POLISH JOURNAL OF NATURAL SCIENCES
Abbrev.: Pol. J. Natur. Sc., Vol 25(1): 47–62, Y. 2010

DOI 10.2478/v10020-010-0004-z

PRELIMINARY CHARACTERISTICS OF THE TROPHIC CONDITION OF LAKES LOCATED IN THE NATURE RESERVE "BEAVER SANCTUARY ON THE PASŁĘKA RIVER"

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K e y w o r d s: eutrophication, clinograde oxygen curve, nitrogen, phosphorus, electrolytic conductivity, primary production.

A b s t r a c t

Studied were the following lakes: Pasłęk, Wymój, Sarąg, Łęguty and Isąg, located in the nature reserve "Beaver Sanctuary on the Pasłęka River". The hypothesis was that lakes located in a nature protection area are subject to eutrophication in a slow rate, however, the research did not confirm it. All lakes are very fertile, as shown by the concentrations of total nitrogen, total phosphorus, electrolytic conductivity and the high negative correlation between chlorophyll a and water transparency. In the peak of the summer stagnation oxygen profile is represented by the clinograde curve typical for eutrophic lakes while free carbon dioxide distribution in the water column is shown by a "reversed" clinograde curve, also typical for fertile reservoirs.

WSTĘPNA CHARAKTERYSTYKA TROFICZNA JEZIOR POŁOŻONYCH NA TERENIE REZERWATU PRZYRODY „OSTOJA BOBRÓW NA RZECE PASŁĘCE"

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S ł o w a k l u c z o w e: eutrofizacja, krzywa tlenowa klinogradowa, azot, fosfor, przewodność elektrolityczna, produkcja pierwotna.

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Abstrakt

Badaniami objęto jeziora: Pasłęk, Wymój, Sarąg, Łęguty oraz Isąg znajdujące się w rezerwacie przyrody „Ostoja bobrów na rzece Pasłęce". Przypuszczano, że położenie tych zbiorników na obszarze chronionym powoduje, iż proces eutrofizacji zachodzi w nich wolno. Badania nie potwierdziły tych przypuszczeń. Wszystkie jeziora są zbiornikami o wysokiej żyzności, o czym świadczy m.in. wysoka koncentracja ogólnych form azotu i fosforu, wartości przewodności elektrolitycznej oraz wysoka ujemna korelacja między zawartością chlorofilu a przezroczystością wody. W szczytowym okresie stagnacji letniej rozkład tlenu w pionie obrazowała krzywa tlenowa klinogradowa typowa dla jezior eutroficznych, zaś rozmieszczenie wolnego dwutlenku węgla w słupie wody miało charakter „odwrotnej" w stosunku do tlenowej klinogrady, co również jest cechą jezior żyznych.

Introduction

Ageing of lakes is a process that has been continuing consistently for approximately 10–12 thousand years which is also when most of the Polish lakes occurred. Input of mineral and organic substance from the catchment is regarded as the main reason for this phenomenon (GROCHOWSKA, TANDYRAK 2008).

In natural conditions, without any interference of man, eutrophication progresses very slowly (even thousands years). The rate of the process depends mainly on the environmental conditions, such like land configuration, type of ground, sorptive capacity of soils, green cover. Equally important are lake morphometry and climatic conditions (precipitation, annual distribution of air temperature) which determine the water mass dynamics – the main stimulus for matter circulation in a reservoir (GROCHOWSKA, TANDYRAK 2006, GROCHOWSKA et al 2006, KAJAK 2001).

Since the mid 1950s, man's impact on the nature has been increasing, the result of which are numerous permanent transformations, often regarded as negative. They are especially visible in the water reservoirs and displayed by algal blooms, deteriorated water transparency, deoxygenation of water or occurrence of unwanted decomposition products near the bottom, like ammonium and hydrogen sulphide (GROCHOWSKA, TANDYRAK 2007, LOSSOW, GAWROŃSKA 2000).

Taking into consideration the fact that input of substances from catchments transformed by man is one of the crucial factors influencing fertility of lakes, it could be argued that lakes localised in nature protection areas, like national parks or nature reserves, should be characterised by very good water quality and slower ageing.

The aim of this work was to make an introductory assessment of the trophic conditions of lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg situated in the nature reserve "Beaver Sanctuary on the Pasłęka River".

Materials and Methods

The nature reserve "Beaver Sanctuary on the Pasłęka River" was established in 5.01.1970 by the decree of Minister of Forestry and Forestry Industry (Monitor Polski, no 2, poz. 20, 21) in order to preserve the beaver sanctuaries. In the historical voivodships olsztyńskie and elbląskie the reserve covered the area of 4258.8 ha. At present, the River Pasłęka is protected within the Nature 2000 framework as a special area of habitat protection and covers the area of 6233.4 ha.

The reserve includes the River Pasłęka from its springs in the boggy meadows near the Gryźliny village to the Braniewo town limits, and the lakes situated on the river, namely Pasłęk, Wymój, Sarąg, Łęguty and Isąg. In addition, protected is the 100-m wide belt alongside the river banks and near the lakes – provided the adjacent area is state-owned or the 10-m wide strip if the ground comprises private property (ENDLER et al 2003a).

Pasłęka flows directly to the sea. It is 211 km long with the average sloping of 1.09%. The drainage basin area is 2230 km^2 and makes the drainage divide between the Vistula and the Niemen Rivers (ENDLER et al 2003b). In the physical and geographical classification, Pasłęka belongs to Eastern Europe, the East European Lowland, the sub-province East Baltic Lakeland, the macro-region Mazurskie Lakeland and the mezo-region Olsztyńskie Lakeland (KONDRACKI 1998). Since the very beginning, Pasłęka has been a natural border between the historic regions called Warmia and Mazuria (BAŁDOWSKI 1982).

Lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg, the trophic condition of which is the subject of this paper, are very variable with respect to morphometric properties (Tab. 1) and catchment development (Figure 1).

Lake Pasłęk is situated approximately 20 km southwest of Olsztyn, at 152.9 m above the sea level. The geographical co-ordinates are: 53°36'21" N and 20°19'21" E. The surface area is 8.5 ha and the max. depth equals 5.0 m. The total catchment of the lake covers the area of 8.4 km^2 and is mostly arable land (52%). In the direct vicinity of the lake (1.8 km^2) prevails mixed forest.

Lake Wymój is situated approximately 15 km from Olsztyn, at 122.4 m above the sea level. Its geographical co-ordinates are: 53°41'36" N and 20°21'03" E. It occupies the area of 47.6 ha and the max. depth is 16.0 m, whereas the mean depth is 5.1 m. The total catchment area equals 22.6 km^2 and the area draining directly to the lake is 0.6 km^2. The whole area surrounding the lake is mostly grown by forests (52%).

Lake Sarąg, situated 14 km west of Olsztyn, direction Ostróda, sits at 113.1 m above the sea level. The geographical co-ordinates are: 53°41'36" N and 20°16'48" E. The lake has large surface area of 183,0 ha but rather low

Table 1

Detailed morphometric data and lake parameters (after IRŚ, Olsztyn)

Parameter	Lake name				
	Pasłęk	Wymój	Sarąg	Łęguty	Isąg
Water table surface area (ha)	8.5	47.3	183.0	60.9	395.7
Maximum depth (m)	5.0	16.0	16.5	22.7	54.5
Mean depth (m)	–	5.1	6.9	8.5	14.2
Relative depth	0.017	0.020	0.012	0.030	0.027
Depth index	–	0.30	0.38	0.30	0.26
Volume (thousand m^3)	–	2413.8	12627.0	5234.0	56189.4
Max. length (km)	0.45	1.30	3.20	1.29	4.94
Maximum width (km)	0,30	0.5	1.1	0.8	1,1
Elongation	1.5	2.6	2.9	1.5	4.5
Shoreline length of the lake bowl (km)	1.1	3.1	9.3	3,7	17.5
Shoreline development	1.1	1.3	1.9	2.5	2.5

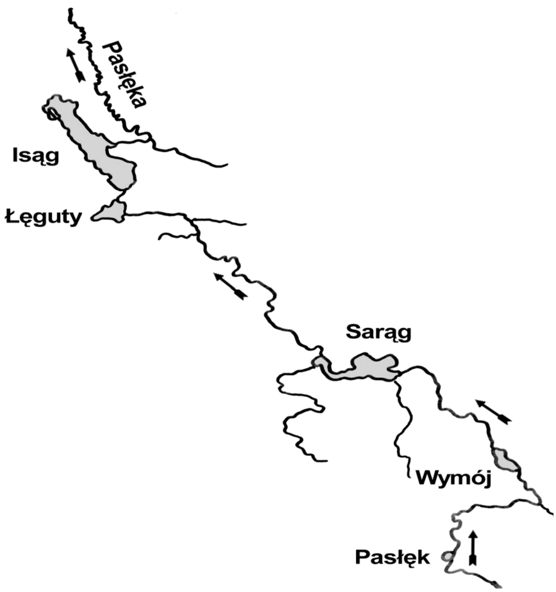


Fig. 1. The map of research area

maximal depth 16.5 m. The mean depth is 6.9 m. The total catchment area of Sarąg is considerable in size: 187.2 km^2. In the direct catchment of 10.5 km^2 prevailing are forests, covering 89.3% (GROCHOWSKA, TEODOROWICZ 2006).

The next lake localized in the nature reserve is Lake Łęguty. Located 20 km west of Olsztyn, between the villages Biesal and Łukta, it sits at 96.3 m above the sea level. The centre of the lake can be described by the following co-ordinates: 53°45'05" N and 20°09'00" E. The lake has the surface area of 60.9 ha and the max. depth of 22.7 m. The total catchment is 241.5 km^2, in 36% grown with forests and 35% cultivated. The direct neighbourhood which is 1.1 km^2 is dominated by forest (56%).

The last study object is a picturesque Lake Isąg which can be found 25 km west of Olsztyn, at 93.3 m above the sea level. The geographical co-ordinates are: 53°46'09" N and 20°08'02" E. Isąg has the surface area of 395.6 ha and a considerable max. depth of 54.5 m; the mean depth is 14.2 m. The total catchment equals 246.7 km^2 and the land draining directly to the lake equals 4.9 km^2. The direct surroundings are mostly forests (58.3%).

The lakes were examined three times: in the spring (April 26), in the summer (August 24) and in the autumn (October 21) in 2005. Water samples for full range chemical analyses were taken from the sub-surface water layer (1 m under the water table) and from the near-bottom water layer (1 m above the bottom). In the summer, additional samples were taken from metalimnion, over the deepest site of each lake determined with the help of the bathymetric charts and gps. In addition, temperature and oxygen profiles were determined at every meter of the depth. For water sampling a 3.5-l Ruttner apparatus was used with an in-built mercury thermometer (reading accuracy 0.2°C). Chemical analyses of the water were performed in accordance with the methods of HERMANOWICZ et al (1999).

Trophic condition of the lakes was assessed on the ground of the criteria provided by PATALAS (1960b), ZDANOWSKI (1983), HILLBRICHT-ILKOWSKA, WIŚNIEWSKI (1994), FARAŚ-OSTROWSKA, LANGE (1998).

Description of the results and discussion

Water mixing is an important parameter to be considered while assessing the trophic state of a lake. Intensity of the circulation movements determines turnover of nutrients and temperature of the deep water layers. Water movements provide for the nutritional and oxygen needs of organisms but also carry away the metabolism products (AMBROSETTI, BARBANTI 2002).

It is commonly believed that in lakes with lower water dynamics eutrophication is slower and the reservoirs are more resistant to man's influence (GROCHOWSKA, TANDYRAK 2006, WETZEL 2001).

The lakes localised in the nature reserve "Beaver Sanctuary on the Pasłęka River" differ by the morphometric properties (Table 1), thus by the water mass dynamics (GROCHOWSKA et al. 2006). Therefore, the normal conclusion is that eutrophication in these lakes would occur with various intensity.

According to OLSZEWSKI'S (1959) division of lakes dynamics based on the epilimnion range and the duration and intensity of the turnover, Lake Pasłęk is a shallow reservoir with hindered water circulation. According to the criteria of PATALAS (1960a) that refer the theoretical mixing range to the maximal depth, the lake features the static properties of type IV. In the lakes of such kind, the division into thermal layers can be incomplete, as observed in the study in the peak of the summer stagnation 2005. In Lake Pasłęk, the epilimnion was 1 m thick and the max. gradient in the underneath metalimnion was 4.2°C m^{-1} (Table 2).

Table 2

Summer temperature profiles in lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg

Pasłęk		Wymój		Sarąg		Łęguty		ISĄG	
depth (m)	temperature (°C)	depth (m)	temperature (°C)	depth (m)	temperature (°C)	depth (m)	temperature (°C)	depth (m)	temperature (°C)
0	20.8	0	21.2	0	21.1	0	20.6	0	20.4
1	20.4	1	20.6	1	21.1	1	20.6	1	20.4
2	19.2	2	18.2	2	21.0	2	20.6	2	20.4
3	17.2	3	16.8	3	17.8	3	20.6	3	20.3
4	14.8	4	16.2	4	16.9	4	20.6	4	20.3
5	10.6	5	14.8	5	16.4	5	20.6	5	20.3
–	–	6	11.8	6	15.4	6	16.2	6	20.3
–	–	7	8.7	7	13.9	7	9.8	7	20.1
–	–	8	7.4	8	10.4	8	8.8	8	20.0
–	–	9	5.6	9	8.8	9	7.2	9	17.0
–	–	10	5.4	10	8.1	110	7.0	10	14.1
–	–	11	5.2	11	7.7	11	6.6	11	11.1
–	–	12	5.0	12	7.3	12	6.2	12	8.0
–	–	13	4.8	13	7.2	13	6.1	13	8.0
–	–	14	4.8	14	7.1	14	6.0	14	7.8
–	–	15	4.7	15	7.0	15	5.7	15	7.5
–	–	16	4.7	16	7.0	16	5.4	20	7.0
–	–	–	–	–	–	17	5.4	25	6.8
–	–	–	–	–	–	18	5.4	30	6.8
–	–	–	–	–	–	19	5.4	35	6.7
–	–	–	–	–	–	20	5.4	40	6.6
–	–	–	–	–	–	21	5.4	45	6.6
–	–	–	–	–	–	22	5.4	50	6.6

The research of GROCHOWSKA et al. (2006) conducted in 1999, as well as the current studies, have revealed that Lake Wymój is characterised by the limited water dynamics. According to OLSZEWSKI'S criteria (1959) it belongs to bradymictic reservoirs or, following the classification of PATALAS (1960a), it is the static type V. In August 2005 the epilimnion was 21°C and 1 m thick while the thermocline had the max. gradient of 3.1°C m^{-1}. Temperature measured in the cold hypolimnion was only 4.7°C near the bottom (Table 2).

Lake Sarąg is characterised by the average water dynamics and belongs to eumictic reservoirs (OLSZEWSKI 1959) or to the static type III (GROCHOWSKA et al. 2006, PATALAS 1960a). In the peak of the summer 2005 the lake stratified into a 3-m epilimnion with the temp. of 21°C, a metalimnion with the max. gradient of 3.5°C m-1 and a hypolimnion with the temp. from 7.0 to 8.8°C (Table 2).

Lake Łęguty sits in a deep land hollow which is the reason for limited wind access. It has the attributes of a bradymictic reservoir (OLSZEWSKI 1959) or the static type V reservoir (PATALAS 1960a). In the summer, the epilimnion was 5 m deep (temp. 20.6°C) and the thermocline below had the max. gradient of 4.4°C m^{-1}. Temperature measured in the hypolimnion near the bottom was 5.4°C (Table 2).

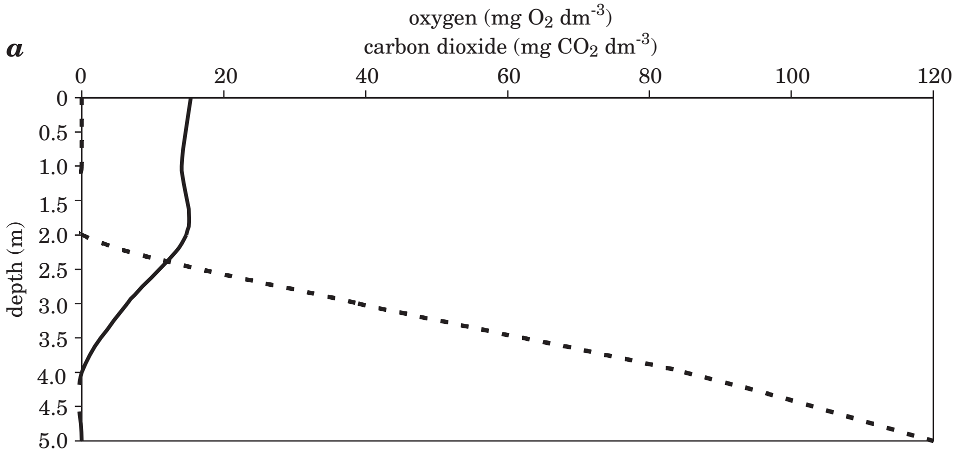
The largest discussed, Lake Isąg, is eumictic (OLSZEWSKI 1959) or the static type III (PATALAS 1960a). In the peak of the summer stagnation determined were the epilimnion of 8 m with the temperature from 20.4 to 20.0°C, the metalimnion of the max. gradient 3.0°C m^{-1} and a voluminous hypolimnion from 12 m depth to the bottom with temperature in the range 8.6–6.6°C (Table 2).

As shown above, water mass dynamics in the analysed lakes are average through poor and allow assuming that the processes of matter circulation in these lakes are not very intense and do not favour primary production. However, the conducted research has not confirmed such assumption. GROCHOWSKA et al. (2006) reports that oxygen settings in a lake depend to a large degree on the intensity of water mixing and the eutrophication level. In many classification systems oxygenation is one of the key criteria for the trophic condition determination (LOSSOW et al. 1979, WETZEL 2001). In the peak of summer stagnation in oligotrophic lakes oxygen content is similar across the whole water column (orthograde oxygen curve). In mezotrophic lakes the maximum or the minimum of oxygen concentration occurs in metalimnion (heterograde oxygen curve, negative or positive). Lastly, in eutrophic lakes oxygen is distributed unevenly across the vertical profile: concentrations near the surface are very high, the drop in metalimnion is very rapid (oxycline), the deficits in the deeper layers are absolute (clinograde oxygen curve) (CHOIŃSKI 1995).

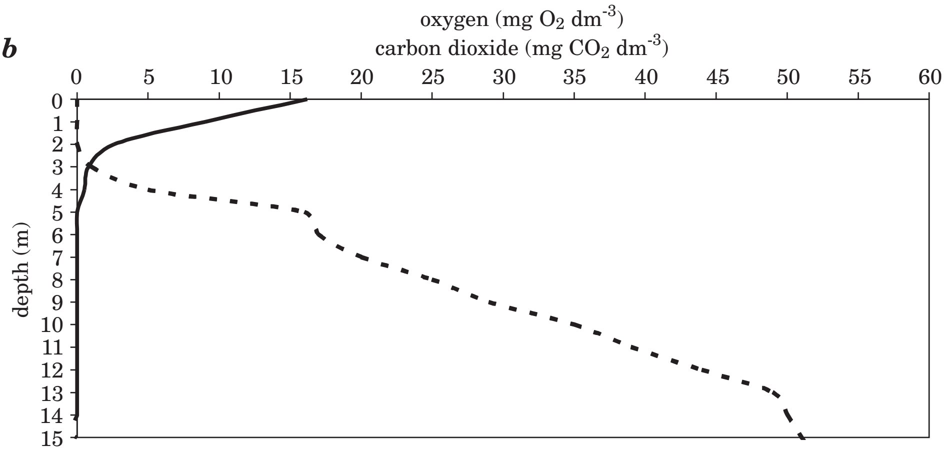
In all discussed lakes, oxygen content in the summer decreased toward the bottom with simultaneous super-oxygenation of the trophogenic water layers (Figure 2).

In Lake Pasłęk, in August, the content of oxygen in the surface water layer was 15.4 mg O_2 dm^{-3} (169.5% saturation). At 3 m depth only 6.4 mg O_2 dm^{-3}

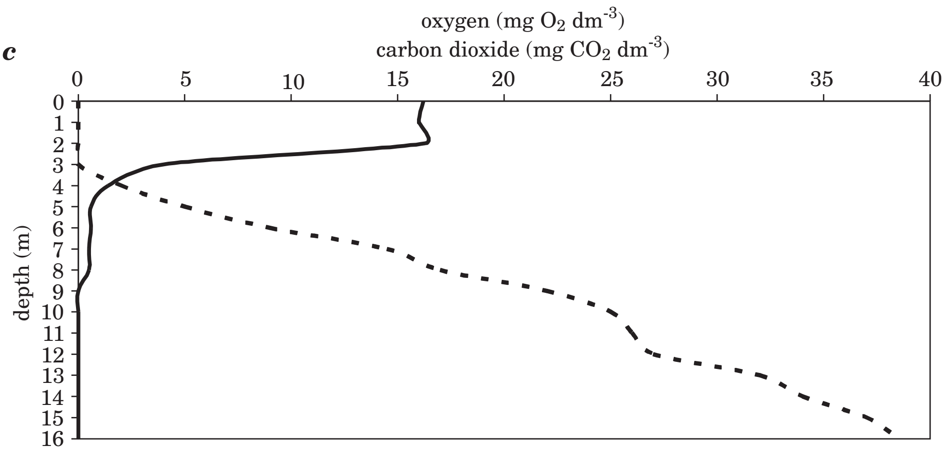
a


oxygen (mg O2 dm-3)
carbon dioxide (mg CO2 dm-3)
0 20 40 60 80 100 120
depth (m)
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0

b


oxygen (mg O2 dm-3)
carbon dioxide (mg CO2 dm-3)
0 5 10 15 20 25 30 35 40 45 50 55 60
depth (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

c


oxygen (mg O2 dm-3)
carbon dioxide (mg CO2 dm-3)
0 5 10 15 20 25 30 35 40
depth (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

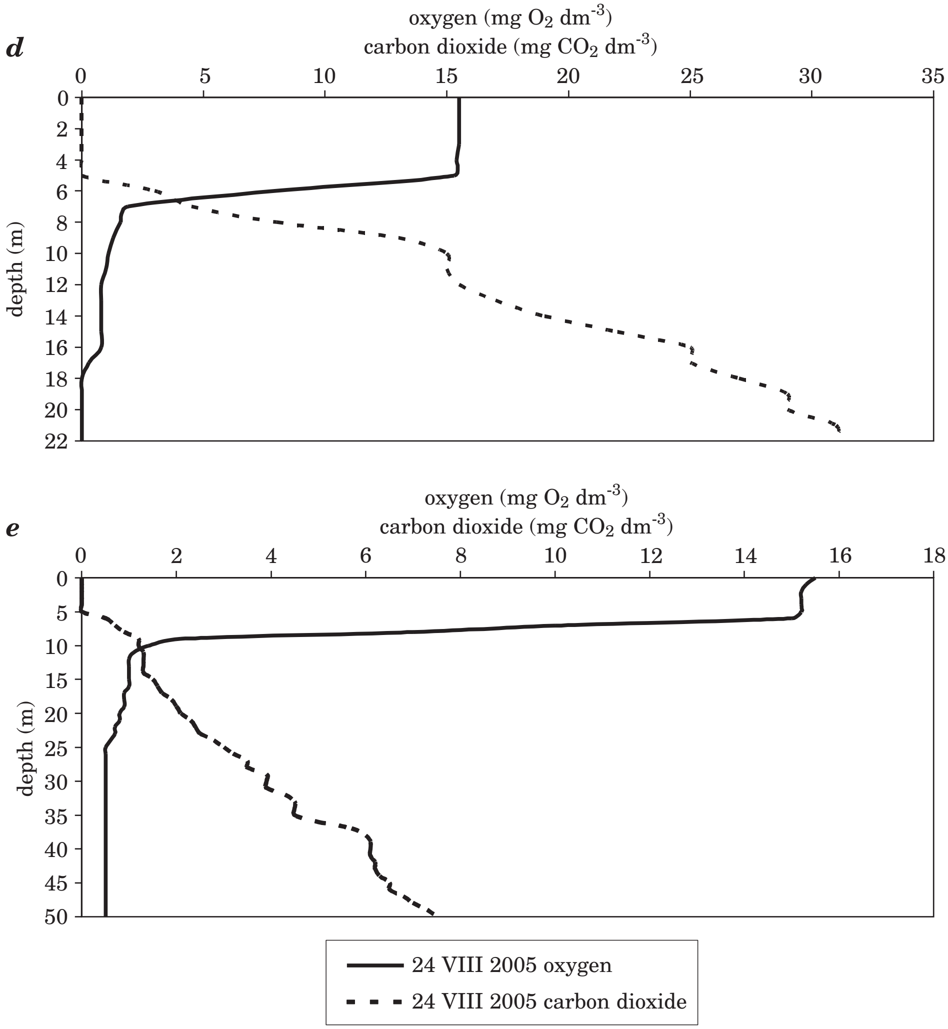


Fig. 2. Summer variation of oxygen and carbon dioxide contents in waters of lakes: *a* – Pasłęk, *b* – Wymój, *c* – Sarąg, *d* – Łęguty, *e* – Isąg

was measured (67.1% saturation) and starting from 4 m depth downward the water was oxygen-deficient (Figure 2a). In the same time, in the upper water layer in Lake Wymój determined was 15.5 mg O_2 dm^{-3} (172.0% saturation) with a rapid drop underneath (oxycline with the max. gradient of 7.2 mg O_2 dm^{-3}). From 6 m depth anoxic conditions occurred (Figure 2b). Comparable situation was observed in Lake Sarąg in which oxygen near the surface was 16.2 mg O_2 dm^{-3} (180.0% saturation). Below was a sharp oxycline with the max. gradient of 12.3 mg O_2 dm^{-3} and from 8 m depth to the bottom oxygen was absent (Figure 2c). In the surface water layers of Lake Łęguty oxygen concentrations oscillated around 15.0 mg O_2 dm^{-3} (170.0% saturation), a large decrease was determined deeper down and a complete deficiency at 18 m depth (Figure 2d). Slightly better were the oxygen conditions observed in Lake Isąg. The epilimnion to 6 m depth was well oxygenated 15.5–15.0 mg O_2 dm^{-3} (approx. 169.0% saturation) and below the concentrations gradually fell to reach the value 0.5 mg O_2 dm^{-3} unchanging from 25 m depth to the bottom (Figure 2e).

Based on the analysis of the oxygen profiles observed in the discussed lakes in the peak of the summer stagnation (oxygen concentrations across the vertical profile represented by an obvious clinograde curve of ABERG and RHODE (1942), it can be unambiguously stated that lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg are heavily eutrophic.

The super saturation with oxygen in the surface layers of the examined lakes was most certainly connected to intensive primary production (KALFF 2002, WETZEL 2001). The simultaneously observed oxygen deficits in the near bottom waters were related to the lytic processes and life processes by the aquatic organisms. Carbon dioxide is strongly correlated to production and decomposition processes. Its distribution in water is different from that of oxygen. Near the surface it is rather scarce but the amount increases with the depth. KAJAK (2001) and CHOJNACKI (1998) found that reduction of free carbon dioxide occurring in the surface waters during the vegetation period is due to intensive primary production and utilization of mineral substances by the autotrophs. The increase toward the bottom is due to the intensive processes of destruction and respiration. This finding has been confirmed in the discussed study. In the summer, free carbon dioxide didn't occur in the surface water layers whereas near the bottom the content reached 120.0 mg CO_2 dm^{-3} in Lake Pasłęk, 52.5 mg CO_2 dm^{-3} in Lake Wymój, 38.5 mg CO_2 dm^{-3} in Lake Sarąg, 31.0 mg CO_2 dm^{-3} in Lake Łęguty, and 7.5 mg CO_2 dm^{-3} in Lake Isąg (Figure 2 a, b, c, d, e). Vertical variability of the carbon dioxide concentrations in the summer in the studied lakes featured the shape of a "reversed" clinograde, as compared to the oxygen clinograde curve. KAJAK (2001) argues that such regularity is the property of very fertile lakes.

The content of free carbon dioxide develops following the pH values, i.e., an increase of the first causes reduction of the second (DOJLIDO 1995). The results obtained in the studies of lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg have confirmed that. When photosynthesis was intense and free carbon dioxide was absent from the surface water layers the reaction of the water was high: 8.78 pH in Lake Pasłęk, 8.93 pH in Lake Wymój, 9.09 pH in Lake Sarąg, 8.30 pH in Lakes Łęguty and Isąg. On the other hand, when the maximal summer concentrations of CO_2 were detected, the reaction was lower:

Table 3

Selected chemical water parameters of lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg

Parameter		Pasłęk			Wymój			Sarąg			Łęguty			Isąg		
		spring	summer	autumn	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn
Reaction (pH)	surface	8.64	8.78	7.82	8.91	8.93	7.86	8.74	9.09	7.88	8.90	8.30	8.00	9.39	8.30	7.89
	bottom	7.69	7.23	7.84	7.70	7.28	7.88	7.70	7.43	7.89	7.37	7.33	7.65	8.04	7.65	7.60
Conductivity (μS cm^{-1})	surface	396	362	438	330	280	354	379	279	342	327	330	392	336	314	343
	bottom	471	599	429	413	436	445	397	419	430	403	432	429	360	369	372
Total phosphorus (mg P dm^{-3})	surface	0.098	0.182	0.188	0.199	0.121	0.182	0.146	0.193	0.252	0.123	0.213	0.415	0.135	0.120	0.150
	bottom	0.165	0.202	0.129	0.348	1.296	1.898	0.121	1.369	1.574	0.114	0.629	0.813	0.176	0.311	0.336
Total nitrogen (mg N dm^{-3})	surface	2.01	1.21	2.50	2.16	0.91	1.70	2.47	1.80	2.0	6.90	2.74	2,71	4.65	2.65	1.55
	bottom	2.61	8.97	2.41	3.51	8.47	5.33	2.44	4.67	5.58	3.92	4.47	3.95	2.80	2.49	1.86

7.23 pH in Lake Pasłęk, 7.28 pH in Lake Wymój, 7.70 pH in Lake Sarąg, 7.33 pH in Lake Łęguty and 7.65 pH in Lake Isąg (Table 3).

Among the most important parameters indicating the trophic condition there is also the penetration of sun rays determined as the visibility of Secchi disc (HÅKANSON et al. 2005). Water transparency is determined by the amount of suspensions and increases along with the abundance of mineral substances that stimulate higher production of organic compounds (VREDE 2005). Secchi disc visibility in most of the examined lakes was very low and assumed the following pattern: Lake Pasłęk from 1.1 to 1.8 m, Lake Wymój from 0.75 to 0.8 m, Lake Sarąg from 0.5 to 0.95 m, Lake Łęguty from 1.05 to 2.30 m, and Lake Isąg from 1.25 to 3.80 m (Figure 3). As already mentioned, transparency of the water depends, among others, on the amount of suspensions thus on the intensity of production. The obtained results confirm the earlier observations by BOROWIAK (2000) and allow concluding that the amount of phytoplankton biomass is the limiting factor for solar radiation penetration in the lake water. The lowest water transparency in lakes Wymój and Sarąg was observed in the peak of the summer stagnation which occurred in parallel to the considerable supersaturation with oxygen in the surface waters, the highest reaction and the absence of free carbon dioxide – all being the parameters indicating intensive photosynthesis (Figure 2a, b, Figure 3, Table 3).

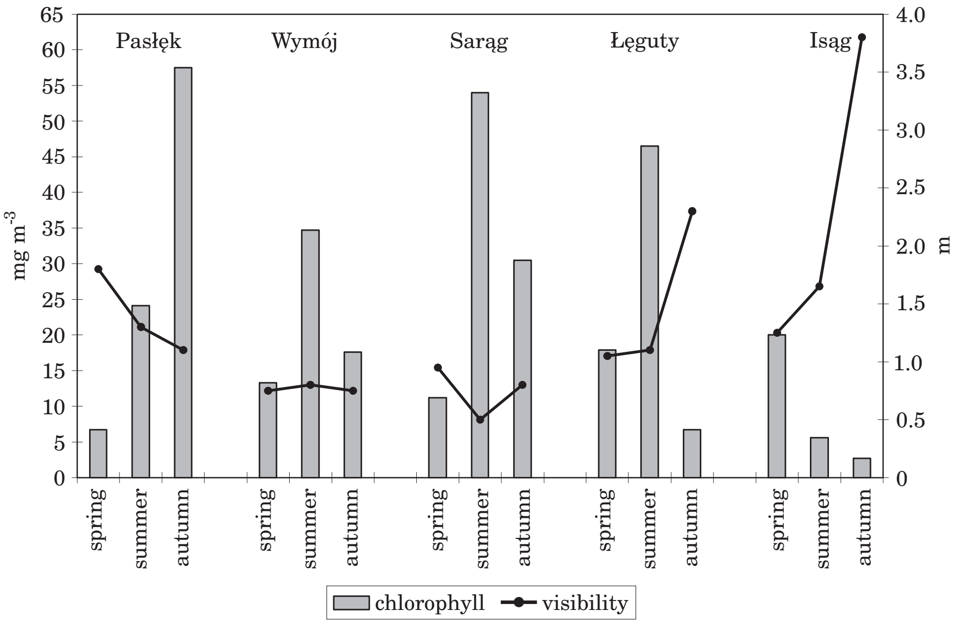


Fig. 3. Changes of chlorophyll a content and Secchi disc visibility in water of lakes located in the nature reserve "Beaver Sanctuary on the Pasłęka River"

In lakes Łęguty and Isąg comparable situation occurred in the spring (April) – Figure 2 d, e, Figure 3, Table 3). Only in Lake Pasłęk the relationships weren't noted (Figure 3, Table 3). In addition, during the studies observed was a very high negative correlation (r = 0.91 in Lake Pasłęk, r = 0.98 in Lake Wymój, r = 0.99 in Lake Sarąg) and a high negative correlation (r = 0.69 in Lake Łęguty, r = 0.74 in Lake Isąg) between the water transparency and the content of chlorophyll a (the best indicator of the intensity of primary production). Increase of the pigment caused by intensive photosynthesis limited the water transparency (Figure 3). Such regularity indicates the high fertility of the examined reservoirs.

Taking into consideration the classification of lakes of FARAŚ-OSTROWSKA and LANGE (1998) based on the depth of Secchi disc visibility, the analysed lakes can be classified as eutrophic – water transparency is below 4 m depth (Figure 3).

When assessing the eutrophication level, it is very important to determine the content of nutrients in the water, especially of nitrogen and phosphorus (BAJKIEWICZ-GRABOWSKA 2002, HILLBRICHT-ILKOWSKA 1999, VREDE 2005).

In Lake Pasłęk, the total nitrogen concentrations ranged from 1.21 to 8.97 mg N dm^{-3} with the higher values occurring usually in the deeper water layers (Table 3). The content of total phosphorus in this lake ranged from 0.098 to 0.202 mg P dm^{-3}. In April and September the values were vertically stratified, with an increase toward the bottom and a reversed trend in the autumn (Table 3). With reference to the nitrogen content, Lake Pasłęk can be described as nitrogen-fertile, type POLY (PATALAS 1960c) whereas according to the classification of HILLBRICHT-ILKOWSKA, WIŚNIEWSKI (1994) based on the visibility of Secchi disc and total phosphorus content and chlorophyll a content, it is eutrophic. Finally, according to ZDANOWSKI'S (1983) criteria, referring to the spring content of phosphorus, Lake Pasłęk can be classified as polytrophic, type IV.

In Lake Wymój, the concentrations of total nitrogen were also very high: from 0.91 to 8.47 mg N dm^{-3}, values characteristic for lakes rich in nitrogen, type POLY (PATALAS 1960b). According to the classification of HILLBRICHT-ILKOWSKA, WIŚNIEWSKI (1994), the lake is heavily eutrophied while following the criteria of ZDANOWSKI (1983) it is polytrophic, type IV because of the total phosphorus content from 0.121 to 1.898 mg P dm^{-3} (Table 3).

The same trophic status, when judged on the content of nitrogen and phosphorus, have lakes Sarąg, Łęguty and Isąg in which the content of total nitrogen developed in the following way: 1.80–5.58 mg N dm^{-3} (Sarąg), 2.74–6.90 mg N dm^{-3} (Łęguty) and 1.55–4.65 mg N dm^{-3}. Notably, the higher values in lakes Sarąg and Łęguty were usually measured near the bottom whereas in Lake Isąg in the surface water layers (Table 3). The content of total phosphorus in these lakes ranged from 0.121 to 1.369 mg P dm^{-3} (Sarąg), from 0.114 to 0.813 mg P dm^{-3} (Łęguty), and from 0.120 to 0.336 mg P dm^{-3} (Isąg) – Table 3 with a tendency to increase toward the bottom.

For the more complete assessment of the eutrophication level, electrolytic conductivity was determined in the studied lakes. This parameter represents inorganic substance from dissociation in the water and indicates the level of water contamination with mineral compounds (CIEŚLIŃSKI 1999, TANDYRAK et al. 2006). MARSZELEWSKI (2005), having examined the lakes in Northern Poland, allocated the group of eutrophic reservoirs with the conductivity in the range from 200 to 400 μS cm^{-1}. In this respect, lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg can be described as eutrophic or heavily eutrophic, as the measured values were contained in the range 279–599 μS cm^{-1} (Table 3).

MAŚLANKA (1998) argues that in high-fertility lakes, stratified thermally in the summer, the seasonal differences in conductivity are visible and displayed by the high values in the tropholytic layer. In all analysed lakes, the vertical stratification of electrolytic conductivity was observed with an increase toward the bottom (Table 3). JANKOWSKI and RZĘTAŁA (1997) hypothesise that high conductivity values might be the effect of the lakes inclusion in the discharge system or the underground feeding, especially from the deep underground water layers. The high values noted in the examined lakes and typical for eutrophic lakes may be related to the flow-through character of these reservoirs. The River Pasłęka which connects the lakes carries in a lot of mineral substances as it drains a vast area with different types of development (GROCHOWSKA, TEODOROWICZ 2006).

Concluding, all discussed lakes are eutrophic, irrespective of their localization in the nature reserve which is a nature protection area. Unfortunately, their catchments are extensive and dominated by arable land or built-up areas which negatively affects the level of mineral and organic substances in the lakes. Eventually, the eutrophication processes are intensified. Finally, the localization of the lakes is very attractive to tourists and anglers.

Conclusions

1. The analysed lakes are characterised by average or hindered water mass dynamics thus the processes of matter turnover are not intense and may not favour the increase of primary production. However, oxygen settings observed in these lakes in the peak of the summer stagnation and displayed by the evident clinograde oxygen curve of ABERG, RHODE (1942) visibly indicate strong eutrophication in lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg. The super saturation with oxygen in the surface water layers is most probably

caused by intensive primary production while the parallel oxygen deficits noted in the near-bottom water result from the lytic processes and life processes of the aquatic organisms.

2. Vertical variability of the carbon dioxide concentrations in the summer in the examined lakes assume the shape of a "reversed" curve compared to the oxygen clinograde. Such regularity is a feature of high-fertility lakes.

3. Taking into consideration the classification of lakes given by FARAŚ-OSTROWSKA, LANGE (1998) based on Secchi disc visibility, the examined lakes can be classified as eutrophic – the water transparency was below 4 m.

4. With regard to nitrogen content, the lakes can be described as rich in nitrogen, type POLY, whereas according to the classification of HILLBRICHT-ILKOWSKA, WIŚNIEWSKI (1994) based on Secchi disc visibility and the amount of total phosphorus and chlorophyll a the lakes are eutrophic.

5. In the division provided by ZDANOWSKI (1983) referring to the spring content of phosphorus, lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg can be classified as polytrophic, type IV of the trophic state.

6. With regard to electrolytic conductivity of the analysed lake waters varying between 279 and 599 μS cm^{-1}, lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg are eutrophic or even strongly eutrophic.

Translated by MONIKA SZEWCZYK

Accepted for print 17.09.2009

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