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THERMAL AND OXYGEN CONDITIONS OF LAKE CHARZYKOWSKIE IN THE YEARS 2014-2016

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ABSTRACT

This paper presents an analysis of thermal and oxygen conditions of the Charzykowskie Lake in the years 2014-2016 in the period from May to August. The measurements were carried out once a month, at points representing three different basins in the lake, and the temperatures and oxygen content dissolved in the water were recorded every 1m from the surface to the bottom at the deepest point of each basin. The changes in temperatures and content of dissolved oxygen were analysed in each of the representative measurement points for particular parts of the lake. It has been shown that the deficit of oxygen dissolved in the bottom layers of the water starts occurring by the beginning of the summer stagnation period, whereas at its peak (August) the anaerobic zone includes hypolimnion and part of the metalimnion. The hypothesis that the thickness of the thermal layers varies within the lake basin was confirmed. It was also shown that the oxygen content curve at representative points, in all years of research, evolves to the form of a clinograde at the peak of summer stagnation, where the concentration of dissolved oxygen decreases with the depth.
Keywords: water stratification, oxygen deficit, Lake Charzykowskie.

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INTRODUCTION

Thermal and oxygen conditions, in addition to the transparency, salinity, and content of biogenic elements, are among the basic indicators characterising abiotic conditions in the assessment and classification of lake ecosystems [1,2,3,4,5,6,7]. During the summer months, a transient layer of a thermal jump develops in the temperate climate zone located between the relatively warm, well-oxygenated and well-exposed epilimnion layer, and the cold dysphotic hypolimnion.

Density differences between the cool water that accumulates from the spring period at the bottom of the lake, and the warm surface layer preserve the stratification until re-mixing in autumn due to the cooling of surface layers [8,9,10]. The occurrence of thermal stratification layers is a cyclical phenomenon and is associated with the heat exchange between the lake and its surroundings in different seasons of the year. This way, lakes stimulate the energy flow and the circulation of matter in inland ecosystems [11]. The water level is a natural limit of energy and mass exchange between the reservoir and its surroundings, the zone of absorption of solar radiation, which is fundamental for the thermal balance of the entire reservoir [12].

The mixing of surface layers, apart from enabling the exchange of thermal energy, provides oxygen, which dissolves in water the better, the lower its temperature is. An equally important source of oxygen in water is the photosynthesis process. In favourable conditions a local saturation of water with oxygen may occur in the surface layers of the body of water, which is most often interpreted as a result of the ecosystem's eutrophication. The determination of thermal-oxygen profiles in this period, apart from determining the extent and thickness of stratification layers, makes it easier to identify the trophogenic and trophic zones in the ecosystem [9,17].

The consequence of eutrophication is the "production" of excessive phytoplankton biomass, which ultimately sediments in the form of dead remains at the bottom of the reservoir. Decomposition of organic compounds occurs in the whole ecosystem, but it is noteworthy that in the hypolimnion and part of the metalimnion, oxygen losses are not replenished in the lake's temperate climate zone throughout the period of the summer stagnation.

As a consequence, this condition contributes to the occurrence of oxygen deficits and even its complete exhaustion in these layers. Re-oxygenation of the whole mass of water may happen as a result of its mixing, and contact, with the atmosphere following the equalisation of the temperature and density between the water from the surface of the lake, and that of the bottom. In addition to the indigenous organic matter, whose source in the ecosystem are living organisms and their remains, water reservoirs are fed with allochthonic matter from the reception basin area.

Even the presence (living) of people in the reception basin area, generates a significant load of organic pollutants. In the calculations performed in relation to urban wastewater treatment, it is assumed that within a day, the statistical household inhabitant "produces" such a load of organic substances, whose biological breakdown (BOD5) requires consumption of 60 grams of oxygen (Article 43. 1, water law).

For these reasons, it seems obvious that stratified lakes should not be a direct receiver of untreated urban wastewater. However, Lake Charzykowskie, located on the border of the "Tucholskie Forests" National Park, was until 1990 the recipient of the untreated municipal wastewater of the forty thousand inhabitants of the city of Chojnice.

Despite the significant reduction in the load of pollutants that have been flowing into the lake since the sewage treatment plant was put into operation, the "Struga Jarcewska" river which carries the waste from Chojnice still remains one of the main sources of anthropogenic pollution. The upshot of the many years of eutrophication of the lake were not only changes in the biocenotic structure [18,19,20,21], but also the deepening deficits and, consequently, lack of dissolved oxygen in stagnant layers of water [22,23,24,25].

In recent years, the lake has also been covered by the EUKALKES programme for Central Europe to support sustainable lake management and cleanliness assessment [26].

The aim of the research was to analyse changes in temperature and oxygenation of water in the largest overdeepenings of the three main basins of Lake Charzykowskie, the study being carried out in the period between the spring mixing and the peak of the summer stagnation. The implementation of the above goal was governed by the following research hypotheses:

1. At each measuring point throughout the entire test period, a statistically significant correlation between the temperature and the dissolved oxygen content in the water is observed.
2. There is variation in the thickness of the stratification layers and the dissolved oxygen content in the main basin of Lake Charzykowskie, this being different in terms of morphometric, hydrographic and receptive features.

GENERAL CHARACTERISATION OF THE RECEPTION BASIN OF LAKE CHARZYKOWSKIE

Lake Charzykowskie is the largest natural water reservoir in the Brda river basin as evidenced by the values of the following basic morphometric parameters:

- water surface - 1363.8 ha,
- water volume in the lake - 134533.2 thous. m3,
- maximum length of reservoir - 10025 m,
- maximum width of reservoir - 2425 m,
- total length of the shoreline - 31925 m,
- maximum depth of the reservoir - 30.5 m,
- average depth of the reservoir - 9.8 m.

The lake fills the southern part of the glacial trough on a NS course from the village of Charzykowy to Małe Swornegacie, the widest part being the central part of the reservoir (in the vicinity of Funka village). The reservoir consists of three clearly separated parts, respectively named: southern, central and northern basin. In the area of ledges there are two small islands. The deepest part of the lake is found in the southern basin about 200 m from the peninsula called "Góra Zamkowa" [Castle Hill].

The central part of the lake is slightly shallower and has two deeper parts, each with the depth of 25 m.

The northern part of the lake has a different character
than the southern and central ones, as it is much shallower (maximum depth: approx. 12 m), and characterised by flat and low banks, and the shoal at the shore is connected directly to the bottom. The Brda river flows through it, which strongly affects this part of the lake.

In administrative terms, the lake is located in the Pomeranian province. It is an area belonging to the macroregion of the South-Pomeranian Lake District, more precisely the of the Charzykowska Plain and Tucholskie Forests. The direct reception basin, and partly the catchment of the four main tributaries feeding this reservoir, is located within the Zaborski Landscape Park, and from the north-east the lake borders with the Tucholskie Forests National Park.

In the area of the lake's catchment, the landscape is mainly of a young glacial type, characterised by the existence of lakes of varying deepness formed as a result of melting ice chunks at the end of the ice age in the area of a former accumulation plain. The erosive activity of glacial waters was best developed by the trough of Struga Siedmiu Jezior [the Seven Lakes Stream] and Lake Charzykowskie itself. Numerous rivers that feed the lakes had and still have an impact on the diversification of this landscape. A good example of this is Struga Siedmiu Jezior [the Seven Lakes Stream], whose reception basin determines the landscape of the aforementioned National Park [28].

Total catchment area of Lake Charzykowskie is 913.5 km^2, with the Brda catchment covering as much as 667.2 km^2, and the remaining area of 246.3 km^2 being divided among:

- the catchment of Czerwona Struga 78.8 km^2,
- the catchment of Struga Jarcewska 52.0 km^2,
- the catchment of Struga Siedmiu Jezior 54.6 km^2,
- direct runoff area 60.9 km^2.

The **Brda River** is the largest tributary, and its beginning is considered to be Lake Smołowe at an altitude of 181 m above sea level. The river flows into Lake Charzykowskie at 120 m above sea level with a slight slope, and ends its course several kilometres east of Bydgoszcz where it flows into the Vistula at just 31 m above sea level. A characteristic feature of this river is the relatively large number of water reservoirs through which it flows, with a distinct separation of the upper course, where its waters feed ten natural lakes of varying size and the lower section in which a cascade of dam lakes of various sizes was built in the post-war period. The largest natural lake through which Brda flows is Lake Charzykowskie.

Struga Czerwona, also known as Kopernica, is a small natural watercourse with a length of 16.9 km, flowing in its initial course through areas used for agriculture, and next through forested areas. The beginning of the river is Lake Kłodzko Małe at an altitude of 152 m above sea level which flows into Lake Charzykowskie at an altitude of 120 m above sea level.

Struga Siedmiu Jezior with a length of 13 km flows out of Lake Ostrowite and through the territory of the "Tucholskie Forests" National Park and the following lakes: Zielone, Jeleń, Bełczak, Płęsno, Skrzynka and Mielnica. The river basin is the practically completely forested area of the National Park.

Struga Jarcewska is its left-bank tributary of the southern part of Charzykowskie Lake. It drains the north-eastern part of the Krajeńska Upland, and at the same time it is a receiver of industrial and communal waste water from the city of Chojnice. Its sources are located south of Chojnice, at an altitude of 150 m above sea level. It flows, partially covered, through the city and drains the wetlands in the section between the villages of Igła and Jarcewo. Forested areas constitute less than 25% of the entire catchment area. At an altitude of 120.3 m above sea level, near the village of Stary Młyn, it flows into Lake Charzykowskie. The length of the Jarcewska Stream is 12 km.

MATERIAL AND METHODS

Measurements of temperature and dissolved oxygen content were made at the place of the largest trim in three points representative of each lake basin. The research was conducted in 2014, 2015 and 2016 from May to August - once in each of these months. Measurements of both the water temperature and oxygen content were collected on the same day in order to reflect the thermal-oxygen conditions within the entire lake in practically unchanged meteorological conditions. Measuring points were defined on the basis of bathymetric plans of the Inland Fisheries Institute in Olsztyn and Garmin's GPSMap 60 CSx. The exact depth of a given point was determined with the HUMMINBIRD MATRIX27 echosounder.

Measurements of temperature and oxygen content at designated measurement points were made from a boat using the OXI 196 WTW oxygen probe in a vertical section every meter from the water surface to the bottom. At each measurement point of the section, the temperature was recorded in °C, the dissolved oxygen content in mg/dm3 and the percentage saturation of water with oxygen.

The obtained results were presented in the form of diagrams showing the dependence of temperature and dissolved oxygen content on depth. These charts illustrate the above-mentioned relationships for each of the three designated representative points of the lake, in the months from May to August in 2014, 2015 and 2016. The location of measurement points is shown in Figure 1.

Fig. 1 The location of measurement points.

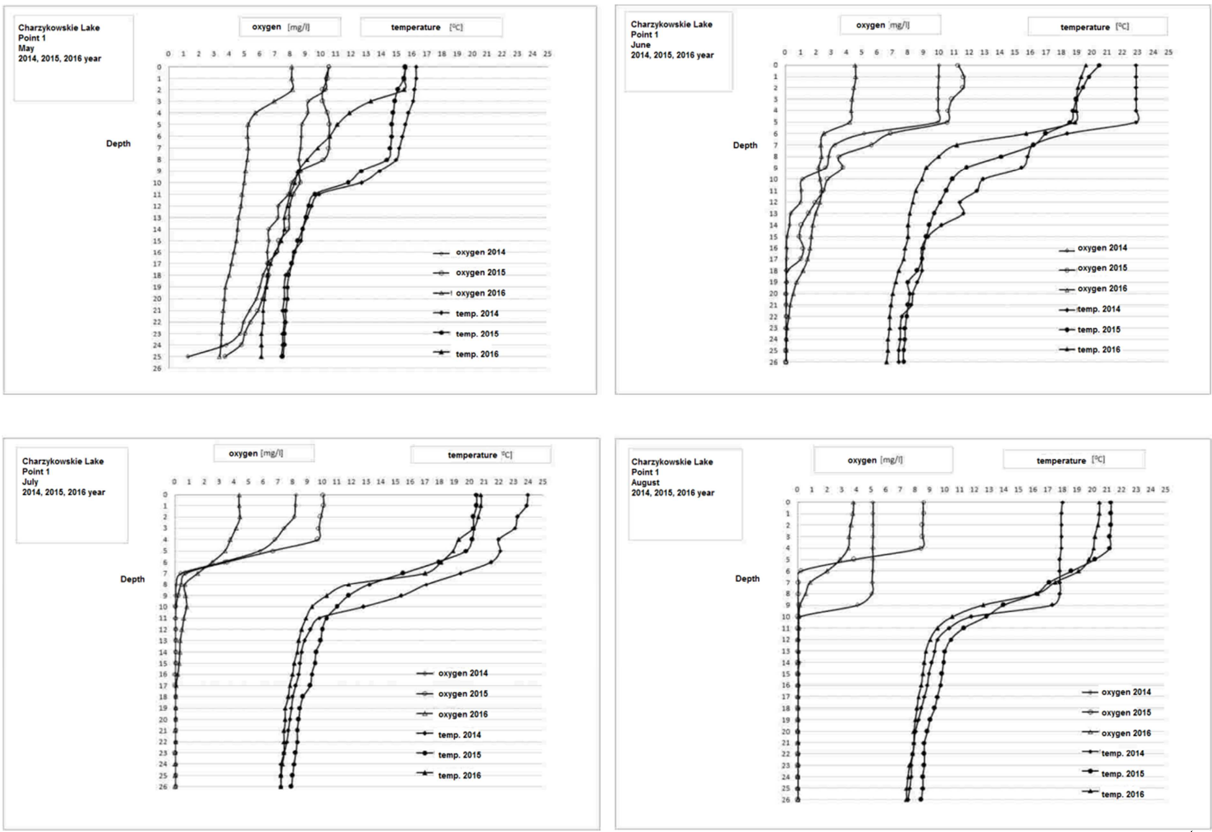

Fig. 2 The dependence of temperature and dissolved oxygen content on depth in May, June, July and August in the years 2014, 2015, 2016 at the 1st measurement point.

Rys. 2 Zależność temperatury i zawartości tlenu rozpuszczonego od głębokości miesiącach maj, czerwiec, lipiec i sierpień w latach 2014, 2015, 2016 w punkcie pomiarowym 1.

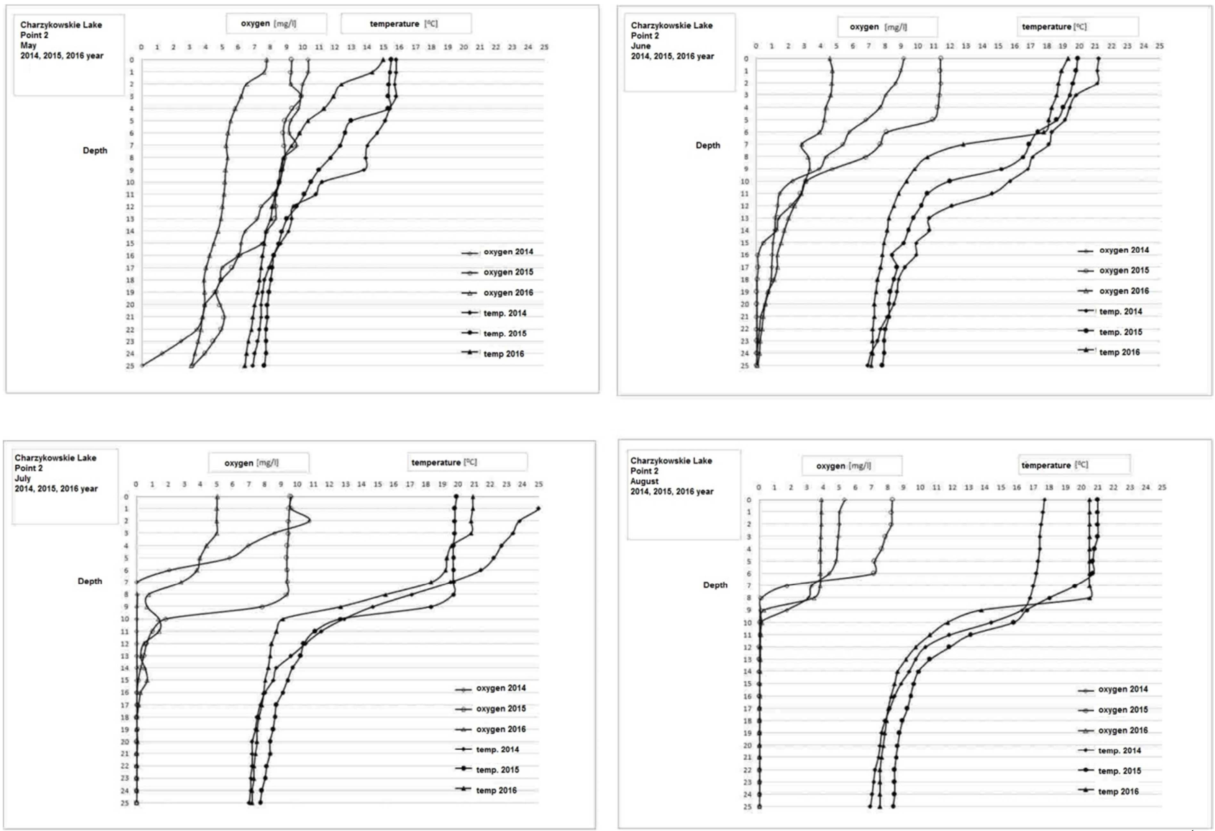

Fig. 3 The dependence of temperature and dissolved oxygen content on depth in May, June, July and August in the years 2014, 2015, 2016 at the 2nd measurement point.

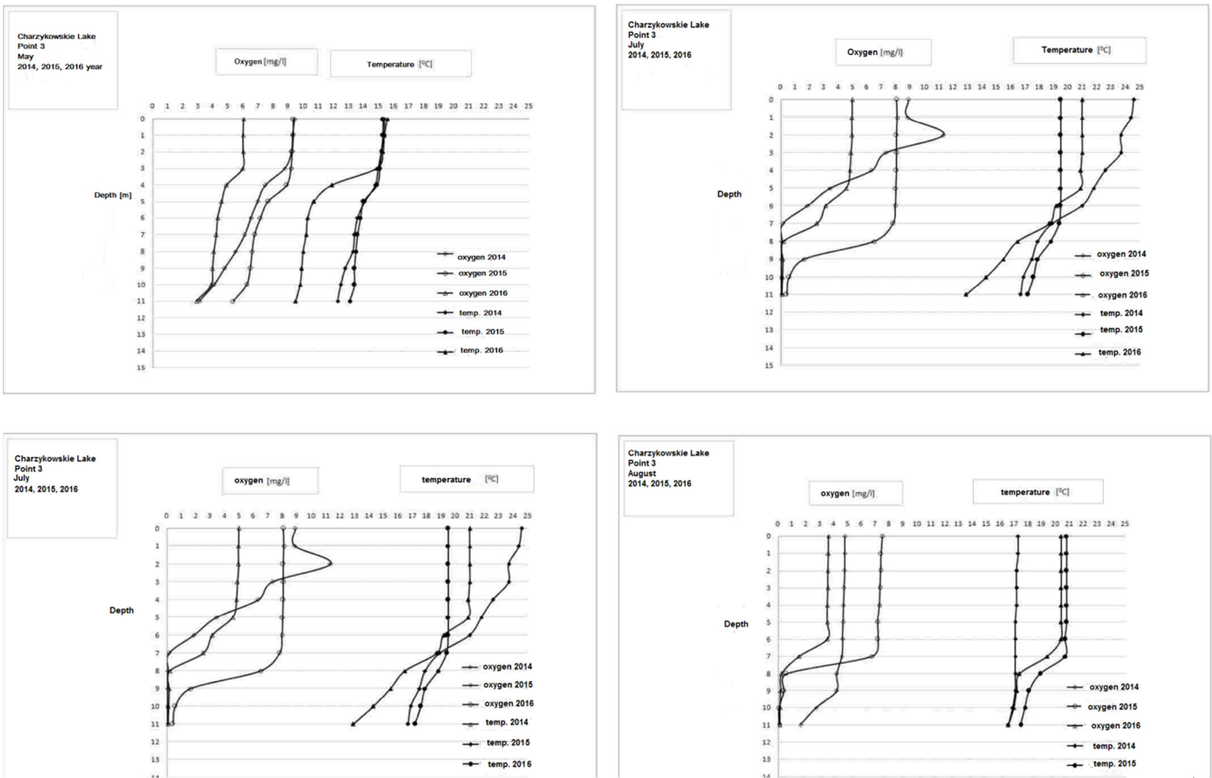

Fig. 4 The dependence of temperature and dissolved oxygen content on depth in May, June, July and August in the years 2014, 2015, 2016 at the 3rd measurement point.

Discussion of results

In order to verify point 1 of the research hypothesis, for each measuring point in each test month of each year, the values of the linear correlation coefficient between the temperature and the dissolved oxygen content in water were calculated. The results of the calculations are presented in Table 1. For the significance level of 0.05 assumed in this study and due to the two-fold nature of the test, the critical values of the correlation coefficient are respectively: 0.3809 for point 1 (27 measurements), 0.3893 for point 2 (26 measurements) and 0.5760 for point 3 (12 measurements).

Based on the data in Table 1 it can be stated, without any exceptions, that all the numbers placed there exceed the minimum statistical significance condition with a significant excess, and out of 36 values only 6 fall within the range 0.8 - 0.9, while the others exceed 0.9, in four cases the result is 1. The obtained result is therefore a strong premise for verification of point 1 of the above research hypothesis.

In May 2014, 2015 and 2016 at three measurement points the values of temperature and dissolved oxygen content in water clearly increases from the bottom to the surface layers. The temperature of the lake surface layers in this period already reached 15°C, and at depths below 15 m did not exceed 9°C. In 2016, despite the similar temperature at the surface, the deeper layers were much cooler than in 2014 and 2015. A similar trend was characteristic of the aerobic conditions.

In points 1 and 2 (particularly in point 1) in May the thermal leap layer (metalimnion) is clearly formed. In the cool layer of the lake (below 9°C) that no longer mixes, the dissolved oxygen content is clearly decreasing, and in 2014 below 24 m there is its clear deficit. In June, the temperature of surface layers within the entire lake is clearly increasing, particularly in 2014.

Tab. 1

Values of the linear correlation coefficient in the system: temperature vs. dissolved oxygen content at particular measuring points of Lake Charzykowskie.

point \ year		2014	2015	2016
	May	0.8677	0.9331	0.9797
	June	0.9702	0.9854	0.9250
	July	0.8762	0.9287	0.9759
	August	0.9816	0.8358	0.9252
	May	0.9058	0.8357	0.9652
	June	0.9535	0.9907	0.9052
	July	0.8482	0.9922	0.9530
	August	0.9059	0.8466	0.9765
	May	0.9856	0.9893	0.9565
	June	0.9972	0.9049	0.9922
	July	0.9293	0.9902	0.9616
	August	0.9485	0.9800	0.9785

At the 1st measurement point (southern basin) the water layer to a depth of 5 m reached a temperature of 23°C. In 2015 and 2016, the thickness of this layer is comparable, although the temperature is lower. Below this layer, the temperature of the entire lake in this period sharply drops, and at a depth of 5 to 7 meters it decreases by a few degrees, even in a much shallower (11 m) northern basin.

In the cool layer from depths of 15 m to the bottom, the oxygen conditions deteriorate, especially in 2015, where in June a lack of it was noted from a depth of 18 m (1st and 2nd measurement point). Poor oxygen saturation (below 5mg/dm3) was also characteristic of surface layers within the whole lake in June, as well as in July and August 2014. In the same months in 2015 and 2016 in the surface layer, the dissolved oxygen concentration in water was almost twice as high (compared to 2014).

Thermal profiles prepared on the basis of measurements carried out in July 2015 and 2016 already have a typical shape for the summer stagnation period of lakes in the temperate climate zone. The thermal leap zone separates the relatively warm epilimnion (about 23°C) over a column of more than 8 meters (point 2) from the hypolimnion, which in 2016 is already about 11 m deep. The highest temperature of surface layers in July was recorded in 2014. In the surface layers of the whole lake (1m below the surface), the water temperature exceeded 24°C.

The reason for the mild but distinct temperature drop in the epilimnion layer at the three measurement points can be a relatively long-lasting, windless period, which is not conducive to the mixing of lake water. The results of the measurements of the dissolved oxygen content in water during the month of July indicate its deficit already below the depth of 8 m (even at point 3), and anaerobic conditions in hypolimnion in three subsequent years (in points 1 and 2) were observed below the depth of 16 m. In 2014, the lack of dissolved oxygen in water was already noted at a depth of 7 m.

At the peak of summer stagnation falling in August, the thermal-oxygen conditions were comparable to those observed in July. Only in August 2014, the temperature of the epilimnion (compared to the measurements from July) clearly decreased from 24°C to 18°C. The reason for such a rapid drop in temperature in the summer months can be the intense mixing of warm near-surface layers with colder ones in the metalimnion zone. The curves of thermal-oxygen profiles, prepared on the basis of the measurements carried out, illustrate the above interpretation of the obtained results.

CONCLUSIONS

1. The dominant part of mutual variability of the dissolved oxygen content and temperature is explained by the linear correlation between these values. Its measure, i.e. the square of the correlation coefficient, reaches values exceeding even 99% and does not fall below 70%. This confirms the accuracy of point 1 of the research hypothesis.
2. Based on the temperature measurements, the accepted hypothesis concerning the varying thickness of the stratification layers in the three main basins of Lake Charzykowskie was confirmed. The most probable reasons for these differences are: the different morphometric structure of particular lake basins and the effect of climatic conditions, including the particularly dominant wind direction.
3. Oxygen deficits in the bottom layers were observed since June, and in the following months the anaerobic zone increased to reach the metalimnion limit in August (peak of summer stagnation). This applies to the southern and middle basins (points 1 and 2), and in the northern basin (point 3), despite the small maximum depth in July and August, clear deficits in dissolved oxygen were observed already below the depth of 8 meters.

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