen saturation below 1 mg O_2 dm^{-3}) was recorded in August near the bottom, and in September and October at depths of 14 and 34 m.

The course of water temperature and dissolved oxygen concentration for particular zones developed during full summer stratification (July), and mean air temperature for July (Lake Roś – Miko ajki station, Lake Rospuda – Suwałki station) is presented in Figure 4.

The above curves suggest no occurrence of evident tendencies in the course of temperature in the analysed decade. The distribution of water temperature was variable in particular years. In the case of Lake Rospuda, the temperature amplitude for the epilimnion in the years 2005–2014 amounted to 8, and water temperature for Lake Roś 4.7°C. In general, temperature of the zone in both of the cases corresponds with air temperature. The two values show a strong correlation (the Pearson's correlation coefficient for Lake Roś is 0.80, and for Lake Rospuda 0.88). The course of air temperature and water temperature

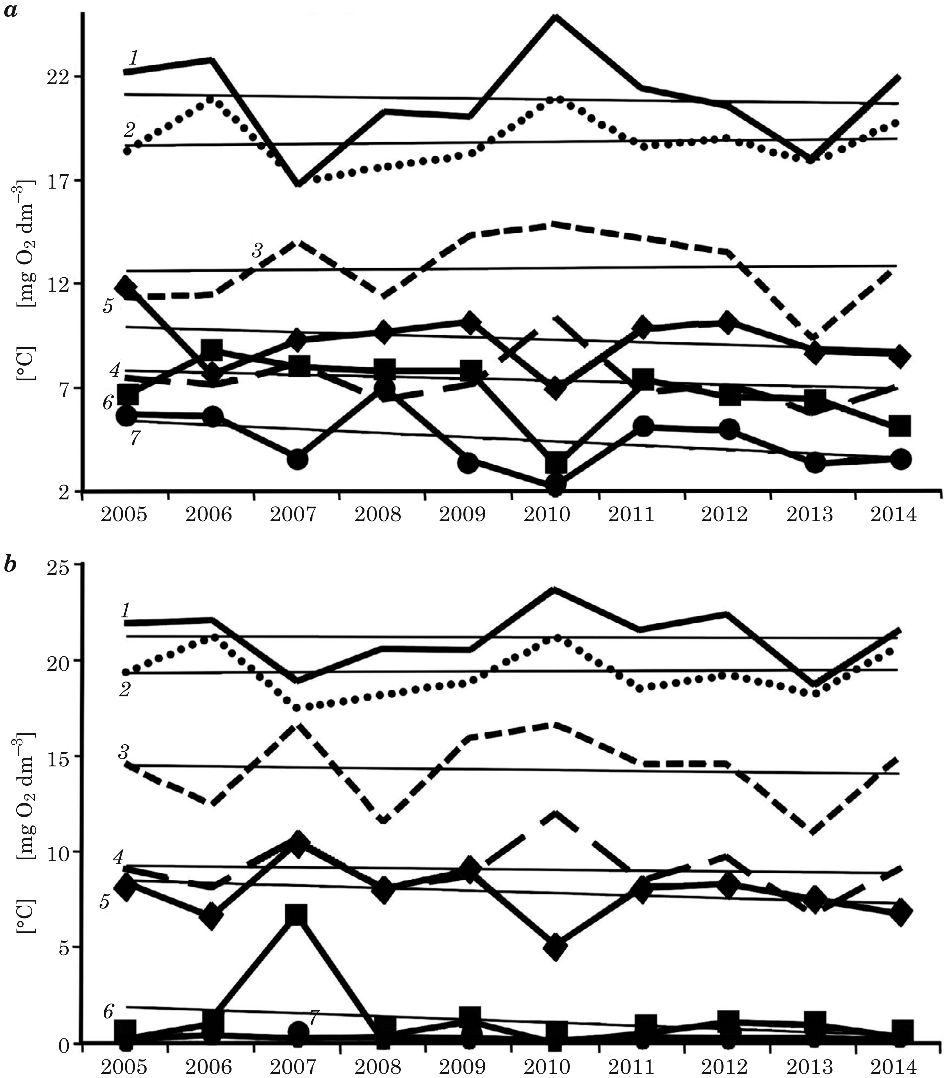

Fig. 4. Changes in water temperature and dissolved oxygen for particular thermal zones during summer stratification (July): *a* – Rospuda Lake, *b* – Roś Lake; *1* – water temperature in the epilimnion; *2* – air temperature; *3* – water temperature in the metalimnion; *4* – water temperature in the hypolimnion; *5* – oxygen concentration in the epilimnion; *6* – oxygen concentration in the metalimnion; *7* – oxygen concentration in the hypolimnion

in the metalimnion is not as synchronic as in the previous case. The variability of the zone was approximate, and amounted to 5.5°C for Lake Rospuda, and 5.6°C for Lake Roś. Similar variability was recorded in the hypolimnion of both lakes, amounting to 4.5°C for Lake Rospuda and 5.2°C for Lake Roś.

An interesting situation was recorded in both of the analysed profiles in July 2010. In the above comparison, this month was distinguished by the highest air temperature, also directly translating into the highest temperature of the near-surface and the deepest water layer. Such a situation was reflected in the second of the analysed parameters, namely concentration of dissolved oxygen. Its lowest value at the highest temperature is related to the Henre's law stating that among others solubility of gases in liquids decreases (concentration of gas decreases) with an increase in temperature. In the monthly scale, the distribution of both of the curves is presented in among others ZĘBEK (2009) based on the example of Lake Jeziorak Mały. In July, the highest water temperature corresponds to the lowest values of dissolved oxygen.

The analysis of water temperature fluctuations and changes in oxygen conditions presented in the paper refers to one of the main research trends in limnology. Both of the issues have been discussed in many publications referring to both single cases and larger groups of lakes (BELLA 1970, SMITH and BELLA 1973, STEFAN and FANG 1994, NOWLIN et al. 2004, ESCOBAR et al. 2009, PICCOLROAZ et al. 2015, XU and XU 2016). In the case of Polish lakes, lack of a larger group of publications based on systematic measurements of both of the parameters is observed. There are studies referring to detailed measurements over periods of several months, e.g. a paper concerning Lakes Dgały Wielkie, Dgały Małe, and Warniak with data from the years 2000–2010 (NAPIÓRKOWSKA-KRZEBIETKE et al. 2012), or MAŚLANKA and NOWIŃSKI (2006) analysing the thermocline of Lake Raduńskie Górne in the years 1995–2005, etc. The majority of the papers, however, are based on shorter periods, including papers by OLSZEWSKI (1953), STAWECKI et al. (2004), TROJANOWSKI and PARZYCHA (2004), JAŃCZAK and MAŚLANKA (2006), JAROSIEWICZ and HETMAŃSKI (2009), CHOIŃSKI et al. (2013).

Both of the lakes analysed in the paper are distinguished by quite similar parameters both in terms of temperature and dissolved oxygen concentration in the profile. The recorded variability is determined by local conditions affecting the functioning of both of the ecosystems. As emphasised earlier, the location of the lake in relation to wind is of key importance. In the case of Lake Roś, the dominant wind direction corresponds to the axis of the lake. The situation favours deeper water mixing, as reflected in less evident development of particular thermal layers (Figure 2). The value of oxygen dissolved in water was determined not only by temperature, but also photosynthesis and mineralisation processes.

Oxygen distribution for Lakes Roś and Rospuda suggests low concentration in the hypolimnion. According to (BIEDKA 2012), such a situation can be explained with mineralisation of organic matter deposited from the surface segments, and organic matter contained in bottom sediments in the conditions of no oxygen supply. According to the *Reports*... (2010, 2013), Lake Rospuda changed its status over a period of several years, and showed susceptibility to eutrophication. It should be also emphasised that the lake was classified as showing good ecological state in 2013 (*Classification*... 2014). According to the classification by CYDZIK et al. (1992), Lake Roś was distinguished by waters of class III, particularly due to the concentration of phosphates above the bottom in the summer period.

As emphasised by ANTONOPOULOS and GIANNIOU (2003), water temperature and oxygen are two of the primary factors of water quality in water ecosystems. In this context, earlier studies suggest that the oxygenation of the hypolimnion has not changed for several decades. Analysing the oxygen conditions of Lake Roś, MARSZELEWSKI (2005) determined that the oxygenation of the hypolimnion in the 1960's was at the level of 32.5%, and at the end of the century (1990's), it already amounted to 0%. Such a situation is maintained until today. The improvement of the state in the near future will be difficult. The first and most important method of protection of lakes is cutting off the supply of pollutants (GROCHOWSKA et al. 2014). In spite of undertaking a broad scope of activities aimed at broadly defined environmental protection, e.g. establishment of new water treatment plants, implementation of the nitrate directive at the moment of Poland's accession to the European Union, etc., the quality of water in many lakes is still not satisfactory. Such a situation should be associated with the internal alimentation of the lakes. In the case of exhausting oxygen resources in the hypolimnion, increased release of phosphorus compounds from bottom sediments is observed, leading to increased production of organic matter in the next season in the surface water layer (BIEDKA 2012). Due to biogene compounds deposited in bottom sediments, even in the case of neutralisation of external pollution sources, the ecological status of a given lake does not always improve. Such a situation is described by SOBCZYŃSKI and JONIAK (2009) in reference to Lake Góreckie. Its trophic status is maintained at a high level in spite of lack of external threats.

Summary

The presented description of thermal-oxygen conditions of two lakes located in the Masurian Lakeland corresponds with one of the primary research trends of limnology. In the case of Polish lakes, studies concerning the thermal-oxygen structure of lakes based on systematic measurements covering several months are relatively rarely performed. The observations conducted over a decade permitted the determination of the scale of water temperature

fluctuations and the closely correlated oxygen conditions. Both lakes were determined to have similar distributions of the analysed characteristics.

The presented analysis of thermal-oxygen conditions in Lakes Roś and Rospuda does not only constitute a source of detailed information on the subject in reference to the current state. The presented data can be used in the future (in a dozen years or several decades) as material for assessment of the tendency and scale of transformations occurring in both lakes.

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