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THERMAL AND OXYGENIC CHARACTERISTIC OF RZUNO LAKE (KASZUBY LAKELAND)

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CHARAKTERYSTYKA TERMICZNA I TLENOWA JEZIORA RZUNO (POJEZIERZE KASZUBSKIE)

W okresie czerwiec 1998 – wrzesień 1999 w wodzie jeziora Rzuno badano temperaturę, widzialność, pH oraz zawartość chlorofilu *a*. Stwierdzono, że jezioro Rzuno charakteryzuje się silną stratyfikacją termiczną i słabą stratyfikacją tlenową. Stopień nasycenia wody powierzchniowej tlenem był raczej umiarkowany (maksymalnie 135%), ale warunki tlenowe w całym jeziorze były dobre, ponieważ całkowity brak tlenu obserwowano tylko latem i to poniżej 20 m głębokości. Podczas cyrkulacji wiosennej i jesiennej koncentracja tlenu przy dnie wynosiła 5 mg O_2 dm^{-3}. Współczynnik korelacji pomiędzy widzialnością mierzoną krążkiem Secchi a stężeniem chlorofilu a wykazywał wysoką wartość r = -0,87. Średnia przezroczystość wody, niski deficyt tlenowy i małe zmiany odczynu wody wskazują, że jezioro Rzuno ma umiarkowany charakter eutroficzny.

Summary

The oxygen and chlorophyll *a* contents, pH, temperature and transparency were studied in Lake Rzuno in the period from June 1998 - September 1999. This lake has a very strong thermal stratification and weaker oxygenic stratification. The degree of surface water saturation with oxygen was rather small (max. 136%) but the oxygen conditions in the whole Lake Rzuno were good because the total lack of oxygen is noted only in summer and only below 20 m depth. Whereas during autumn and spring circulation the oxygen concentration reaches 5 mg O_2 dm^{-3} at the bottom. The correlation between visibility of Secchi disc and chlorophyll *a* concentration featured high correlation indicator (r = -0.87). The awerage water transparency, low oxygen deficit and small changes in water reaction show that this lake has moderate eutrophic character.

INTRODUCTION

A thousand years' lasting eutrophication process of surface waters went on slowly, unnoticeable for man and whole generations. The rapid eutrophication was observed in the last century. It was caused by inflow of large amounts of nutrients and organic matter to water ecosystems. Furthermore, it results in large oxygen deficits, hydrogen sulphide presence, algal bloom and other negatives successions [1, 13].

Pollution increase of surface waters influences disadvantagous physico-chemical environment changes and what's more, causes disturbances in natural lake ecosystem and consequently in biological balance.

As municipal waste waters have a large content of organic and mineral matter, they stimulate a development of phytoplankton [3]. However, their excessive quantities inhibit primary producers [9, 11]. It brings about the total degradation of lakes, which is described as saproby [11].

About 50% of Polish lakes are highly polluted. Relatively unpolluted lakes can be met only in some regions. For example, Kaszuby Lakeland, where we can meet not only politrophic [5] but also oligothrophic lakes [4].

The purpose of the presented work was determination of the trophic state of Rzuno Lake, Kaszuby Lakeland, basing on existing temperature and oxygenic conditions.

STUDY AREA, MATERIALS AND METHODS

Rzuno Lake is a small reservoir in Kaszuby Lakeland. It has gutter character and lies in a ravine. On the west side of the lake, wooden hills are about 30 m high above water level. On the south-east side of the lake, Dziemiany village is situated (Fig. 1). On the north-east side there is also a wood.

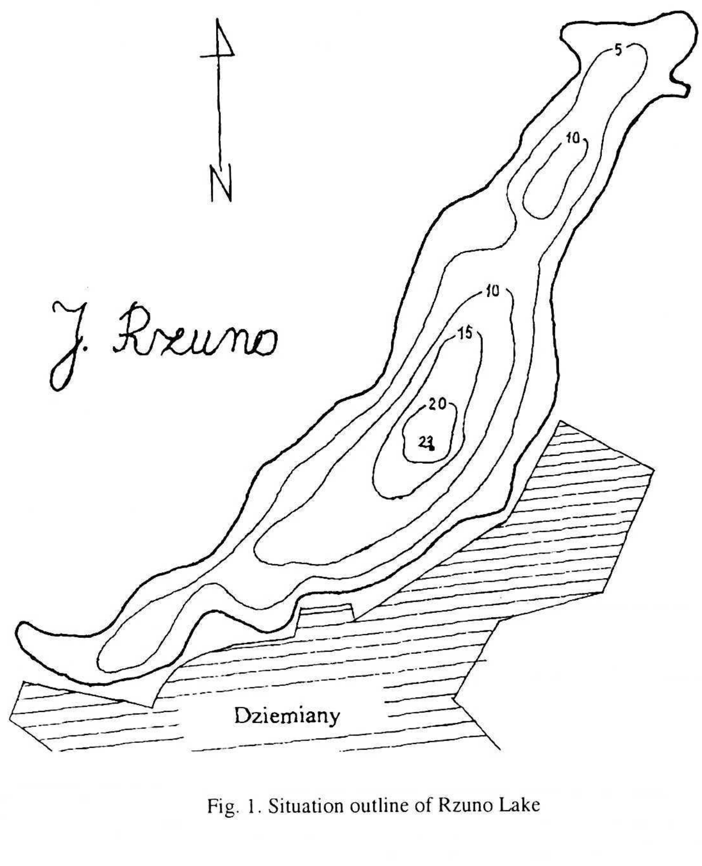


Fig. 1. Situation outline of Rzuno Lake

A bathymetric chart of the lake and calculation of main morphometric data were done by IRS in Olsztyn (Fig. 1, Tab. 1). Rzuno Lake has elongated shape with axis going in the north-west direction. It is a deep lake with average depth of 7.9 m and maximum depth of 23 m in the central part of it.

Table 1. Morphometric properties of Rzuno Lake

Property of Lake	Value
Surface area (ha)	34.8
Volume (10^3 m^3)	2753.4
Maximal depth (m)	23.0
Mean depth (m)	7.9
Index of depth	0.34
Maximal length (m)	1610
Maximal width (m)	325
Elongation	4.9
Length of shore line (m)	4130
Geographical co-ordinates:	
latitude N	54°00.9'
longitude E	17°46.4'
altitude a.s.l. (m)	152.3

Studies were made in the deepest part of the lake from June 1998 to September 1999 with a frequency of every two weeks. Water sample was taken from every 1 m depth using Ruttner's sampler with an in-build mercury thermometer with the accuracy of 0.1°C.

Oxygen content in analysed water was determined by Winkler's method and water reaction using pH-meter. Water transparency was measured by Secchi disc.

In order to determine chlorophyll *a*, water samples were filtered through Synpor filters (pore diameter 0.6 μm). The rest was homogenized and extracted with 90% acetone. Light absorption was measured in the solution at λ = 665 and 750 nm on the pecrtrophotometer SCHIMADZU. The concentration of chlorophyll *a* was calculated using Lorenzen formula [14].

RESULTS

Thermic properties of lake water depend mainly on atmospheric conditions, climate zone and morphologic and hydrologic conditions of the reservoir. In 1998–1999 it was confirmed that in the region of Rzuno Lake air temperature oscillated from -12 to +29°C. Temperature changes of air and water are shown in Fig. 2.

When the samples were taken in summer 1999 the air temperature was between 18 and 24°C. The slowly decrease of temperature was observed in the autumn, from September, to 8°C in the middle of November and further. In the winter on the turn of 1998/1999 the temperatures were below 0°C. The lowest temperatures were observed at the end of January and in the first days of February. In the middle of February the temperature began to increase slowly, reaching in March values above zero. From the be-

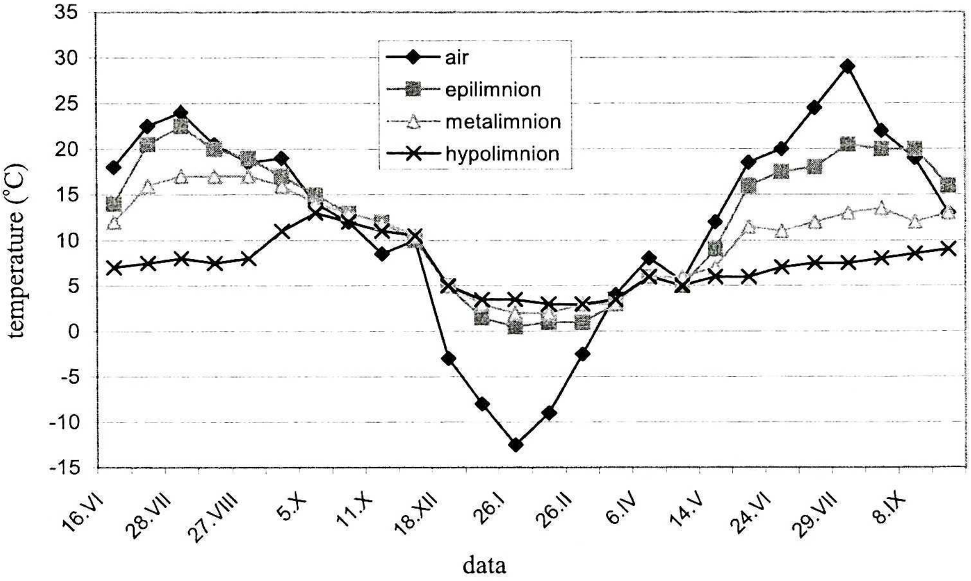


Fig. 2. Changes of temperature in air and in trophic layers of Lake Rzuno water

ginning of May the quick increase of temperature to 18°C in June was noted. In the summer 1999 temperatures were higher (18 – 29°C) than in 1998.

Undoubtedly, the factors which influence water temperatures are a type of reservoir, first of all it's depth, motions and mixing of water masses, inflow of cool or warmed up waters and many others. The intensity of solar radiation and wind energy influence thermal stratification and heat exchange in water bodies.

The temperature changes in Rzuno Lake were presented in particular stratification layers in Fig. 2. With the moment the measurements were started in vertical profile in June 1998, strong thermal stratification was observed (Fig. 3). The temperature of surface water was 14°C. The epilimnion layer reached 7 m and in July decreased to 5 m and stayed unchanged till about the end of August. The thickness of metalimnion layer changed from 4 m in June to 6 m in July, at the same time the water temperature in epilimnion increased to 22.5°C. In both months the range of metalimnion reached 11 m depth. Maximum thermocline gradient in June was 3.0°C m^{-1} between 9 and 10 m depth and in July 4.8°C m^{-1} between 8 and 9 m (Fig. 4). In August the water temperature in epilimnion decreased to 19°C. The metaliminion layer had a smaller range and at the end of August was between 5 and 9 m depth. Maximum gradient was 4.2°C m^{-1} at the depth 7 – 8 m. In September the temperature of surface water decreased to 17°C. The range of epilimnion increased to 8 m and the thickness of metalimnion decreased to 2 m. At the same time thermocline gradient decreased and reached 1.8°Cm^{-1}.

During summer stratification, till the middle of September, the temperature of thick hypolimnion layer was on average 7°C. In higher hypolimnion layers (below 11 m), water temperature was about 9°C and below 20 m about 5–6°C. The beginning of

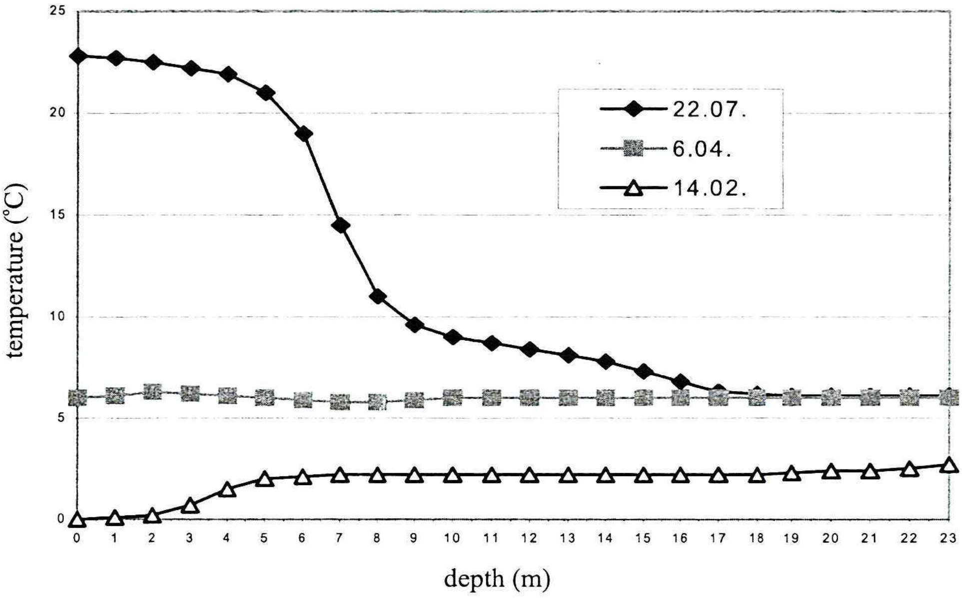


Fig. 3. Temperature profiles of water in Rzuno Lake

autumn circulation was confirmed at the beginning of October. Then thermal jump was observed below 16 m and its gradient was 2.0°C m^{-1}.

The autumn circulation caused a homothermy state at the end of November at temperature 9°C in the whole water column. The homothermy state was still observed in the middle of December, when as a result of continual decreasing of air temperature, water temperature in the whole water column was 5°C. A further decrease of temperature caused a formation of ice cover, which was observed till the end of February. In January thermal jump with gradient 1.2°C/m between 4 and 5 m depth was noted. As strong cooling of water took place in January and February. The temperature of surface water till 5 m depth oscillated between 0.1 to 1.5°C. At larger the depths temperature range was between 2.0 and 3.0°C, and below 18 m from 2.5 to 3.6°C. The strongest cooling was in the second half of January, when the maximum temperature of surface water was 0.5°C.

A spring mixing started at the beginning of March. The homothermy of the whole water column was noted at the temperature of 4.8°C. The homothermy state was still observed at the beginning of April, when the upper layers of water reached 6°C and near bottom ones 5°C.

The division of water masses into layers thermally diversified took place in May. In the middle of May the thermal stratification of water produced epilimnion with range 5 m of depth. The range at this level was noted till the end of August. The average temperature of epilimnin in May was 10°C. The layer of thermal jump in this month reached from 5 m to 7 m and its maximum gradient was 1.4°C m^{-1}. The water tempera-

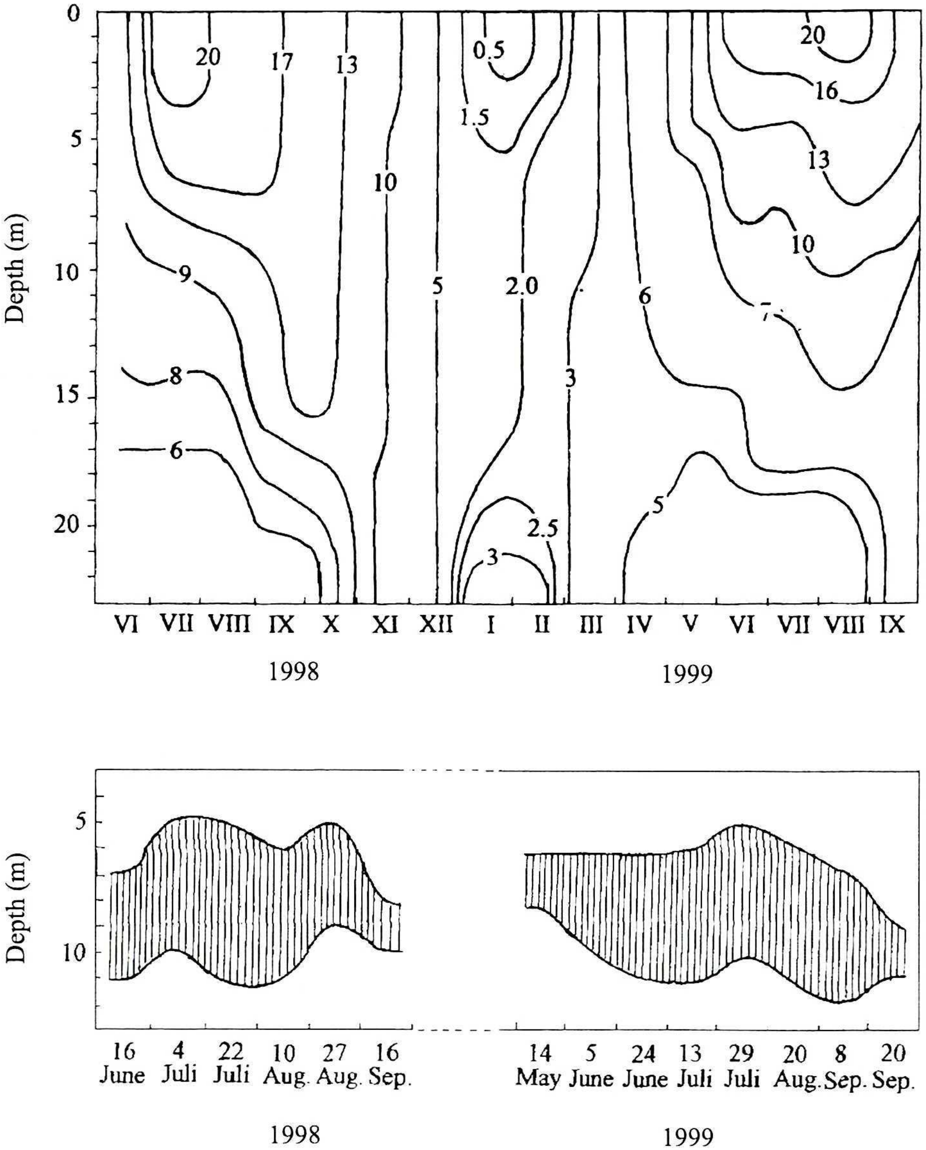


Fig. 4. The isotherms of Rzuno Lake in °C between June 1998 - September 1999 and metalimnion thickness

ture considerably increased in June and on average was 16°C in epilimnion. The range of epilimnion was 5 m and was smaller than in June 1998. Thickness of metalimnion increased at first to 4 m and by the end of month to 5 m reaching even 10 m depth. The maximum gradient was 4.2°C m^{-1} and was observed between 6 and 7 m depth. The similar range of metalimnion was in July and August with maximum gradient respectively 4.5 and 5.1°C m^{-1} between 7 and 8 m depth.

In the first decade of September the range of epilimnion increased to 6 m and the layer of thermal jump decreased and was observed between 6 and 11 m depth. The maximum gradient was 3.5°C m^{-1} between 8 and 9 m. In the third decade of September the decrease of water temperature by 4°C was observed in comparison to the beginning of the month. The epilimnion layer increased to 8 m depth and thickness of metalimnion decreased to 2 m with maximum gradient 2.3°C m^{-1} between 9 and 10 m.

In the summer 1999 thermal stratification was noted from May to September (inclusive). In this period the temperature in hypolimnion waters was constant (6°C on average).

To resume we have to state that the period of thermal stratification in Rzuno Lake involved five months (October, November and December) whereas spring circulation two months (March, April). January and February are the months of winter stagnation. During warm winters, when winter stratification is not recorded or this period is very short, the time of water masses mixing is much longer

In the studied lake during summer stratification epilimnion reached 5 m and in September its range was larger. The metalimnion layer in 1998 was noted between 5 and 11 m and in 1999 between 5 and 10 m. In September the thickness of this layer decreased during the passage of time. The cold hypolimnion layer was recorded below, with temperature 5–8°C.

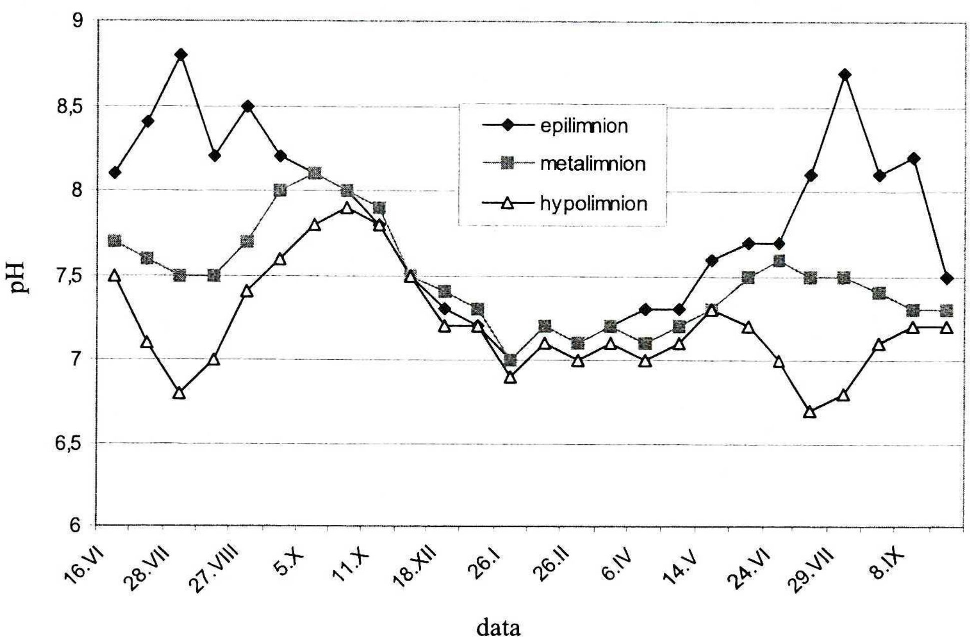


Fig. 5. Changes of reaction (pH) in trophic layers of Lake Rzuno water

The pH – value in Rzuno Lake oscillated in small pH range from 6.7 to 8.8. Those differences depended on year season and depth (Fig. 5). The largest differences of pH – values between particular thermal layers were observed in summer. In this period epilimnion waters had the highest reaction and hypolimnion waters had the lowest one. The largest differences were noted in July 1998 (epilimnion – pH = 8.8, metalimnion – pH = 7.5, hypolimnion – pH = 6.8). High pH – values of epilimnion were observed till the end of September. From October the gradual decrease of those values was noted. Whereas in hypolimnion already in September, water reaction increased and reached in October the highest value of pH = 7.9. During the autumn circulation the reaction compensation took place in the water column. As time went on, the pH – value decreased and reached the lowest value of 7.0 in January, during the winter stagnation. During the spring circulation the average pH – value was 7.2. In May significant differences between epilimnion and hypolimnion water reactions were noted.

At the moment thermal stratification formed during summer stagnation in 1999, district differences in water reaction were observed with the same regularity as in the previous year. The water reaction in epilimnion increased from pH = 7.3 at the end of April, to 7.7 in June and 8.7 in July. At the same time water reaction in hypolimnion decreased from pH = 7.3 in May to 7.0 in June and 6.7 in July. In next months the decrease of pH – value in epilimnion was observed and its increase in hypolimnion waters.

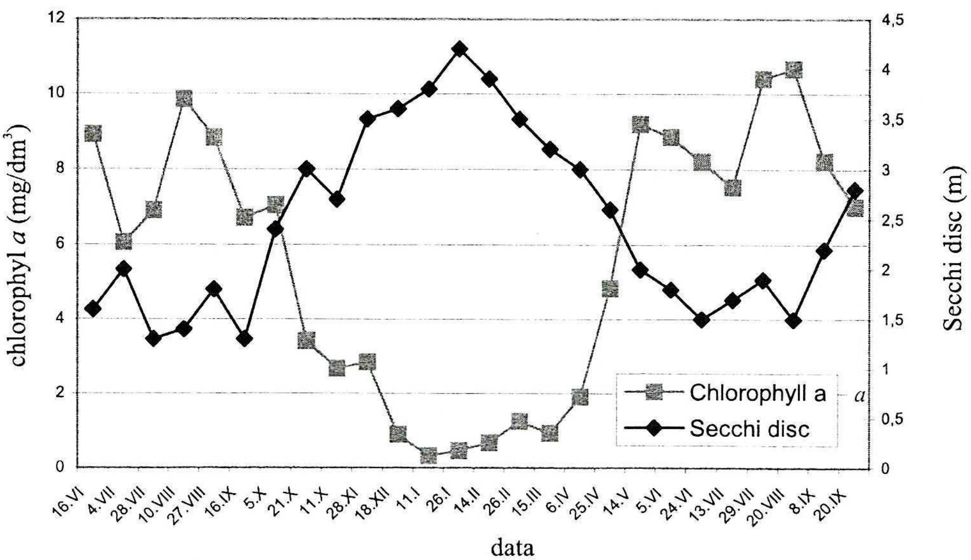


Fig. 6. Changes of chlorofil *a* concentration and Secchi disc visibility (m) in Rzuno Lake

To generalize we have to say that in summer the water in Rzuno Lake has slightly basic character due to the processes which take place there and therefore pH value exceeds 8. Whereas in deeper waters those processes cause contrary direction of changes and as result water has neutral character. During mixing of water masses in autumn and spring circulations, water reaction in the whole lake compensates with average pH value = 7.3. In that time the water reaction changes at the beginning pH – values decrease to minimum during the winter stagnation and then increase slightly during the spring circulation.

Water transparency in Rzuno Lake was measured as visibility of Secchi disc. Changes of that indicator in the studied period shows Fig. 6. During the whole studied period, visibility of Secchi disc was not lower than 1.3 m. In the summer 1998 the visibility was the lowest (1.6 m on average). The distinct increase of transparency took place on the turn of September and October, when the visibility exceeded 2 m depth. This upward tendency lasted till the winter stagnation. The highest water transparency was observed in January, when ice cover occured and amounted 4.2 m of Secchi disc the visibility. In March visibility decreased to 3.2 m. The downward tendency lasted till the end of June and reached the lowest value 1.4 m. Since August the water transparency has improved.

The high water temperatures in summer are conducive to intensive vegetation of all living organisms in this environment. Phytoplankton develops intensively and together with mineral suspensions in water its transparency decreases. The proof for that is the course of changes of chlorophyll *a* concentration in the studied period (Fig. 6) and the statistic analysis, which involves correlation between those two parameters. Chlorophyll *a* is an indicator of phytoplancton biomass.

The highest concentration of chlorophyll *a* in the surface layers was observed in Rzuno Lake in summer. I the summer 1998 the high values of this indicator were noted in June – 8.92 mg m^{-3} and in August – 9.86 mg m^{-3}. In September there was a rapid decrease of chlorophyll *a* concentration till 2.67 mg m^{-3} in November and 0.05 mg m^{-3} in January. That level was still in March. Then together with the increase of temperature, chlorophyll *a* concentration started to increase and reched the first maximum in May 1999 – 9.20 mg m^{-3}. The second maximum value was noted in August 10.67 mg m^{-3} and after that the rapid decrease took place.

The very high value of correlation coefficient ($r = -0.87$, $n = 26$, significance level = 0.05) between visibility of Secchi disc and chlorophyll *a* contents shows that water transparency in the studied lake depends mainly on phytoplankton biomass. This correlation is described through rectilinear regression equation: $y = -4.21x + 15.98$.

The thermal water stratification in the lake influence also oxygen contents. The oxygen concentration depends mainly on the exchange with atmosphere, oxygen production during photosinthesis of vascular plants and algae and its consumption through microorganisms during the organic matter decomposition.

The change of oxygen concentration in particular thermal layers in the studied period 1998–1999 in Rzuno Lake is presented in Fig. 7. In summer months the strong oxygen stratification of water column was observed and is shown as an example in Fig. 8.

When we started our measurements in June the oxygen contents in surface water till 2 m exceeded 13.0 mg O_2 dm^{-3} (Fig. 9). The layer of oxycline jump started at 8 m depth with the oxygen concentration 9.1 mg O_2 m^{-1}. The thickness of that layer was 3 m and the maximum gradient was 1.3 mg O_2 dm^{-3}. Below 11 m in hypolimnion the average concentration of that element was 3.4 mg O_2 dm^{-3}. In the next months the oxycline jump moved into the surface and started at 5 m depth and reached 8 m. Then the

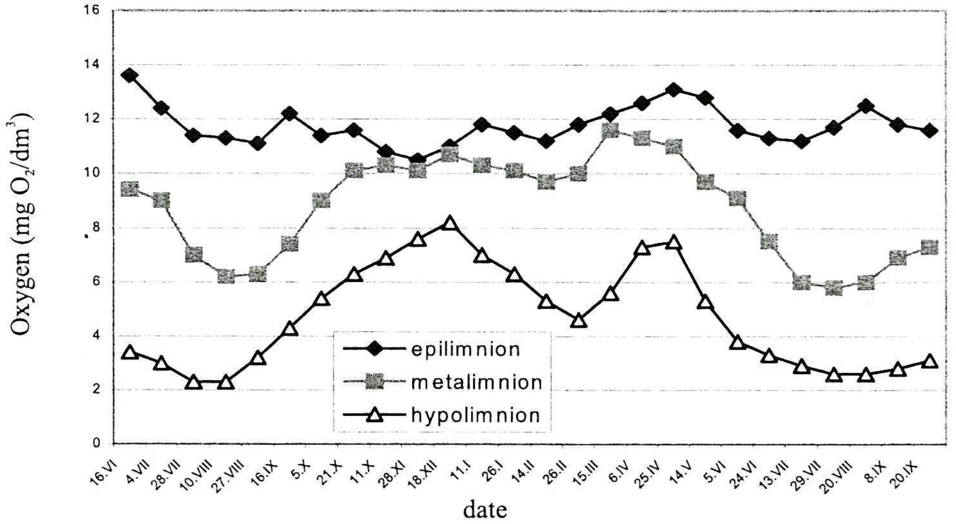


Fig. 7. Changes of oxygen concentration (mg O_2 dm^{-3}) in trophic layers of Lake Rzuno water

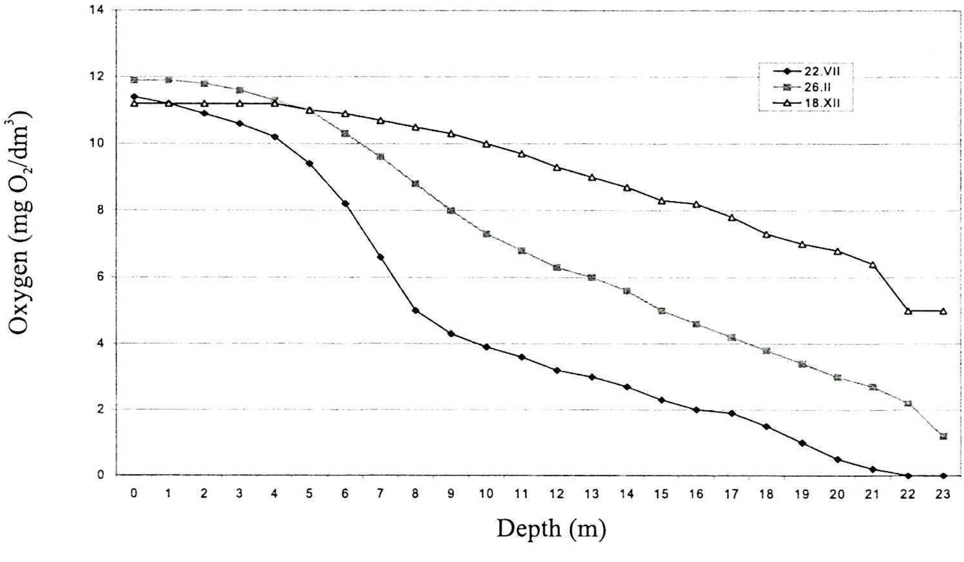
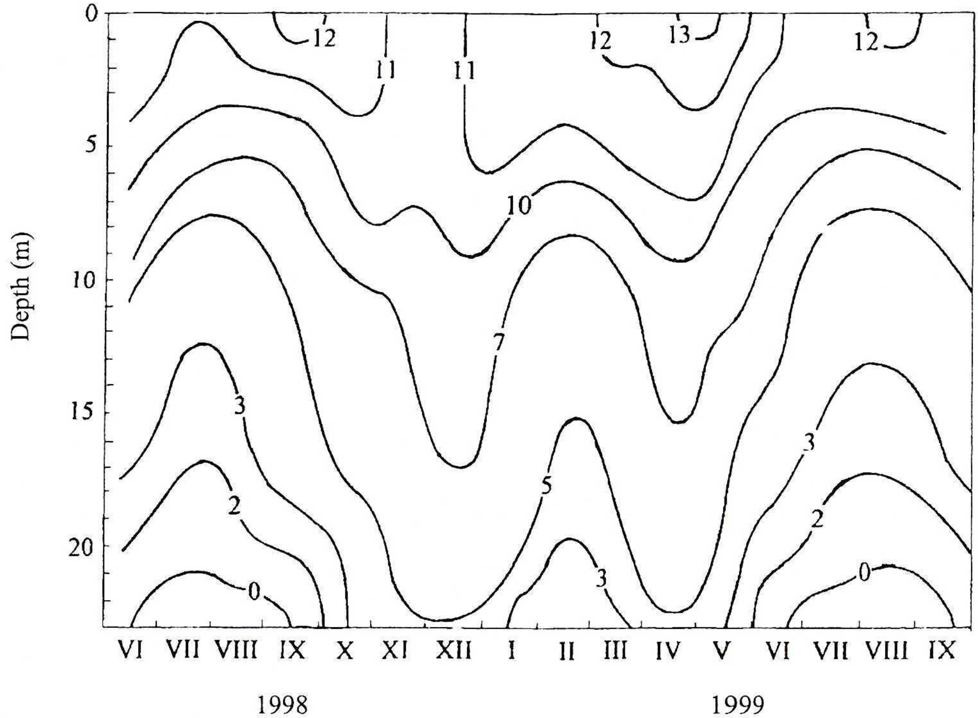


Fig. 8. Oxygen profiles of water in Rzuno Lake

average oxygen concentration in epilimnion was 11.3, in metalimnion 6.2 and in hypolimnion 2.3 mg O_2 dm^{-3}. In all water thermal layers the decrease of oxygen concentrations was noted. In September the oxycline jump was still at the depth of 6 m but with 2 m thickness. As a result of water masses mixing, during autumn circulation the oxygen concentration increased in deeper waters. At the beginning of December the concentration of that element in epilimnion was on average 11.0, i metalimnion 10.7, in hypolimnion 8.2 and at the bottom 5 mg O_2 dm^{-3}.



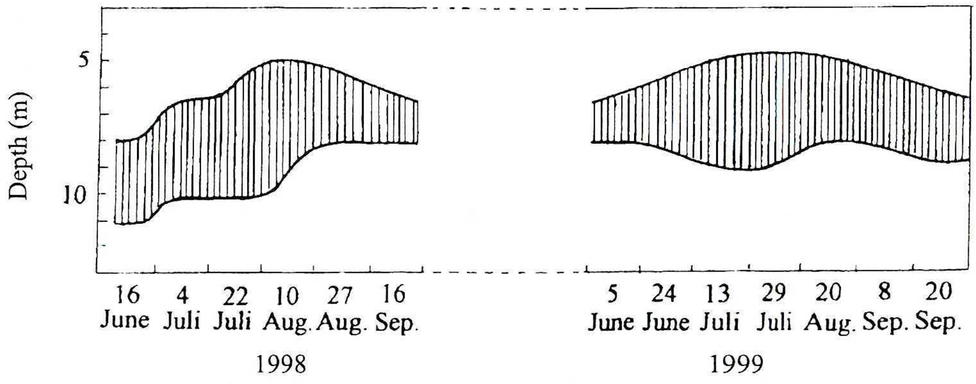


Fig. 9. The oxygen concentration of Rzuno lake (June 1998 - September 1999) and oxycline jump

During the winter stagnation the oxygen concentration in epilimnion and metalimnion waters was more or less at the same level, whereas in hypolimnion was decreasing during the passage of time and reached the lowest average value 4.6 mg O_2 dm^{-3} at the end of February. Those differences are distinct in Fig. 8, which shows the changes in the oxygen concentration in vertical profile during the autumn circulation and winter stagnation. The spring circulation caused on increase of the oxygen contents in the whole water mass. At the beginning of April the oxygen concentration in epilimnion was 12.6, in metalimnion 11.3 and in hypolimnion 7.3 mg O_2 dm^{-3}.

The oxygen stratification with the oxycline jump beginning at 6 m depth and ending at 8 m depth, with maximum gradient 1.2 mg O_2 m^{-1} was noted in June. The oxycline layer broadened the thickness to 4 m and started at 5 m depth in July. The largest value of maximum gradient was observed in August (2.6 mg O_2 m^{-1}) at 5 m depth. The oxygen stratification was still in September. The oxygen jump was noted between 6 and 9 m depth with maximum gradient 1.4 mg O_2 m^{-3}. During the summer stagnation the average oxygen concentration in epilimnion was 11.7 mg O_2 dm^{-3} with oscillation from 10.6 to 12.5 mg O_2 dm^{-3}.

At this time the significant decrease of oxygen content in water was observed in hypolimnion. The average oxygen concentration was 2.8 mg O_2 dm^{-3} and at the bottom decreased to zero. Such conditions existed from the beginning of July till the end of September.

In Rzuno Lake homooxygenation was not observed, this means such period in which the oxygen concentration in the whole water column would be the same. The most similar situation to such phenomena was noted during the autumn circulation. That means that hypolimnion waters are not oxygenated enough. The values of water saturation with oxygen are proof for that (Fig. 10). The epilimnion layer is the best oxygenated, the O_2-saturation exceeds generally 120% from June to September. This is considerably weaker from December to March, when the water saturation with oxygen is on average 86%. More weaker oxygenation has metalimnion which values of O_2-saturation oscillate between 43 and 78%. However, the worst oxygen conditions are in hypolimnion especially in summer when the saturation with oxygen does not exceed 30%. The best oxygen conditions in this thermal layer are noted during autumn circulation. Then the water O_2-saturation exceeds even 60%.

DISCUSSION

The water motion resulted from hydrological conditions and water masses motion resulted from winds influence a reservoir has essential effect on thermal and oxygen relations of ecosystem. In the case of Rzuno Lake the intensive exchange of water does not take place because it is not a flow lake and has no inflows or outflows. It is supplied mainly with underground water, precipitation and postprecipitation waters flowing on the surface from the nearest land.

To some extent the wind influence is also united because the lake is situated in a ravine and is protected by wood and buildings in Dziemiany village. In such conditions it never comes to the right concentration of oxygen of the whole water column and the degree of surface water saturation with oxygen is rather small (max. 136%). The similar

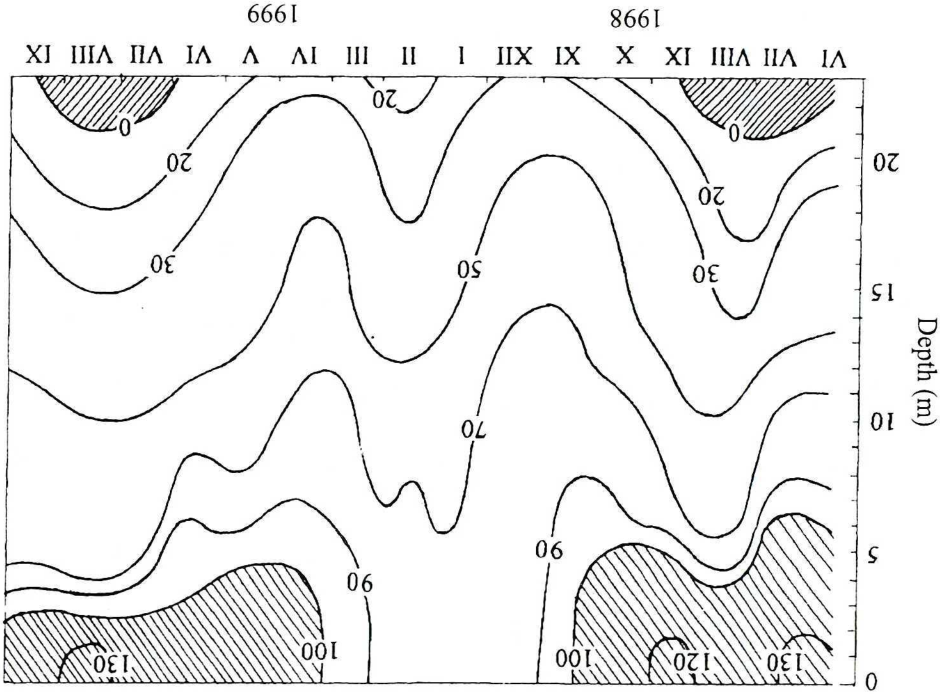


Fig. 10. Water saturation with oxygen in Rzuno Lake (June 1998 - September 1999)

degree of saturation with oxygen was observed in Ukiel Lake [10]. Much higher values (more than 160%) were noted in Łętowskie Lake [8] and in Długie Lake [2] and in a dam reservoir Dzierżno Małe (even 200%) [6]. Less concentration of oxygen of water is registered in deeper parts of Rzuno Lake particularly by in summer. Then below 15 m depth the oxygen deficit is noted because the oxygen concentration is less than 3 mg O_2 dm^{-3} and 2 m above the bottom are oxygen-free conditions. This period does not lasts long, about 4 months a year. In Ukiel Lake [10], which is twice deeper, oxygen-free conditions begin already below 15 m during the summer stagnation.

Undoubtedly the reason for such situation is the very strong stratification of this lake. Its division into thermally and oxygenic diverse layers is very distinct and stable. The thermal stratification is observed not only in summer but also in winter. It is hindrance for intensity of the range of water mixing. As a matter of fact during a year there is no such a period that the full deep water oxygenation would take place in the whole lake. In comparison to other lakes situated in northern Poland [7] we have to say that the oxygen conditions in Rzuno Lake are good because the total lack of oxygen is noted only in summer and only below 20 m depth. Whereas during the autumn and spring circulation the oxygen concentration reaches 5 mg O_2 dm^{-3} at the bottom. The metalimnion layer forming in summer, which makes it impossible for the surface and deep waters to mix, has the range from 5 m to about 10 m depth. The thermocline gradients were relatively high, whereas the oxycline gradients were low.

The oxygen and chlorophyll *a* concentrations in water show that biomass production conditions are favourable, including primary production (phytoplankton) in epilimnion of Rzuno Lake. The intensive development of algae essentially influence water transparency. The correlation between visibility of Secchi disc and chlorophyll *a* concentration featured high correlation coefficient. The level of chlorophyll *a* and transparency shows that Rzuno Lake belongs to moderate eutrophic lakes [12], the same with Płotycze Lake [15]. The small oscillations of pH – values during *a* year and in the lake's vertical profile confirm the above. On the basis of vertical thermal and oxygenic differences in the lake some differences in water reaction were noted in summer. In epilimnion, water had the highest pH – values and going deeper pH – value gradually decreased. The reason for such changes is probably the different biochemical processes in particular water layers. The consumption of carbon dioxide by phytoplankton on the surface supports alkalization of the environment. On the other hand the oxygen deficit at the bottom supports the denitrification reactions which cause the decrease of water pH – value. The general decrease of water pH – value in autumn may be caused by strong rainfalls that have acid reaction.

To generalize, looking at Rzuno Lake from the point of view of susceptibility to water mixing, it is a dimictic reservoir with low intensity of mixing with strong thermal stratification and less oxygen stratification.

The average water transparency, low oxygen deficit and small changes in water reaction show that this lake has moderate eutrophic character.

It is important to maintain the lake as an ecosystem of natural, biological, scenic and recreational value. Every effort should be made for its complete protection.

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