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Katarzyna SOBCZYŃSKA-WÓJCIK[1*], Józef KOC[1]
and Małgorzata RAFAŁOWSKA[1]

TEMPERATURE AND OXYGEN PROFILES OF RESTORED WATER BODIES

STRUKTURA TERMICZNO-TLENOWA WÓD ZRENATURYZOWANYCH ZBIORNIKÓW WODNYCH

Abstract: The study covered three lakes: Nowe Wloki (with two pools – Main Basin and Northern Bay), Setalskie Duze and Setalskie Male – connected by the Setal Stream (Struga Setal) to form a riverine-lacustrine system. Due to their specific location (slope), the investigated water bodies form a cascade system. They are situated 25 km from the city of Olsztyn, in the Dywity municipality (Olsztyn Lakeland), in an agricultural catchment. Due to their low average depth (1 to 2 m), the analyzed water bodies can be classified as polymictic.

The aim of this study was to analyze the temperature and oxygen profiles of water bodies restored approximately 30 years ago. The profiles were determined during winter stagnation (2005 and 2006) and summer stagnation (2007).

An analysis of temperature and oxygen conditions performed in the summer confirmed close correlations between the studied parameters. All lakes were characterized by incomplete thermal and oxygen stratification, typical of shallow water bodies. The oxygen profiles determined in the winter showed a temperature distribution pattern characteristic of reverse thermal stratification. In all investigated water bodies, surface water temperature was close to 0 ^{o}C, and it increased gradually from a depth of 30–50 cm. During winter stagnation, the highest dissolved oxygen content was noted in the top layer of water under the ice, and oxygen concentrations varied widely between years. The lowest oxygen content was observed at the bottom, and critically low values (from 0.16 $mgO_2 \cdot dm^{-3}$ to 0.29 $mgO_2 \cdot dm^{-3}$), were recorded during the severe winter of 2006, when ice cover thickness reached 40 cm and organic matter decomposition and aerobic respiration processes led to almost complete oxygen depletion.

Keywords: restored water bodies, thermal-oxygen profiles, oxygen saturation

Introduction

Temperature and oxygen are among the most important abiotic characteristics of natural aquatic ecosystems. Oxygen plays a key role in all chemical and biochemical

[1] Department of Land Reclamation and Environmental Management, Faculty of Environmental Management and Agriculture, University of Warmia and Mazury in Olsztyn, p. Łódzki 2, 10–727 Olsztyn, Poland, phone: +48 89 523 39 92, email: ksw@uwm.edu.pl

* Corresponding author: ksw@uwm.edu.pl

processes in water bodies, and it is essential for the survival of aquatic organisms. Oxygen is needed for aerobic respiration processes which reduce the concentrations of various pollutants in water. Oxygen deficiency supports anaerobic processes which lead to a deterioration in water quality and limit biological processes.

In shallow (polymictic) water bodies, waters mix multiple times during the year, making the water body more susceptible to environmental stress. Water mixing also significantly influences temperature and oxygen distribution in the vertical profile. In water bodies, the main sources of oxygen are the atmosphere and photosynthesis processes.

The transfer of oxygen across calm water surfaces is relatively ineffective, and oxygen is able to penetrate deeper layers of the water body only in the process of water mixing. Oxygen conditions in water bodies are determined not only by mixing dynamics, but also by the level of pollution.

Substances that are leached from farmland have a highly adverse impact on the quality of surface waters. The inflow of fertilizers into aquatic environments supports massive growth of algae. High density of the algae leads to higher oxygen consumption due to the decomposition of algal biomass in deeper strata of the water body. Oxygen depletion supports decomposition processes, and the loss of oxygen in deeper water layers initiates the release of minerals from bottom deposits where nutrients are immobilized in the process of organic matter sedimentation [1].

Excessive accumulation of organic matter in water bodies contributes to eutrophication, and it makes lakes very short-lived sites on the geological time scale that is measured in terms of millennia. An increase in fertility levels in catchments, in particular in rural areas, can be observed even over a period of several years [2, 3].

Objective and description of the analyzed sites

The solubility of oxygen in water is largely determined by temperature, and the concentrations of dissolved oxygen decrease with a rise in temperature. For this reason, oxygen levels fluctuate significantly throughout the year.

The aim of this study was to analyze the temperature and oxygen profiles of water bodies restored approximately 30 years ago, located in rural areas. The profiles were determined during winter stagnation (2005 and 2006) and summer stagnation (2007). Owing to the considerable surface area of lakes Nowe Wloki and Setalskie Duze, temperature and oxygen profiles were analyzed in eastern as well as western sections of those water bodies. The profiles of Lake Setalskie Male were studied in the deepest section. The only exception was made during the harsh winter of 2006, when the investigations in Lake Setalskie Duze were restricted to deep waters. Measurements were performed with the use of an oxygen sensor with automatic temperature compensation (WTW OXI Top OC 100). Water pH, electrolytic conductivity and redox potential were determined. In summer, water transparency was additionally measured with the Secchi disc.

The study covered three lakes: Nowe Wloki (with two pools – Main Basin and Northern Bay, connected by a stream), Setalskie Duze and Setalskie Male. The studied

Table 1

Morphometric parameters of the studied water bodies and catchment area characteristics (total catchment and subcatchments)

Site	Surface area [ha]	Average depth [m]	Catchment	Area [ha]	Slope [%]	Type of land use
Lake Nowe Wloki	19.7	1.5	*Total catchment*	**408.19**		52 % – arable land, 13 % – water, 5 % – forests, 29 % – meadows, 1 % – developed area
			Direct catchment	145.73	3.1	
Main basin	15.5	1.5	• catchment area of the Setal stream feeding into the main basin	77.62	2.9	60 % – arable land, 10 % – forests, 29 % – meadows, 1 % – developed area
			• catchment area of the canal feeding into the main basin	11.96	6.6	94 % – arable land, 1 % – water, 6 % – meadows
Northern bay	4.3	1.5	• catchment area of the drainage ditch feeding into the northern bay (covered by the catchment area of the northern bay in its entirety)	172.88	1.7	66 % – arable land, 7 % – forests, 21 % – meadows, 6 % – developed area
Lake Setalskie Duze	41.4	2.5	*Total catchment*	**757.23**		54 % – arable land, 19 % – water, 10 % – forests, 16 % – meadows, 2 % – developed area
			Direct catchment	199.29	1.7	
			• indirect catchments (including the catchment area of Lake Nowe Wloki)	408.19		
			• catchment area of the stream feeding into the lake	149.75	4.4	86 % – arable land, 1 % – water, 3 % – forests, 10 % – meadows
Lake Setalskie Male	8.0	1.1	*Total catchment*	**883.82**		82 % – arable land, 10 % – water, 1 % – forests, 6 % – meadows, 1 % – developed area
			Direct catchment	126.59	3.8	
			• indirect catchment, including the catchment areas of lakes Nowe Wloki and Setalskie Duze	757.23		

objects were drained in the 19th century during a comprehensive land improvement project to create agricultural grassland. Field flooding was a recurring problem in the region due to excessive water logging. In view of the need for small retention reservoirs and fire water reservoirs in rural areas, the discussed water bodies were restored at the turn of the 1970s and the 1980s as part of a land reclamation scheme initiated by the Regional Farmland Improvement Authority in Olsztyn. The lakes were created as a result of water damming on the Setal Stream. Due to their specific location (slope, 3.1–6.6 %), the investigated water bodies form a cascade system (Table 1). They are located in the Protected Landscape Area in the Valley of Middle River Lyna, 25 km from the city of Olsztyn, in the north-eastern part of Dywity municipality (Fig. 1). The studied riverine-lacustrine system is situated in a rural, scantily wooded area, used for agricultural purposes (Table 1).

Fig. 1. General map of the investigated area. Source: geoportal.gov.pl

Lake Nowe Wloki (19.7 ha) – the southern part of the lake, which is the main basin, has an elongated profile, and it is adjacent to farmland on the right bank and meadows on the left bank. The northern bay has a much smaller area, and it is found in the vicinity of a road leading to Setal. In the north, the lake directly neighbors three farming estates without livestock. The upper section of Setal Stream feeds into the main basin of the lake. On the eastern side of the lake, there is a canal that drains the catchment occupied by farmland in more than 94 %. In the catchment on the northern side of the lake there is the village of Nowe Wloki which does not operate a sewer system. The area is drained by a drainage ditch which feeds into the northern bay of Lake Nowe Wloki. Lake Nowe Wloki is situated at the highest altitude (142.5 m above sea level), and it connects with Lake Setalskie Duze (124 m above sea level) via the Setal Stream. Lake Setalskie Duze is the largest of the studied objects, with an area of 41.4 ha. Its eastern part features a bay, and the western, much larger part is situated in the catchment occupied by farmland in more than 54 %. The lake's total catchment area incorporates the inflows from the catchment of the higher situated Lake of Nowe Wloki. The western part of the catchment features three land plots with holiday cottages made of brick. Water is evacuated from Lake Setalskie Duze via a ditch, and it is carried along farm fields to Lake Setalskie Male (8 ha), separated from Lake Setalskie Duze by a (straight line) distance of approximately 300 m. Lake Setalskie Male is situated in a catchment which, together with the catchments of Lake Nowe Wloki and Lake Setalskie Duze, has a total surface area of 883.82 ha.

Due to their low average depth (≤ 2.0 m), the analyzed water bodies can be classified as polymictic (Table 1, Fig. 2).

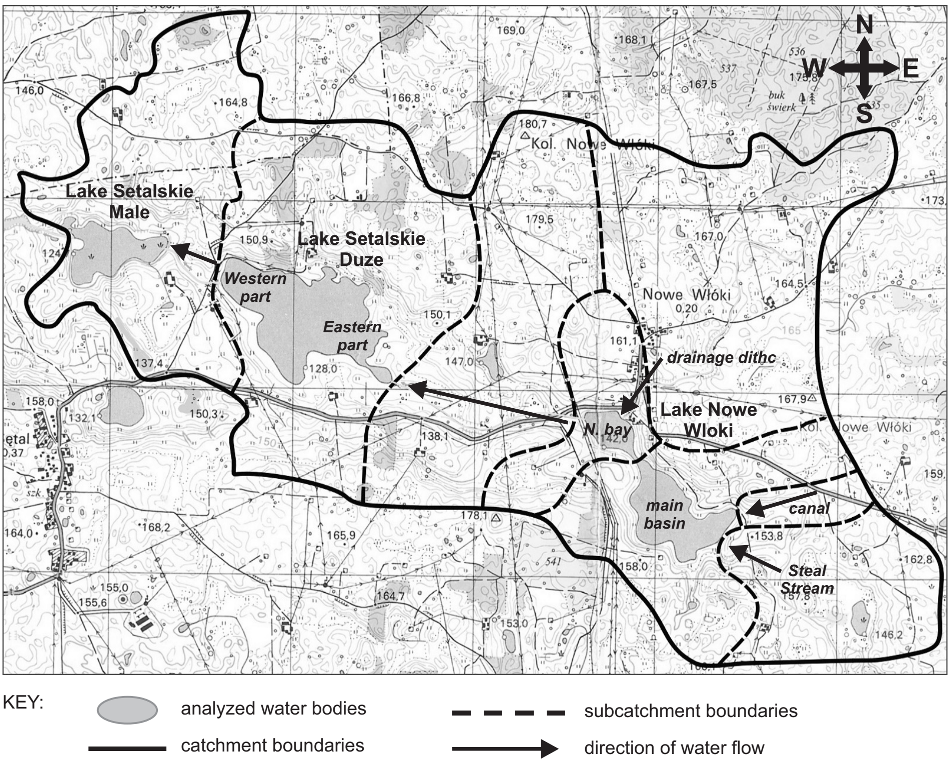

Fig. 2. Location of the analyzed sites

Results and discussion

The oxygen profiles determined in winter showed a temperature distribution pattern characteristic of reverse thermal stratification. Due to the presence of ice cover, temperature profiles in all studied lakes differed in comparison with the summer season. Low water oxygenation is connected with ice formations which make it difficult for atmospheric oxygen to dissolve in water, which is also confirmed by the research others authors [4]. In all investigated water bodies, surface water temperature was close to 0 ^{o}C, and it increased gradually from a depth of 30–50 cm, to reach around 3–4 ^{o}C at the bottom. In the profiles determined in the winter of 2005, a clear temperature gradient was observed at a depth of 0.5 to 1.5 m (1.7 to 2.8 ^{o}C), whereas a smoother temperature distribution pattern was reported in the vertical profile in the winter of 2006 when the thickness of ice cover on the studied lakes reached 40 cm (Figs. 3 and 4). Water cooling is directly dependent on the lake's depth and water volume. Shallow bodies of water are characterized by low thermal inertia [5].

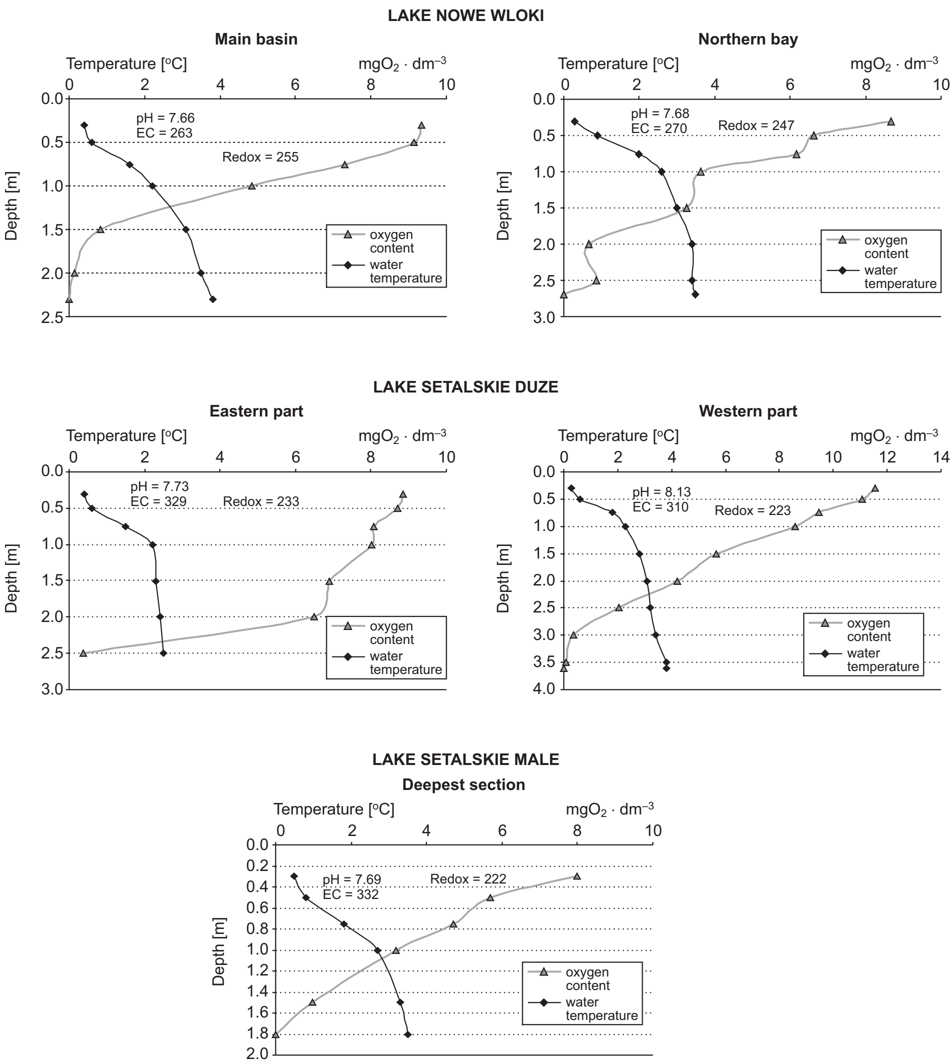

Fig. 3. Temperature and oxygen profiles in the analyzed flow-through lakes in the winter of 2005

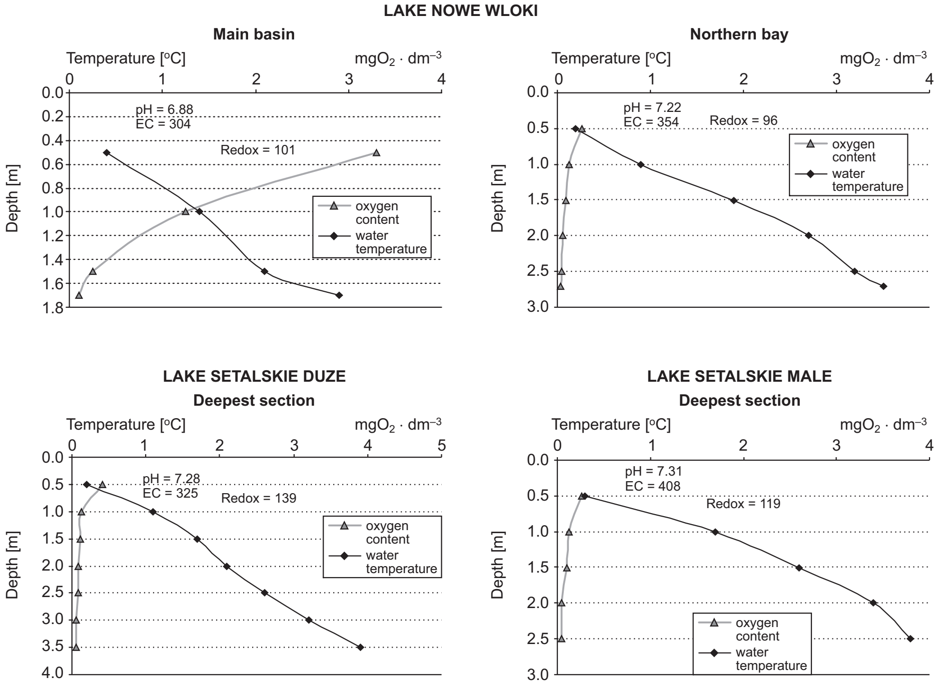

Fig. 4. Temperature and oxygen profiles in the analyzed flow-through lakes in the winter of 2006. * In 2006, the measurements in Lake Setalskie Duze were performed in the deepest section

During winter stagnation, the highest dissolved oxygen content was noted in the top layer of water under the ice, and oxygen concentrations varied widely between years. The winter of 2005 was milder (temperature in January –0.6 °C), and oxygen content near the surface layer of water ranged from 7.98 $mgO_2 \cdot dm^{-3}$ in Lake Setalskie Male to 11.55 $mgO_2 \cdot dm^{-3}$ in the western part of Lake Setalskie Duze (Fig. 3). In the winter of 2006 (temperature in January –8.3 °C), oxygen content was significantly lower in the range of 0.26 $mgO_2 \cdot dm^{-3}$ in the northern bay of Lake Nowe Wloki to 0.42 mg $O_2 \cdot dm^{-3}$ in the western part of Lake Setalskie Duze (Fig. 4). Oxygen concentrations in the main basin of Lake Nowe Wloki were determined at 3.3 $mgO_2 \cdot dm^{-3}$, indicating that the lake's oxygen resources had not been completely depleted despite the presence of ice cover. The above could be attributed to the fact that low temperatures slow down the oxidation of organic matter in bottom deposits, thus preventing complete oxygen depletion at the deepest strata of the water body. In the main basin of the lake, light penetrating the ice cover was used by the remaining phytoplankton in the photosynthesis process, thus increasing oxygen supply. Oxygen concentrations in the northern bay of the lake were significantly lower (0.27 $mgO_2 \cdot dm^{-3}$) due to higher levels of biogenic pollutants which are regularly supplied to the lake by the drainage ditch from a nearby village with no sewer system. The noted drop in oxygen levels was significant, and it led to fish oxygen starvation and death. During the severe winter of 2006, when ice cover thickness reached 30–40 cm, organic matter decomposition and aerobic respiration processes led to almost complete oxygen depletion in the studied water bodies (except for the main basin of Lake Nowe Wloki).

An analysis of temperature and oxygen conditions performed in the summer confirmed close correlations between the studied parameters. All lakes were characterized by incomplete thermal and oxygen stratification, typical of shallow water bodies. In summer, intense water heating led to a rapid increase in water temperature over a short period of time. The temperature of top water layers in the studied lakes ranged from 22.7 ^{o}C to 24.7 ^{o}C, and it decreased to around 18–20 ^{o}C at the bottom. The highest water temperature was noted in Lake Setalskie Male (Fig. 5).

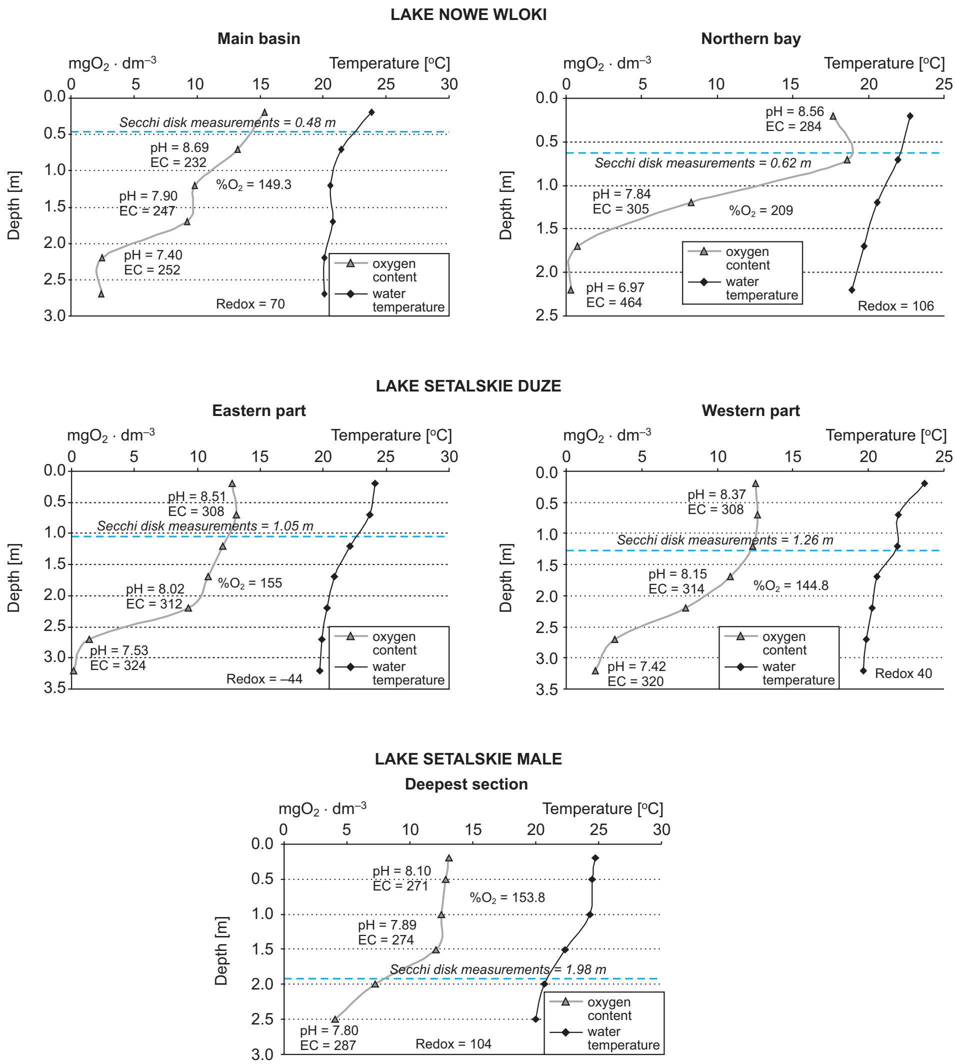

Fig. 5. Temperature and oxygen profiles in the analyzed flow-through lakes in the summer of 2007

Shallow lakes have a thermal regime that is characteristic of polymictic water bodies. Permanent water circulation contributes to a uniform temperature profile and free oxygen distribution [6]. In the studied lakes, oxygen distribution patterns were correlated with temperature curves. The vertical profile of dissolved oxygen is illustrated by oxygen curves characteristic of eutrophic lakes which have a limited trophogenic zone and contain large quantities of organic matter that cannot be effectively mineralized in the oxygen-rich epillimnion. The oxygen curve has a clinograde profile which points to a decrease in assimilation processes and a rapid drop in dissolved oxygen levels to the point of complete depletion.

In all studied lakes, maximum values were noted in the layer between the lake's surface and a depth of 1.7 m (excluding the northern bay of Lake Nowe Wloki). At the above depth, dissolved oxygen concentrations were reported in the range of 9.21 $mgO_2 \cdot dm^{-3}$ in the main basin of Lake Nowe Wloki to 12.87 $mgO_2 \cdot dm^{-3}$ in Lake Setalskie Male. In the northern bay of Lake Nowe Wloki, oxygen concentrations were most similar (8.3 $mgO_2 \cdot dm^{-3}$) in the shallower zone at a depth of 1.2 m. Extensive growth of vegetation characteristic of wetland ecosystems, including sedge, common reed and bulrush, led to intensified oxygen consumption to support plant respiration, lowering oxygen concentrations in water. In the vertical profile of the northern bay, a significant drop in oxygen levels was observed at a depth of 1.2 m, and the difference in oxygen concentrations between a depth of 1.2 m and 1.7 m reached 7.57 $mgO_2 \cdot dm^3$ (Fig. 5).

Oxygen saturation in the studied lakes was very high in the range of 145 % to 155 %, and the highest saturation levels of 209 % were noted in the northern bay of Lake Nowe Wloki. High oxygen saturation is characteristic of eutrophic water bodies with a high level of primary production [7, 8]. In summer, high levels of dissolved oxygen result from photosynthesis and the release of free oxygen due to strong light penetration and the growth of aquatic vegetation [9]. In the summer season, oxygen saturation exceeds 100 %, as demonstrated in the studied lakes (Fig. 5).

In the analyzed lakes, a clear drop in the vertical profile of dissolved oxygen was determined at a depth of 1.7 m (excluding the northern bay of Lake Nowe Wloki – at a depth 1.2 m), and the lowest concentrations (from 0.16 to 4.07 $mgO_2 \cdot dm^{-3}$) were noted in the bottom layer. The lowest oxygen concentrations were reported in the eastern part of Lake Setalskie Duze (0.16 $mgO_2 \cdot dm^{-3}$) and the northern bay of Lake Nowe Wloki (0.29 $mgO_2 \cdot dm^{-3}$), *ie* the shallower parts of the studied lakes (Fig. 5). The above resulted from intensified mineralization of organic matter which was produced in the lake and stored in bottom deposits [7, 10].

In periods of stagnation, the differences in oxygen concentrations at various depths result from the release of oxygen during photosynthesis in surface layers as well as the uptake of oxygen for plant respiration and oxidation reactions, which are most intense in layers with a high content of organic matter [10].

Negative redox potentials were determined in the eastern section of Lake Setalskie Duze and the northern bay of Lake Nowe Wloki at – 106 mV and – 44 mV, respectively. The above is indicative of intensified reduction reactions which, if they persist for longer periods of time, are generally accompanied by the release of H_2S and NH_4 (due to decomposition) (Fig. 5).

In view of the above, it can be assumed that the vertical profile of oxygen distribution in various seasons of the year is a reflection on turbulent water mixing processes, the intensity of organic processes and hydrochemical reactions. Dissolved oxygen saturation is a function of the lake's productivity and the degree of environmental pollution in the aquatic ecosystem [7, 8].

The pH and electrolytic conductivity (EC) of lake water decreased with depth. High EC values in bottom layers also point to an increase in the mineral content of bottom sediments. Maximum EC values (464 $\mu S \cdot cm^{-1}$) were also reported in the northern bay of Lake Nowe Wloki, which is situated in the direct vicinity of farm buildings, and in the eastern part of Lake Setalskie Duze (324 $\mu S \cdot cm^{-1}$) where cattle are grazed on grasslands neighboring this part of the catchment area (Fig. 5).

Secchi disk measurements revealed the highest water transparency in Lake Setalskie Male (1.98 m) where color and turbidity values were low. The lowest transparency values were determined in Lake Nowe Wloki at 0.40 m in the main basin and 0.62 m in the northern bay. In the discussed lake, water had a greenish color which is characteristic of algal blooms (Fig. 5).

Conclusions

The results of our study confirmed the unsatisfactory condition of water bodies that had been restored more than 30 years ago. The ecological status of the studied lakes is similar to that of small water bodies in the nearby Olsztyn Lakeland. Oxygen conditions in the examined lakes varied significantly, and the northern bay of Lake Nowe Wloki showed the highest levels of oxygen depletion due to local conditions (proximity of farmland and rural settlement without a sewer system). The dissolved oxygen content of the analyzed water bodies indicate that with the current pattern of ecological succession, the lakes may soon reach the hypertrophic stage.

In additional to natural factors, the adverse effects of anthropogenic pressure have a particularly strong influence on the rate of changes in the relatively recently restored lakes in rural areas.

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STRUKTURA TERMICZNO-TLENOWA WÓD ZRENATURYZOWANYCH ZBIORNIKÓW WODNYCH

Katedra Melioracji i Kształtowania Środowiska
Uniwersytet Warmińsko-Mazurski w Olsztynie

Abstrakt: Badaniami objęto trzy zbiorniki wodne: jezioro Nowe Włóki (o dwóch plosach – basen główny i zatoka północna), jezioro Sętalskie Duże i jezioro Sętalskie Małe, połączone Strugą Sętal w jeden system rzeczno-jeziorny. Obiekty te ze względu na charakterystyczne położenie (spadki terenu) tworzą układ kaskadowy. Położone są one 25 km od Olsztyna w gminie Dywity (Pojezierze Olsztyńskie) w zlewni o wyraźnym ukierunkowaniu rolniczym. Analizowane akweny ze względu na małą głębokość średnią (od 1 do 2 m) należą do polimiktycznych.

Celem pracy była analiza termiczno-tlenowa wód zbiorników wodnych, odtworzonych przed około 30 laty. Profile zostały wykonane zarówno w okresach stagnacji zimowej (2005 i 2006 r.), jak i letniej (2007 r.).

Badania stosunków termiczno-tlenowych wykonanych latem wykazały dużą zbieżność elementów temperatury i tlenu. We wszystkich jeziorach stwierdzona została charakterystyczna dla wód płytkich niepełna stratyfikacja termiczno-tlenowa.

Wykonane zimowe profile tlenowe wykazały charakterystyczny układ dla temperatur, kiedy to zachodzi zjawisko stratyfikacji odwróconej – katotermii. We wszystkich badanych zbiornikach temperatura wody przy powierzchni była zbliżona do 0 °C i od głębokości około 30–50 cm stopniowo rosła. Największa zawartość tlenu rozpuszczonego w czasie stagnacji zimowej znajdowała się w górnej warstwie, tuż pod lodem i wyraźnie różniła się w poszczególnych latach. Najniższe stężenia O_2 występowały przy dnie, z krytycznie niskimi wartościami (od 0,16 $mgO_2 \cdot dm^{-3}$ do 0,29 $mgO_2 \cdot dm^{-3}$) odnotowanymi w akwenach w czasie bardzo ostrej zimy 2006 r., kiedy to pokrywa lodowa sięgała 40 cm. Wówczas procesy rozkładu materii oraz procesy oddychania tlenowego organizmów doprowadziły prawie do całkowitego zużycia tlenu w zbiornikach.

Słowa kluczowe: profile termiczno-tlenowe, odtworzone zbiorniki, nasycenie tlenem