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CHANGES IN OXYGEN CONDITIONS IN PŁAWNIOWICE RESERVOIR AS A RESULT OF RESTORATION WITH HYPOLIMNETIC WITHDRAWAL METHOD

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Keywords: Lake restoration, oxygen conditions, hypolimnetic withdrawal.

Abstract: The restoration of the anthropogenic Pławniowice water reservoir with the hypolimnion withdrawal method (the Olszewski's tube) began in December 2003. The decision to restore the reservoir had been taken due to its terrible condition resulting from the hypertrophy, which had been indicated by the research from the years 1993–1998.

The following paper presents the results of eight-year-long research into the formation of oxygen conditions and restoration settings. They were compared with the data obtained from the research before the restoration. Positive changes were witnessed. It was showed that grasping the changes in oxygen conditions enables the comparison of oxygen profiles in the same months in subsequent years. The ratio of anoxic water layer thickness to the oxygenated layer thickness was suggested as a factor characterizing oxygen conditions. The area described with an izooxa in the xy coordinate system was suggested as a factor [O_2 mg /m^2] allowing researchers to understand and describe occurring changes. It was observed that the oxygen solved in water as a result of the restoration occurred in the whole water column in the third decade of July. The oxygen concentration in the hypolimnion gradually rose in May, June and July each year. It was showed that the improvement in oxygen conditions stemmed from progressing oligotrophy of the reservoir.

INTRODUCTION

The presence and amount of the oxygen solved in water is a result of physical and biological factors. The former include water masses mixing under the influence of winds [22, 27, 29], while the latter embrace various processes of organic matter production and decomposition [1, 17, 26, 28].

Changes in the hydrological conditions (particularly water flow rate slowdown) influence water self-purification conditions [4, 10, 11]. Those elements seem to be completely overlooked when water reservoirs are designed and constructed [12, 17–19].

Introducing excessive mineral loads of phosphorus and nitrate compounds into the limnic ecosystem accelerates its natural ageing processes. In extreme cases, it causes sudden degradation [13, 17, 21, 24]. Even though it positively affects water quality (especially water that leaves the reservoir) at first, there is also a number of negative changes such as oxygen depletion in the hypolimnion, starting the intra-reservoir enrichment process, primary production increase and phytoplankton bloom [5, 8, 12, 25, 35, 36].

Cyclical changes in oxygen concentration in water depend on the season. They are also determined by the trophy observed in a given ecosystem [2, 5, 10, 15, 33, 34]. Researchers agree with those findings and emphasize the importance of the oxygen balance for the limnic ecosystem efficiency [4, 5, 6, 13, 19]. However paradoxical it may sound, the total oxygen amount necessary for the mineralization of the forming organic matter can be found even in an extremely eutrophic reservoir. Unfortunately, the location of oxygen during summer stagnation period is not even [16, 20, 22]. Oxygen concentrations in the epilimnion are definitely too high, while the hypolimnion is completely devoid of oxygen.

Those who start the restoration of a lake or a water reservoir hope for the ecological condition improvement. Nevertheless, many researchers claim that usually not many changes in oxygen conditions are found within the first years of the restoration process [21, 23, 25, 32]. The literature data clearly shows that the research into oxygen conditions resulting from restoration processes is very complex due to its characteristics such as long-term observations [10, 21, 25, 33, 36].

The following paper presents the findings of the research into the formation of oxygen conditions in the anthropogenic Pławniowice reservoir. The author has conducted limnological research into the reservoir since its establishment. The first period, i.e. the years 1975–1998, embraced the time before the restoration. The second one included years 2004–2011, i.e. a period when the restoration with the Olszewski's tube method began.

Measuring oxygen concentrations in water and water saturation with oxygen helped to collect certain data. It included information concerning the dynamics of the oxygen stratification process, differences in the duration of the complete hypolimnetic anoxia in given years as well as other positive changes arising from the restoration process.

MATERIAL AND METHODS

The Pławniowice reservoir was established in 1975. The water of the Toszecki Potok (Toszecki Stream) was directed into the stowing sand borrow pit. It is oblong and located in the West-East direction. It corresponds to the direction of the winds blowing in this area. The reservoir area is 225 ha. Its volume is 29.1 million m^3 and its maximum depth reaches 15 m. Details describing the reservoir from the morphometric viewpoint were given in previous studies [8–12].

The Pławniowice reservoir is stable and dimictic [6]. In the mixing terms, it meets the conditions of the degree IV according to Olszewski and Patalas [26, 28]. Thus, it is a reservoir that strongly stratifies into thermally variegated layers. Consequently, the exchange between the epilimnion and hypolimnion is limited. The reservoir has a littoral zone area smaller than the pelagic one and hence is classified as type III according to Dołgoff [3]. As the water time retention amounts to 2–2.5 years, it is classified, according to Starmach [34], as extremely limnic. The first research into the thermic-oxygen conditions and basic physical and chemical water quality factors [8, 9] was carried out in 1976, a year after the borrow pit had been filled. The limnological investigations were performed again in the years 1993–1994 [10] and were continued in the years 1996–1998

[11–13]. The obtained material allowed for the description of changes that had taken place within the twenty-three years of the reservoir exploitation. The water drainage method changed in December 2003. The surface spillway was replaced with the bottom out-flow. The Olszewski's tube was put into use and the hypolimnion removal began. The limnological research was constantly conducted in the years 2004–2011.

Oxygen concentrations in water were measured at the pelagic measurement position in the deepest part (15 m) of the reservoir. The solved oxygen concentration (mg/dm^3) and water saturation with oxygen (%) were measured with an oxygen gauge in the whole water column at 1-meter space gaps between the surface and the bottom. On the whole, measurements took place every month or every two weeks in fall, winter and early spring. They were conducted every week during summer stagnation periods. The number of the discussed measurements in specific years is presented in Table 1.

Table 1. Number of measurements concerning oxygen concentration and water saturation with oxygen in specific years

Year	1976	1993	1996	1997	1998	2004	2005	2006	2007	2008	2009	2010	2011
Number of measurements	15	20	18	20	21	24	20	25	20	30	26	18	21

RESULTS AND DISCUSSION

Some researchers claim that there occurs deterioration of oxygen conditions resulting from the hypolimnion withdrawal. They see it as one of few drawbacks of this method, especially at the beginning of its use [16, 20, 21, 29, 30]. The author of the following paper has not discerned such a process in the Pławniowice reservoir. Nonetheless, he agrees that the improvement in the oxygen conditions is difficult to observe. During the eight years' research a reduction in the duration of the oxygen deficit in the hypolimnion was observed during summer stagnation period.

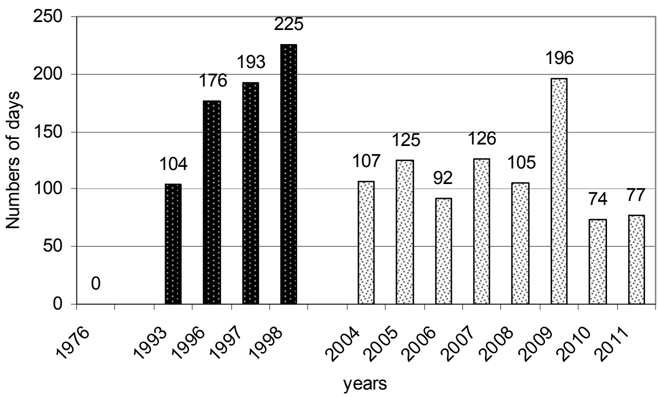

Fig. 1. Number of days with the complete water deficit in the hypolimnetic water layer – the Pławniowice reservoir, 1976–2011

The oxygen deficit had been rising yearly before the restoration started. The oxygen concentration drop had been faster and faster and the periods in which there was no oxygen in the hypolimnetic layer had been longer (Fig. 1). Oxygen was not detected in this zone for 104 days in 1993. The number rose to 176 in 1996, to 193 in 1997 and up to 225 in 1998. The oxygen deficit period in the hypolimnion gradually decreased after the restoration began. It lasted between 104 and 125 days in the years 2004–2006, and finally reached the value of 74 days in 2010 and 77 in 2011. The improvement in oxygen conditions in the Pławniowice reservoir also manifests itself through decreasing the lower limit of the oxygen solved in water present at the depth of 7–9 meters. Preliminary calculations indicate that, as the consequence of this process, the bottom area in contact with oxygen-containing water (lower concentration limit approx. 1 mg/dm^3) increased more than three times, i.e. from 35 to 125 ha.

Comparing oxygen profiles for June and July in the years 2004–2011 revealed positive changes in oxygen conditions in subsequent years (Fig. 2 and 3). In order to perform the parameterization of the observation methods, it was assumed that reducing the lower limit of the occurrence of the oxygen solved in water would cause increase in the area graph defined with axes y (depth in meters) and x (O_2 mg /dm^3) as well as izooxa describing the oxygen profile. The area unit used was area defined with the value of 1-meter depth and 1 O_2 mg/dm^3. After individual areas were counted, values expressed in [g/m^2] were obtained. They enabled objective comparison of the oxygen situation in June and July in specific research years (Fig. 4).

Fig. 5 shows the ratio of the anoxic layer thickness to the thickness of the layer containing oxygen concentration that is higher than 1.0/dm^3 in June and July in the years 2007–2011. This factor also indicates that oxygen conditions gradually and significantly improved. The water column was divided into two even layers, i.e. anoxic and oxygenated ones, in June and July 2007. Oxygen occurred in the afore-mentioned concentrations in the whole water column, i.e. between the surface and the bottom, in June and July 2010 and 2011. In this way continuing reduction in the total anoxia period and oxygen reaching lower depth levels were demonstrated.

It is thought that removing hypolimnion water reduces summer stagnation duration and thus the occurrence of anoxic conditions on the sediment surface is also decreased [4, 21, 22]. This belief needs to be verified. The summer stagnation duration is rather dependent on the climate conditions. An early establishment of the thermocline can extend thermic and oxygen stratification periods even though the hypolimnion is removed.

From the time Pławniowice reservoir restoration was completed the periods of the oxygen absence in the hypolimnion were gradually reduced despite long summer stagnation periods [11–13]. The total anoxia period in the hypolimnion ranged between 74 and 128 days in the years 2004–2010. The shortest periods were noted in 2010 and 2011.

At present, the oxygen occurrence is observed in the epilimnion layer at the depth of 8 to 9 meters during summer stagnation. It is a positive result of the Pławniowice reservoir restoration. The most notable positive changes have been noted since 2007. The epilimnion thickness was 4 meters in June 2007. The oxygen concentration in the epilimnion came to between 12 and 13 mg/dm^3. The thickness of the oxycline layer located below amounted to 2 meters (at the depth of 4 to 6 meters). The oxygen concentration at the 7-meter depth was 1 mg/dm^3. Total anoxia occurred between the 7-meter depth and the reservoir bottom.

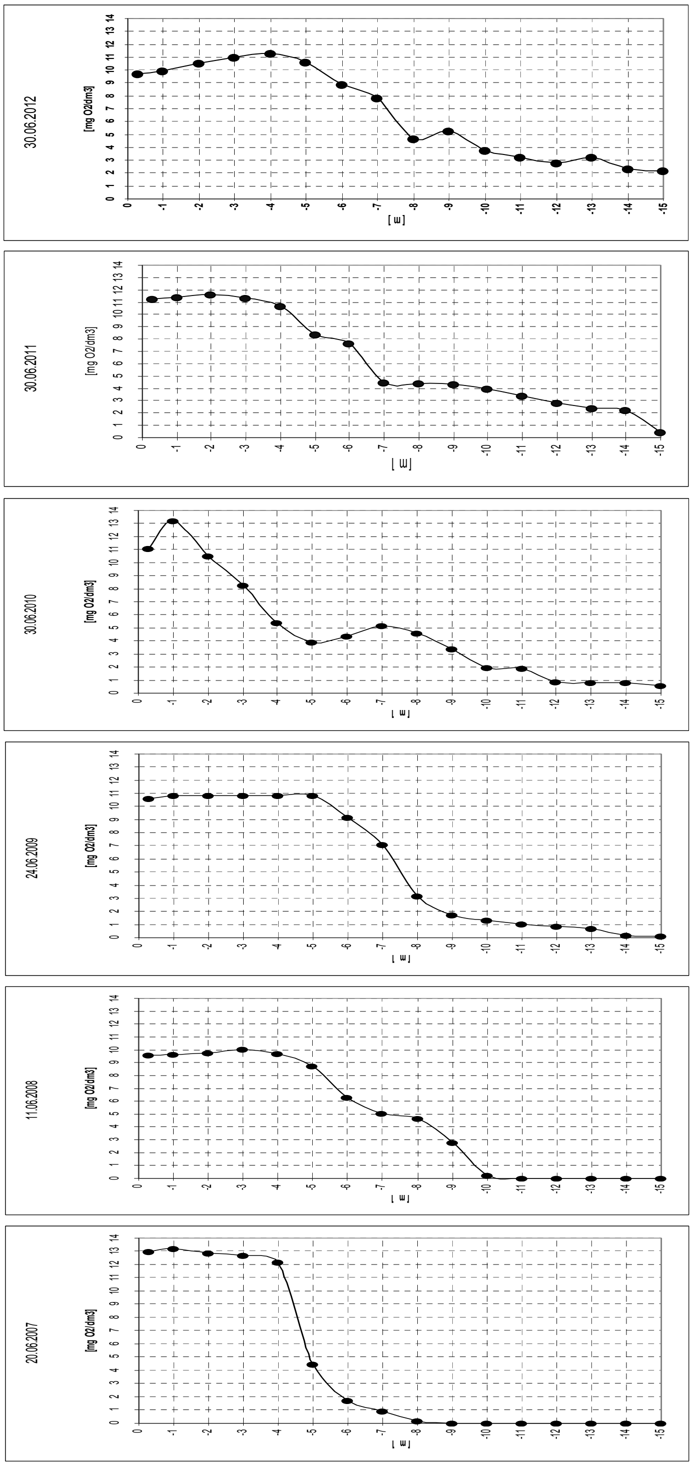

Fig. 2. Oxygen profiles – Pławniowice reservoir – June 2007–2011

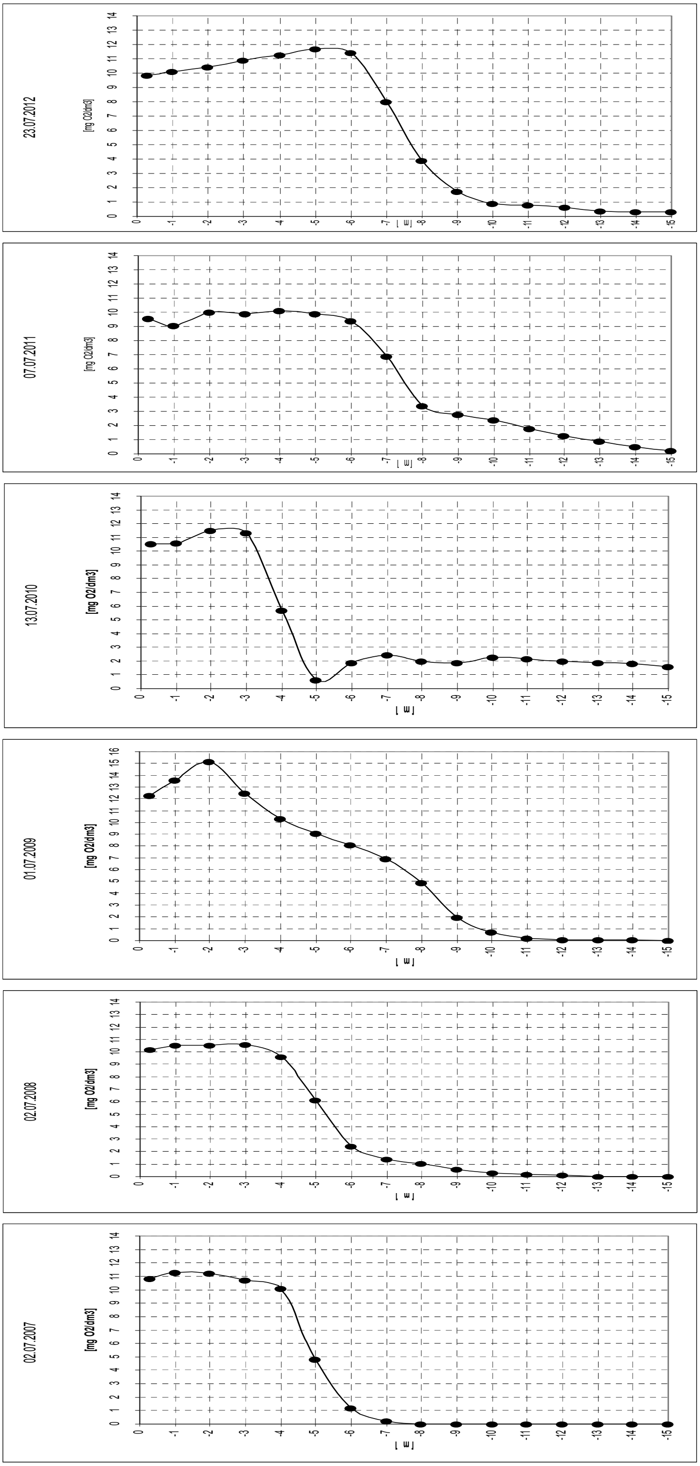

Fig. 3. Oxygen profiles – Pławniowice reservoir – July 2007–2011

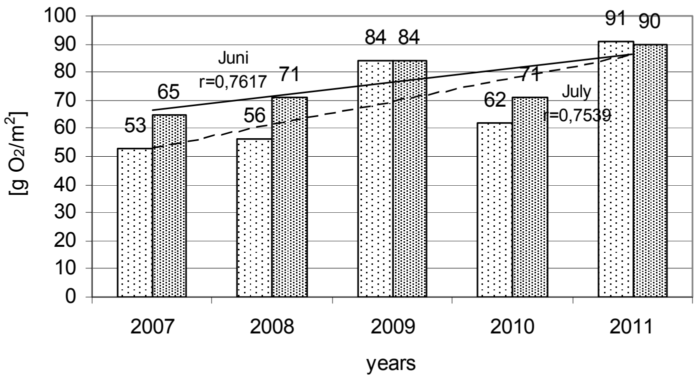

Fig. 4. The oxygen burden [g/m²] as a factor of oxygen condition improvement in June and July in the years 2007–2011

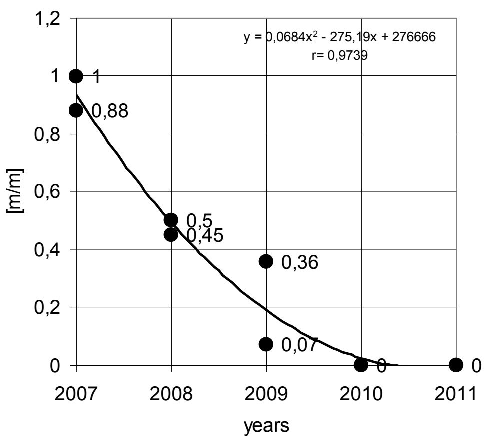

Fig. 5. Ratio of the anoxic layer thickness to the oxygenated layer thickness as a factor of oxygen conditions in June and July in the years 2007–2011

The epilimnion thickness was 5 meters and its oxygen concentration amounted to 10 mg/dm³ in June 2008. The oxycline occurred between the 5-meter and 7-meter depths. The oxygen concentration was nearly 3 mg/dm³ at the 9-meter depth. Total anoxia was observed between the 10-meter depth and the reservoir bottom.

The epilimnion thickness was 5 meters and its oxygen concentration ranged between 10 and 11 mg/dm³ in June 2009. The oxycline thickness increased and it extended between the 5-meter and 9-meter depths. Oxygen occurred down to the 13-meter depth. Anoxia was observed at the depth of 14 and 15 meters.

The epilimnion became the oxycline layer in June 2010. What is important is the fact that a slight double maximum oxygen amount was observed. The first one was detected at the 1-meter depth while the other was found at the 7-meter depth (Fig. 2 and 3). Oxygen occurred between the reservoir surface and bottom in June 2010. The oxygen concentration over the bottom was 0.6 mg/dm^3. The existence of the maximum oxygen amount in the metalimnion is seen as a characteristic of mesotrophic lakes. Consequently, the Pławniowice reservoir showed the first symptoms of passing from eutrophy to mesotrophy in June 2010.

The improvement in oxygen conditions is difficult to observe as this process lasts very long and many years are required so that the progress could be seen [32]. There were significant changes in oxygen conditions of the Pławniowice reservoir during its existence. They mainly concern the stratification of the water masses and the oxygen content. The research conducted in the years 1993–1998 [9–12] revealed that the reservoir stratified into a shallow epilimnion (4 m), metalimnion (extended at first but decreasing during summer stagnation) and hypolimnion devoid of oxygen.

The gradual oligotrophy of the reservoir brought about a visible improvement in the oxygen conditions. The lower level of the layer containing oxygen went from 4-meter depth in 1998 to 8 to 9-meter depth in 2011 as a consequence of the restoration process. As a result, the bottom area in contact with water containing oxygen (the lower oxygen concentration limit was approx. 1 mg/dm^3) rose from 35 ha to 125 ha, i.e. over three times.

The drop in water saturation with oxygen indicates a reduction in the intensity of phytoplankton bloom [2, 4]. Moreover, gradual changes in the hypolimnion anoxia duration took place [11, 12, 22, 24]. The anoxic period decreased from 225 days in 1998 to 77 days in 2011.

The literature data demonstrates that effective restoration of the limnic ecosystems is not frequent [7, 14, 17]. The process of reversing negative changes that have occurred in the reservoir requires many years and numerous organizational and technological actions taken in the drainage area [13, 19, 27, 30, 32]. The limnic ecosystem reaction to the restoration process differs in each case due to the complexity of various environmental conditions [22, 25, 28–30, 32]. Each ecosystem responds in its own specific way. Because of that, the author of the following paper must emphasize that each year of the limnological research is “another individual point” in the research timeline.

The application of the hypolimnion withdrawal method (the Olszewski’s tube, Kortowski’s Lake method) was successful. It is important to remember that constant functioning of an outlet device for water drainage does not only improve the present ecological condition. It also makes a permanent defensive mechanism that protects the reservoir against negative eutrophic effects.

CONCLUSIONS

The following conclusions were drawn from the long-term research into oxygen conditions of the anthropogenic Pławniowice reservoir restored with the hypolimnion removal method (the Olszewski’s tube):

- The oligotrophy of the limnic ecosystem causes gradual and visible improvement in the oxygen conditions.
- It manifests itself through decreasing total anoxia periods in the hypolimnion and gradual increase in oxygen concentration at lower depths.
- Describing changes in oxygen conditions is possible by means of constant comparison of oxygen profiles from the same months during summer stagnation periods collected in the course of many years.

- Spatial oxygen load and the ratio of the anoxic water layer thickness to the oxygenated layer thickness constitute factors that enable the description of changes (positive ones in the Pławniowice reservoir case) in oxygen conditions from a long-term viewpoint.
- Reducing the lower level of water containing oxygen produces a significant increase in the bottom area under the influence of the oxygenated water zone, which results in the improvement in the ecological condition of the ecosystem.

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ZMIANY STOSUNKÓW TLENOWYCH W STRATYFIKUJĄCYM ZBIORNIKU ANTROPOPGENICZNYM JAKO SKUTEK REKULTYWACJI METODĄ USUWANIA HYPOLIMNIONU (NA PRZYKŁADZIE ZBIORNIKA PŁAWNIOWICE)

W grudniu 2003 roku rozpoczęto rekultywację antropogenicznego zbiornika wodnego Pławniowice metodą usuwania hypolimnionu („rura Olszewskiego"). Decyzja o rekultywacji została podjęta w związku z dramatyczną sytuacją zbiornika wynikającą z jego hipertrofii, co wykazały badania z lat 1993–1998. W niniejszym opracowaniu przedstawiono wyniki ośmioletnich badań nad kształtowaniem się stosunków tlenowych, warunkach rekultywacji. Wyniki te porównano z danymi uzyskanymi w trakcie badań przed rekultywacją, wykazując pozytywne zmiany. Wykazano, że uchwycenie zmian stosunków tlenowych umożliwia porównywanie profili

tlenowych w tych samych miesiącach, w kolejnych, następujących po sobie latach. Zaproponowano stosunek miąższości warstwy wody pozbawionej tlenu do miąższości warstwy natlenowanej, jako wskaźnik charakteryzujący warunki tlenowe. Zaproponowano pole powierzchni określone izooksą w układzie osi (x, y) jako wskaźnik [mg O_2/m^2] umożliwiający uchwycenie i opisanie zachodzących zmian. Stwierdzono, że w wyniku rekultywacji rozpuszczony w wodzie tlen występuje w całym słupie wody jeszcze w trzeciej dekadzie lipca. Z roku na rok stężenie tlenu w hypolimnionie, w maju, czerwcu i lipcu z roku na rok stopniowo wzrasta. Wykazano, że poprawa stosunków tlenowych wynika z postępującej oligotrofizacji zbiornika.