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Anna HILLBRICHT-ILKOWSKA, Rajmund Jan WIŚNIEWSKI

Department of Hydrobiology, Institute of Ecology, Polish Academy of Sciences, Dziekanów Leśny
(near Warsaw), 05-092 Łomianki, Poland

TROPHIC DIFFERENTIATION OF LAKES OF THE SUWAŁKI LANDSCAPE PARK (NORTH-EASTERN POLAND) AND ITS BUFFER ZONE – PRESENT STATE, CHANGES OVER YEARS, POSITION IN TROPHIC CLASSIFICATION OF LAKES

ABSTRACT: Measurements of physico-chemical parameters (temperature, transparency, oxygen, phosphorus, nitrogen and chlorophyll concentrations) made in summer periods in 25 lakes of Suwałki Landscape Park (north-eastern Poland) have shown that according to Polish and foreign classifications the majority of them are meso or meso-eutrophic, especially deep and/or big lakes like Hańcza, Szurpiły, Szelment Wielki, Jegłówek, Kopane, Perty, Jaczno, Kamendul, Kojle.

Generally, archival documents of SLP lakes show that the big and deep lakes (Hańcza, Szelment Wielki) do not show sings of advanced eutrophication. Whereas in shallow through flow lakes the transparency of waters decreased over the last several tens of years. In the majority of lakes phosphorus accumulation in the waters above the bottom observed in summer was not related directly to oxygen deficit.

KEY WORDS: eutrophication, lakes, lakeland region, Suwałki Landscape Park.

1. INTRODUCTION

The group of 25 natural lakes on the area of Suwałki Landscape Park (SLP) (north-eastern Poland) and in its direct neighbourhood belong to the river Niemen watershed¹ and are geologically and genetically connected with the

¹ In Lithuania.

youngest postglacial lakeland region in Poland, called Suwalszczyzna. They are the most northwards group of natural lakes in Poland. The lakes are located on a relatively small area (study area about 150 km², this including about 65 km² of SLP) (Fig. 1).

The detailed questions in this study are as follows: (1) what is the present trophic state of lakes and their differentiation according to indices used in the trophic classification; (2) what is the rate of their eutrophication (in the light of archival material) and especially of the most valuable, unique lake Hańcza, the deepest (max depth – 108.5 m) lowland lake in Poland.

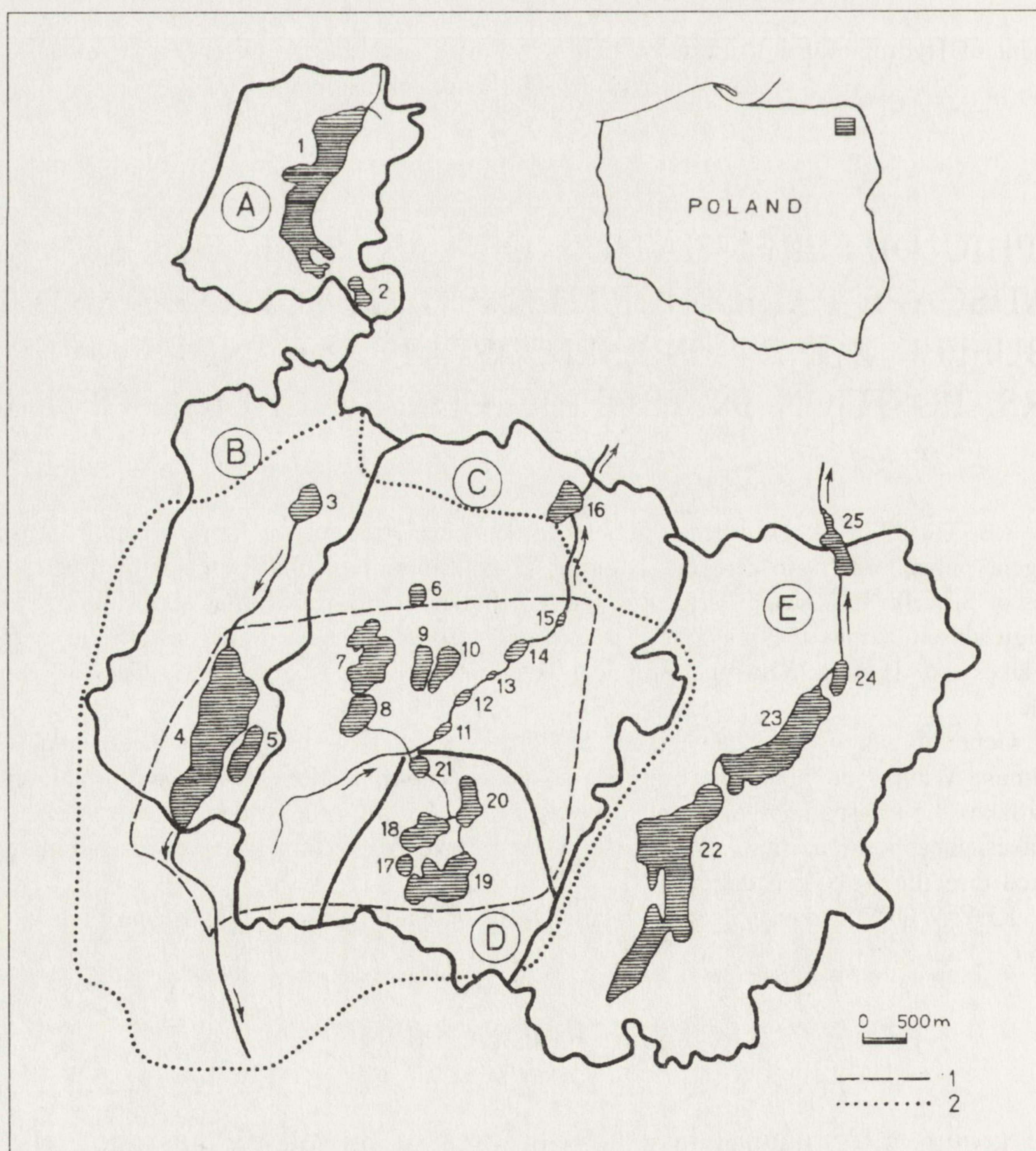


Fig. 1. Simplified outline of investigated area; distribution of lakes (1–25) in main watersheds of the Suwałki Landscape Park (SLP) and its neighbourhood (A–E)

1 – SLP boundaries, 2 – boundaries of the SLP buffer zone, A – the Pissa watershed, B – the Czarna Hańcza watershed – main Szeszupa tributary in SLP, C – the Szeszupa watershed, D – the Szurpiłówka watershed, E – the Szelmentka watershed, names of lakes in Table 1

2. AREA, MATERIAL AND METHODS

The object of investigations conducted in summer periods (August) in the years 1983–1985, were 25 lakes within the SLP and in its neighbourhood, connected with watersheds (see Hillbricht-Ilkowska 1993a) of rivers: Szeszupa, Szelmentka, Czarna Hańcza and Pissa (Fig. 1, Table 1).

The biggest group of 16 lakes were those connected with the river Szeszupa watershed. Among them lakes Gulpin, Okrągłe, Krajwelek, Przechodnie, Postawełek and Pobondzie are in the Szeszupa reach, lakes Kluczysko, Jegłówek, Szurpiły, Kopane and Udziejek are in the course of direct watershed of the Szurpiłówka river – the biggest in SLP tributary of the Szeszupa river, deep lakes like Kamendul, Jaczno, Kojle and Perty are connected with the Szeszupa river by small streams (Fig. 1, Table 1). The list of lakes in the Szeszupa watershed is completed by lake Czarne (near Smolniki) without outflow (Table 1).

In the Czarna Hańcza watershed and directly connected with it are lakes Jegliniszki, Hańcza and Boczniew (Fig. 1, Table 1). Four of the lakes examined: Szelment Wielki, Szelment Mały, Ilgieł and Kupowo are in the Szelmentka course (right tributary of the Szeszupa joining it in Lithuania) (Fig. 1, Table 1). Two of the lakes examined: Wizańny and Wistuć belong to the Pissa watershed (by means of lake Wysztyńskie in Lithuania) (Fig. 1, Table 1).

The lakes examined differ greatly as regards morphometry (Table 1). Among them are lakes big and deep (maximum depth over 25 m), including the deepest in Poland lake Hańcza (maximum depth 108.5 m) which is the reserve (the lake and bank are under protection) recorded in the world list of lakes under protection (Luther and Różka 1971). There are also small and very shallow lakes (to 2 m of depth) such as Wistuć and Jegliniszki.

The lakes examined differ also in their hydrological system (Bajkiewicz-Grabowska 1993). The flow-through lakes are distinguished, directly connected with the Szeszupa and also lakes in the low reach of the Szelmentka and Szurpiłówka. Annual exchange of water in these lakes is usually above 10, whereas the annual hydraulic load – several tens and even several hundreds metres per year (Table 1). In other lakes (where water exchange could be estimated) these indices are much lower and annual hydraulic load did not exceed $20 \text{ m} \cdot \text{yr}^{-1}$.

In summer (August), once in each lake, at 1–3 station, depending on lake size and fragmentation, water transparency (Secchi disc readings, SD) was determined, vertical stratification of temperature and oxygen concentration (YSI model oxygen meter) were measured, and water samples were taken from the surface and above the bottom for chemical analyses. The electrolytic conductivity (EC) was determined and the concentration was measured of: (1) total phosphorus in unfiltered (TP) and P dissolved (P diss) in filtered water through filter paper Whatmann GF/F (wet digestion in perchloric acid and determination by molybdenum blue method using

Table 1. Lakes of Suwałki Landscape Park and its neighbourhood – basic morphometric data (material from the Institute of Inland Fishery and others sources)

Watershed ¹ (A–E) Lake (1–25)	A (ha)	V (10 ³ · m ³)	Z (m)	Z max (m)	L (shoreline development)	Length of shoreline (m)	Percent of lake area overgrown by vegetation		Flushing rate ² (Q/V)	qs ² hydraulic load (m · yr ⁻¹)
							emergent	sub- merged		
A. Pissa r.										
1. Wiżajny	393.1	7746.1	2.6	5.3	2.46	14150	11.0	18.9		
2. Wistuć	(25) ³			(2.0) ³						
B. Czarna Hańcza r.										
3. Jegliniszki	16.0	198.0	1.2	2.4	1.66	2200	8.7		7.8	9.4
4. Hańcza	311.4	120364.1	38.7	108.5	1.88	11750			0.07	2.7
5. Boczniew	18.2	324.1	1.7	4.3	2.09	3175				
C. Szeszupa r.										
6. Czarne near Smolniki	6.5			6.5	1.18					
7. Jaczno	36.7	3964.6	10.0	25.0	2.24	5000			0.6	6.3
8. Kamendul	25.5	1730.5	6.8	24.5	1.30	2300			2.2	14.9
9. Kojle	15.4	1394.0 ⁵	9.05	33.0		1875 ⁶			0.3	2.7
10. Perty	20.0	1384.5 ⁵	6.9	32.0	1.73 ⁴				0.4	2.8
11. Gulbin	7.6 (7.4) ³	268.0 (265.8) ³	3.6 (5.6)	9.4	1.23	1125 ⁶			40	145.0
12. Okragłe	14.2 (15.8)	688.8	4.7 (4.4)	8.0 (7.0)	1.19				15	70.5
13. Krajwelek	9.6 (9.5)	316.4 (474.1)	3.3	7.2 (6.0)	1.37				(44)	145.2

14. Przechodnie	25.9 (25.5)	831.3	3.3	6.4 (5.4)	1.21			16	52.2
15. Postawełek	3.45	91.9	2.6	5.3 (4.8)				(264)	696.9
16. Pobondzie	52.3 (53.1)	1918.0	3.6	10.0	1.99		16.5	38.2	(30) 108.0
D. Szurpiłówka r.									
17. Kluczysko	3.5 (3.6) ³	212.1	5.8	(13.6) ³					
18. Jegłówek	20.3 (19.6)	1878.6	9.6	(26.6)		2655 ⁶		0.2	1.7
19. Szurpiły	81.6 (80.9)	8168.0	10.0	46.8	2.27	7000 ⁶		0.3	2.7
20. Kopane	15.19	851.8 (821.0)	5.6	18.7	1.43	1925 ⁶		3.1	17.4
21. Udziejek	7.01 (6.1)	228.9	3.8	7.2		996 ⁶		13.4	50.2
E. Szelmentka r.									
22. Szelment Wielki	356.2	53492.0	15.0	45.0	2.86	19100	3.3	25.0	0.1 1.4
23. Szelment Mały	168.5	12577.3	7.5	28.5	2.12 (2.02) ⁴	9525		2.5	18.5
24. Iłgieł	17.1	698.9	4.1	9.7	1.67 (1.51) ⁴	2450	14.6	28.6	50.0 205.0
25. Kupowo	32.8	1625.0	5.0	13.2	1.84 (1.97) ⁴	3725	8.2	48.4	22.0 110.0

¹ See Fig. 1, ² Acc. to Bajkiewicz-Grabowska (1993), data and additional information (in brackets), ³ Data in brackets are those from present investigation, ⁴ Acc. to Stangenberg 1936, 1937, ⁵ Acc. to Mackiewicz 1977, ⁶ Acc. to Jankowski

stannous chloride as a reducing agent); (2) sum of organic and ammonium forms of nitrogen in unfiltered (TKN) and filtered (KN diss.) (standard Kjeldahl combustion with subsequent analysis of resulting ammonia using the indophenol blue method); (3) nitrate and nitrite nitrogen forms in unfiltered water (N-NO_3 and N-NO_2) (analysed with phenoldisulphonic acid after evaporation of water sample to dryness); (4) seston (dry weight at 105°C of suspension left on filter paper Whatmann GF/F after filtering water); (5) Ca, Mg, total Fe (tot-Fe), K and Na.

Concentration of total nitrogen (TN) was estimated as a sum of TKN, N-NO_3 and N-NO_2 , of dissolved nitrogen (N diss) as a sum of KN diss. N-NO_3 and N-NO_2 . Adequate differences of phosphorus and nitrogen in filtered and unfiltered water were estimated as the particulate forms and this in turn allowed to estimate the percentage of these two elements in seston. On the basis of temperature and oxygen concentration measurements, the rate of oxygen consumption for an average litre of hypolimnion water was determined (volume deficit). It was assumed that thermal stratification in lakes examined started at the beginning of May and temperature at that moment was 5°C in the entire water column, whereas oxygen saturation attained 100%.

Chlorophyll a concentration, abundance, biomass and taxonomic composition of plankton were also analysed (Karabin and Ejsmont-Karabin 1993, Simm unpublished data).

Archival data, especially from papers (Stangenberg 1936, 1937) from the nineteen-thirties on chemical composition and lake transparency were collected, as well as data of local water quality control agencies collected in the nineteen-seventies for some lakes including those found in the Atlas of Lake Water Quality (Cydzik et al. 1982).

3. RESULTS

3.1. TROPHIC INDICES OF LAKE WATERS AND THEIR POSITION IN TROPHIC LAKE CLASSIFICATION

The analysis of the group of 25 lakes against studies of Kajak (1983) and Zdanowski (1983) (Table 2) and the trophic classification of lakes (Hillbricht-Ilkowska and Kajak 1986) based on summer and surface layer values of four basic parameters: TP (primary parameter), SD, chlorophyll a and total biomass (wet wt.) of phytoplankton, shows a relatively weak eutrophication of lakes examined. All lakes answering this classification (apart from dystrophic and bog lakes) are in the I class of trophy or transitory I/II including deeper lakes stratified in summer (dimictic) as well as shallow ones with a tendency for polymixis (polymictic) (Table 3). Usually this is decided by at least two or three of the above four parameters. In the majority of lakes TP concentration is usually less than $100 \mu\text{g} \cdot \text{l}^{-1}$, chlorophyll a – less than $10 \mu\text{g} \cdot \text{l}^{-1}$, biomass of algae – less than

Table 2. Trophy classes of lowland harmonious* lakes of temperate climate acc. to Hillbricht-Ilkowska and Kajak (1986) and Hillbricht-Ilkowska (1990a)**

Class of trophy	Values in summer			Surface waters, biomass phytoplankton fresh wt. (mg · l ⁻¹)
	TP (mg · l ⁻¹)	SD (m)	chl a (μg · l ⁻¹)	
Dimitic lakes (D):				
DI. mesotrophic	≤ 0.05	≥ 3	≤ 10	< 10
DII. moderately eutrophic	≤ 0.100	< 3	≤ 30	≤ 20
DIII. highly eutrophic	> 0.100	≤ 2	> 30	> 20
Polymictic lakes (P)				
PI. mesotrophic and/or moderately eutrophic	≤ 0.100	≤ 2	≤ 30	≤ 30
PII. highly eutrophic	≤ 0.300	≤ 2	≤ 100	≤ 100
PIII. hypertrophic	> 0.300	≤ 1	> 100	> 100

*Disharmonious lakes, e.g., dystrophic or other "stress" ones can not be classified to this system.

**Acc. to studies of Kajak (1983) and Zdanowski (1983).

$5.0 \text{ mg} \cdot \text{l}^{-1}$, whereas visibility (SD) equals or exceeds 2.0 m. Generally speaking, the whole collection of lakes in the region investigated should be considered as mesotrophic or moderately eutrophic lakes; highly eutrophic lakes do not occur as well as the more hypertrophic ones.

Among lakes examined some are especially valuable because of water purity and low trophy, and these are deep mesotrophic lakes such as: Szelment Wielki, Szelment Mały, Jeglówek, Szurpiły, Kamendul, Jaczno, Kojle, Perty and unique – α -mesotrophic lake Hańcza (distinguished by Stangenberg 1936) of a highest transparency (SD = 8.5) and lowest chlorophyll concentration and phytoplankton biomass. Similar characters of distinct mesotrophy can be observed in two shallow lakes connected with lake Hańcza watershed – Jegliniszki and Boczniel and also lake Kluczysko connected with lake Szurpiły (Table 3).

All the above mentioned deep mesotrophic lakes show also oxygen stratification of negative heterograde type (decrease of oxygen in metalimnion, but no deficit above the bottom) as is the case of lake Szelment Wielki, or – a positive heterograde (increase of oxygen concentration in metalimnion and lack of deficit over the bottom) as is the case of lakes Hańcza, Szurpiły, Jeglówek and Szelment Mały (Fig. 2a).

Table 3. Lakes of Suwałki Landscape Park and its vicinity

Watershed ¹ (I–V) Lake (1–25)	SD (m)	TP (mg · l ⁻¹)	TN (mg · l ⁻¹)	TN:TP	chl ² (µg · l ⁻¹) (epil)	Carlson's trophic indices ³		
						(SD)	(TP)	(chl)
A. Pissa r.								
1. Wizajny	1.0	0.088	1.704	20	32.1	60	69	65
2. Wistuć	0.65	0.096	2.812	30	36.3	66	70	66
B. Czarna Hańcza								
3. Jegleniszki	2.0	0.040	1.328	33	9.9		57	53
	(to the bottom)							
4. Hańcza ⁷	8.5	0.034	1.044	31	(0.1) ⁵	29	55	8.0
5. Boczniel	2.0	0.048	1.203	25	(0.1) ⁵		60	8.0
	(to the bottom)							
C. Szeszupa r.								
6. Czarne near Smolniki	2.3	0.240	0.710	3.0	21.4	48	83	60
7. Jaczno	3.8	0.044	1.031	23	2.9	40	59	41
8. Kamenduł	2.7	0.088	1.292	14	–	46	69	–
9. Kojle	5.3	0.030	0.864	29	2.9	36	54	41
10. Perty	4.2	0.016	1.082	67	0.7	39	44	27
11. Gulbin	1.9	0.040	0.760	19	16.4	51	57	58
12. Okrągłe	1.75	0.052	0.800	15	–	52	61	–
13. Krajwelek	1.65	0.058	0.800	17	44.5	53	63	68
14. Przechodnie	1.5	0.048	1.105	23	24.0	54	60	62
15. Postawelek	1.7	0.032	0.981	31	14.1	53	54	57
16. Pobondzie	1.7	0.048	1.012	21	18.3	52	60	59
D. Szurpiłówka r.								
17. Kluczysko	1.9	0.036	0.797	22	1.0	51	56	31
18. Jegłówek	6.1	0.024	0.770	32	1.1	34	50	32
19. Szurpiły ⁷	4.7	0.031	0.602	19	1.4	38	54	32
20. Kopane	3.0	0.040	0.737	18	4.8	44	57	46
21. Udziejek	1.85	0.048	0.867	18	38.7	51	60	66
E. Szelmentka r.								
22. Szelment Wielki ⁷	6.4	0.031	0.935	30	5.5	33	54	48
23. Szelment Mały ⁷	3.0	0.070	0.618	9	6.7	44	65	49
24. Iłgieł	2.25	0.232	0.581	2.5	10.7	48	83	54
25. Kupowo	2.1	0.148	1.369	9	21.5	49	76	60

¹See Fig. 1, ²Acc. to Simm (unpublished data), ³The so-called Lake Trophic Index after Carlson (1977), ⁴Acc. to trophic classification based on TP (primary parameter) and SD and chlorophyll concentration (secondary parameters) acc. to Hillbricht-Ilkowska (1989), P – polymictic, D – dimictic, ⁵Chlorophyll measurement below the apparatus sensitivity, i.e. 1 µg, for estimations of

– basic trophic data (August, epilimnion)

Oxygen stratification type ⁶	Oxygen over the bottom (mg · l ⁻¹)	Rate of oxygen decrease in the hypolim.(µgO ₂ · l ⁻¹ per day)	Biomass of algae ² (mg · l ⁻¹)	Mictic type ⁴	Trophic type ⁴	Limnological type acc. to Stangenberg (1936, 1937)
regular decrease to the bottom	0		4.8	P	I/II	
	0		13.8	P	I/II	
no stratification	8		0.5	P	I	pond
+O ₂ (metalimn.)	5–8	43–58	0.1	D	I	α-mesotroph.
no stratification	8		0.4	P	I	
decrease in hypolimnion	0	128	1.7	–	–	peat lake
+O ₂ metalimnion	0	115	0.4	D	I	
+O ₂ metalimn.	0	128	1.3	D	II	eutroph.
+O ₂ metalimn.	0	121	0.6	D	I	
+O ₂ metalimn.	0	121	0.2	D	I	β-mesotroph.
regular decrease to the bottom	0	133	2.3	P	I	pond
"	0	127	2.1	P	I	"
"	0	132	3.2	P	I/II	"
"	0	132	6.2	P	I	"
"	0	131		P	I	"
"	0	130	1.8	P	I	"
decr. in hypolimn.	0	130	2.4	D	I/II	
+O ₂ (metalimn.)	3	80	0.1	D	I	
"	0–5	80–108	0.3	D	I	
decr. in hypolimn.	0	128	1.4	D	I	eutroph.
"	0	130	3.1	P	I/II	
–O ₂ (metalimn.)	5–8	60–75	0.5	D	I	α-mesotroph.
"	0–1	120–123	1.3	D	I/II	β-mesotroph.
decr. in hypolimn.	0		5.0	P	I/II	eutroph.
"	0	129	4.7	P	I/II	eutroph.

trophic indices 0.1 µg · l⁻¹ is assumed, ⁶–O₂, +O₂, decrease or increase, respectively of oxygen concentration in the metalimnion, decrease in hypolimnion – oxygen decrease in hypolimnion, regular decrease to the bottom – gradual O₂ decrease from the surface to the bottom, ⁷ mean values of 2–3 stations for at least one parameter.

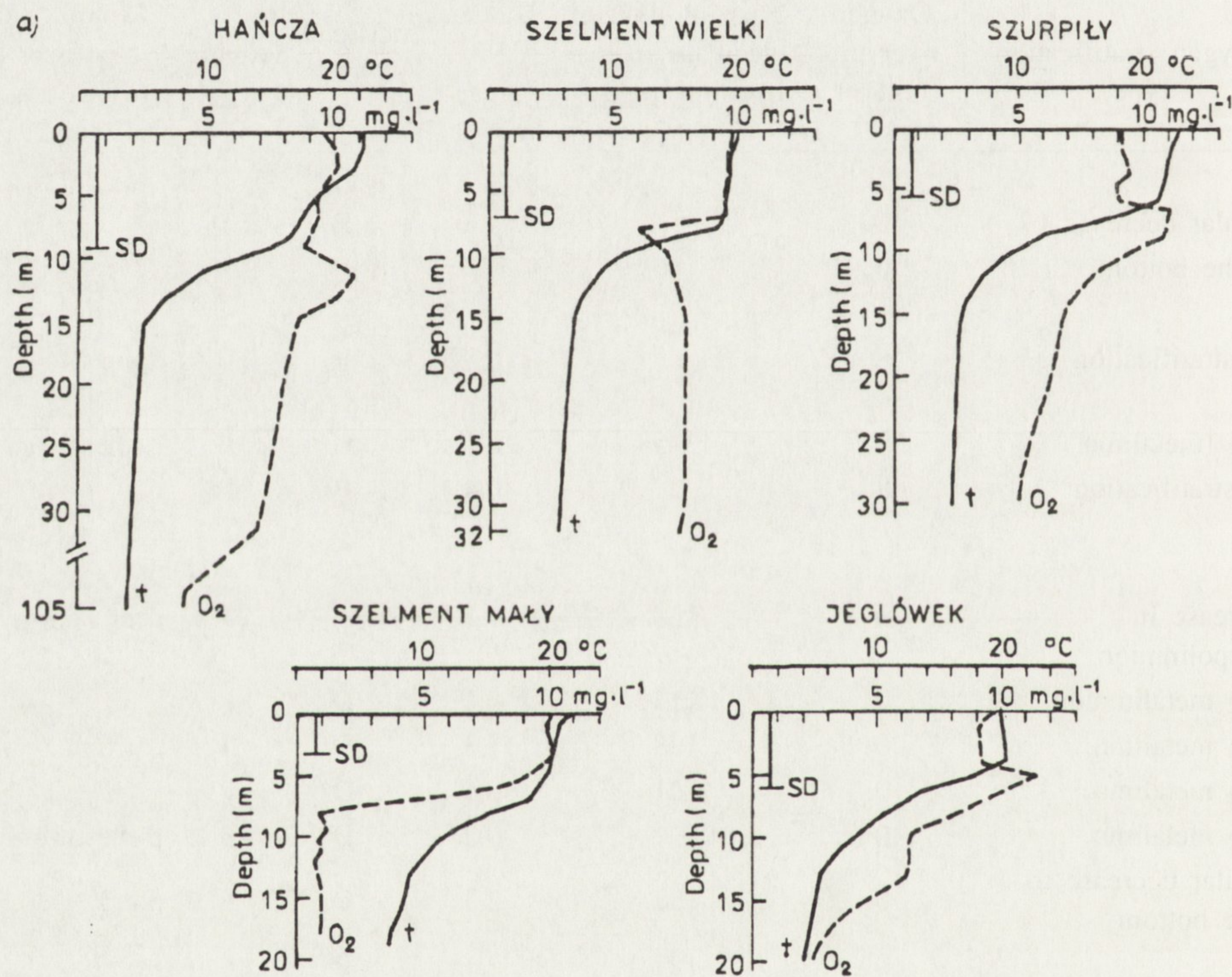
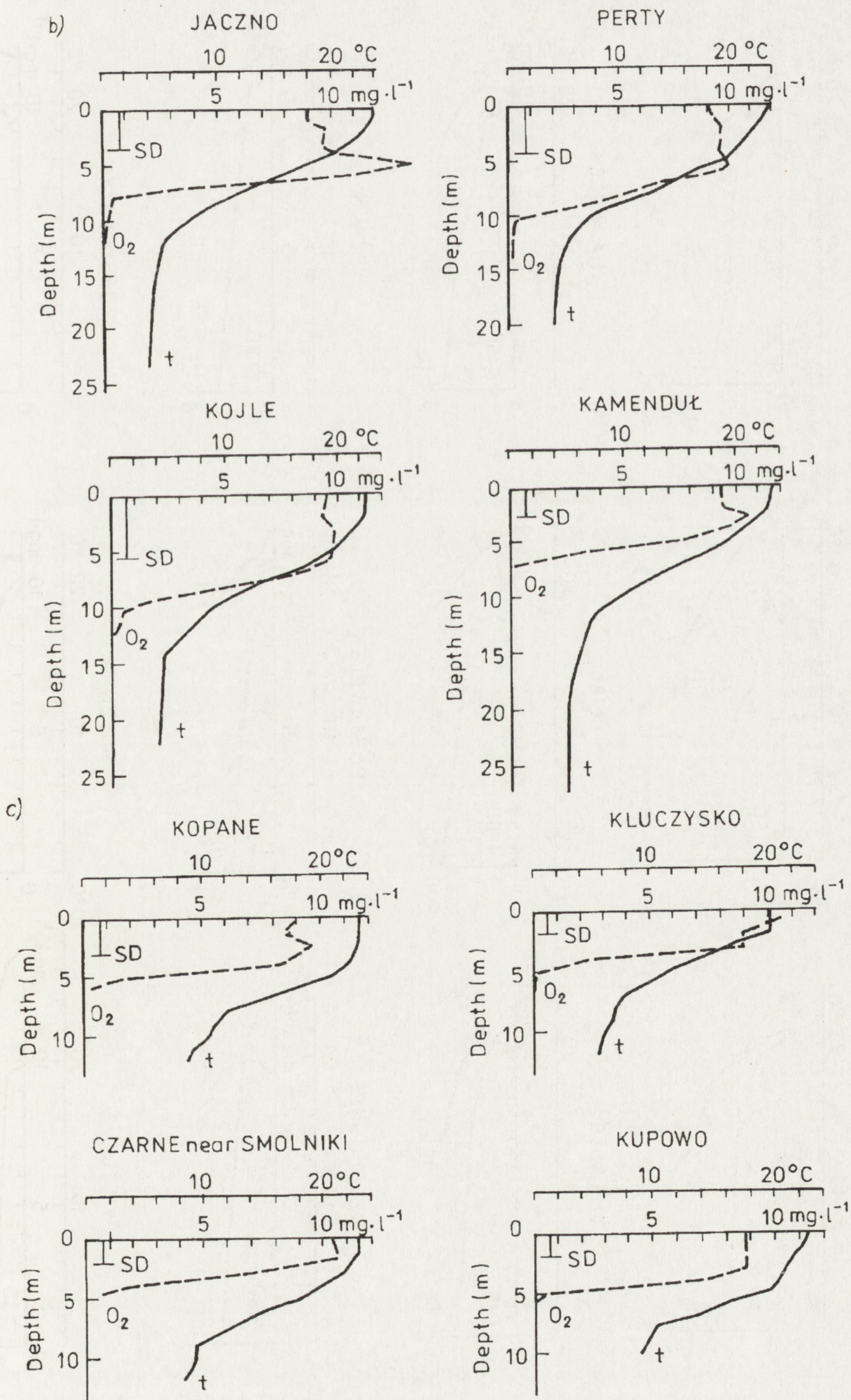
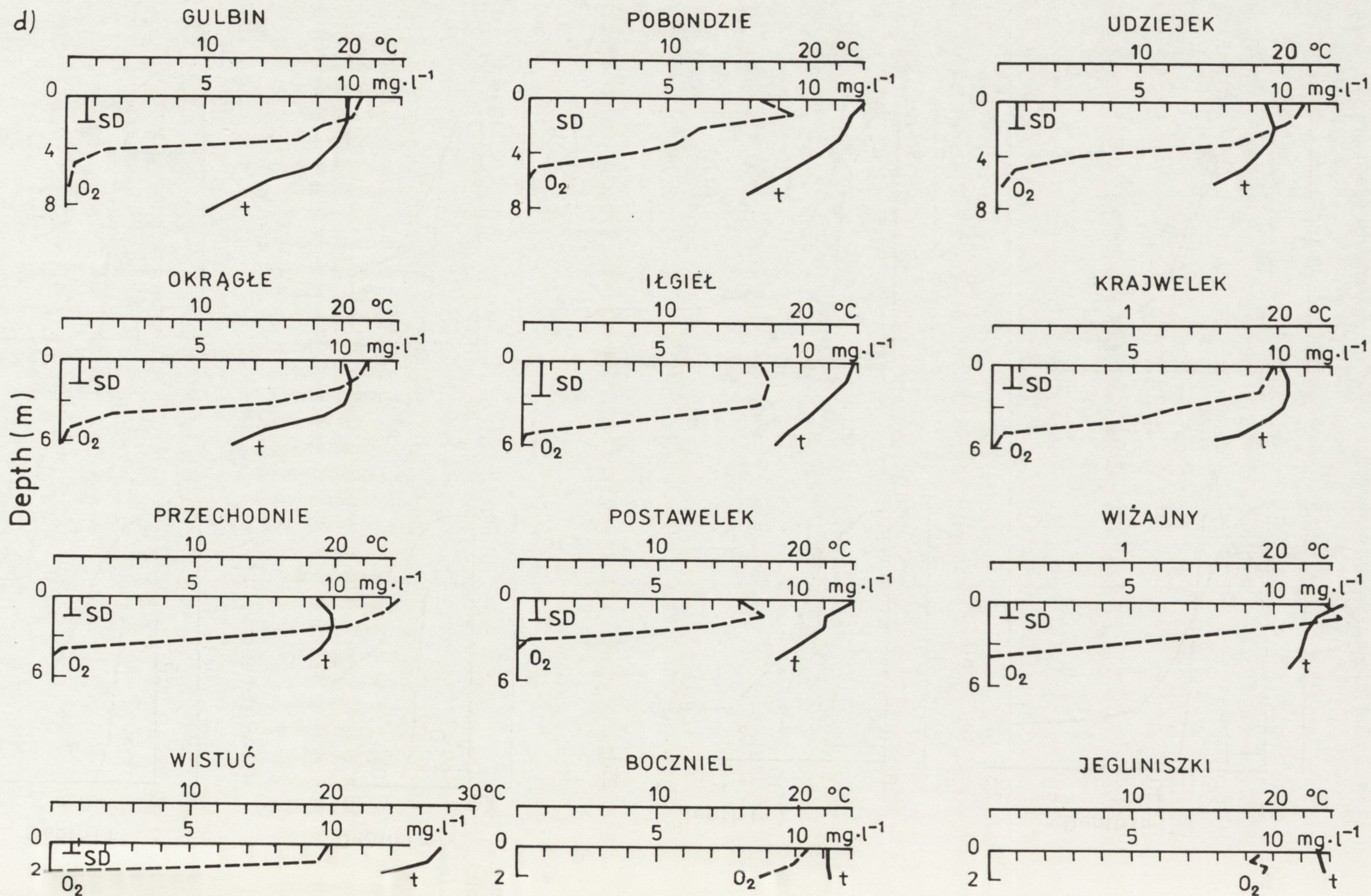


Fig. 2. Thermal and oxygen stratification in summer in lakes of Suwałki Landscape Park and its buffer zone

a – deep mesotrophic lakes with oxygenated hypolimnion, b – deep mesotrophic lakes with oxygen deficit in the hypolimnion, c – lakes with oxygen deficit in meta- and hypolimnion, d – polymictic lakes, t – temperature (°C), O₂ – oxygen concentration (mg · l⁻¹), SD – Secchi disc reading (m)





In four deep lakes of the Szeszupa watershed: Kamendul, Jaczno, Kojle and Perty there is a distinct increase of oxygen concentration in the metalimnion, but in hypolimnion it gradually decreases till exhaustion in the near bottom layer (Fig. 2b). The rate of oxygen decrease in hypolimnion is about $120 \mu\text{g} \cdot \text{l}^{-1}$ per day, i.e., almost the same as in more eutrophic lakes (Table 3). Such oxygen stratification is a consequence of high value of the depth to surface ratio and low exchange rate of water in these lakes (Table 1). It causes fast oxygen exhaustion in hypolimnion, even at a low productivity of surface layers (low concentrations of chlorophyll and algal biomass and high transparency) (Table 3).

In deep mesotrophic lakes as well as in the two shallow mesotrophic ones connected with lake Hańcza the TN:TP weight ratio in surface waters in summer was close to or exceeded 20 (Table 3). It proves a relative phosphorus deficit and may be also a factor maintaining low trophic state of these lakes (Kajak 1983, Zdankowski 1983).

The indices of the state of trophy of lakes TSI acc. to Carlson (1977) based on SD, chlorophyll or TP concentration are usually less than 50 for the above deep mesotrophic lakes (Table 3), i.e., below the limit value accepted for meso-eutrophy, which is 45–55 according to Carlson's classification. However, it should be pointed out that the values of these indices calculated on the basis of three trophic parameters already mentioned are sometimes quite different, usually indices based on TP concentration are higher (Table 2).

Some of the 25 lakes show a more advanced eutrophication in relation to above discussed mesotrophic lakes, because of their shallowness and low water retention. This concern first of all six relatively shallow flow-through lakes of the Szeszupa (lakes Nos 11–16, Table 3), characterized by low transparency (SD below 2 m) (Table 3), higher chlorophyll concentration and regular decrease of oxygen from the surface to the bottom with the deficit over the bottom (Fig. 2d). All these Carlson's indices indicate values over 50. Stangenberg (1936, 1937) has included all these lakes to pond-type ones.

The flow-through and shallow lakes situated in the lower reach of the Szelmentka (Iłgieł and Kupowo) and the Szurpiłówka (lake Udziejek) and the big and relatively shallow lakes Wiżajny and Wistuć (natural pond) as well as the dystrophic lake Czarne (Table 3) belong also to the group of more eutrophic lakes. In these lakes, there were either very high TP (Iłgieł and Kupowo) or chlorophyll concentrations (Wiżajny, Wistuć, Udziejek, Czarne) or of phytoplankton biomass (of the order of few and more $\text{mg} \cdot \text{l}^{-1}$) (Table 3). The majority of Carlson indices attain for these lakes values exceeding 50 and sometimes even 60 (Table 3). Oxygen content drops regularly already in the metalimnion and usually there is no oxygen over the bottom. The rate of oxygen decrease in the hypolimnion is (approximately) about $130 \mu\text{g} \cdot \text{l}^{-1}$ per day.

The TN:TP ratio in this group of lakes is much differentiated. Generally it does not differ much from the values for deep mesotrophic lakes, and in some cases (lakes Czarne, Iłgieł, Kupowo) it attains very low values (Table 3).

Interesting is the comparison of values of some indices of trophic state of SLP lakes with boundary values used in OECD trophic classification of lakes and dam reservoirs suggested by Vollenweider and based on investigations of a great number (several hundred) of water bodies and commonly used in different countries (Table 4). The last version of this classification (Vollenweider 1989) takes into consideration both the average annual values of the basic parameters for the trophic state as well as their extreme values.

Assuming that chlorophyll concentrations recorded in Suwałki lakes in August approximate the maximal values for these lakes and SD – the minimal ones (Table 3), it can be said that the majority of SLP lakes remain within the mesotrophic or oligotrophic category if at least one of the compared indices (i.e., SD, chlorophyll and oxygen over the bottom) is taken into consideration. In the case of lakes Hańcza and Szelment Wielki all the indices compared place them in the oligotrophic category. An exception are four lakes (Jaczno, Perty, Kojle and Kamenduł) which are mesotrophic in terms of chlorophyll and SD concentrations, but the eutrophic in terms of oxygen deficit above the bottom.

Among examined lakes only five: Kupowo, Krajwelek, Postawelek, Przechodnie and Udziejek have chlorophyll concentrations and/or SD and oxygen deficit placing them in the category of eutrophic lakes, whereas the two further ones – Wistuć and Wizajny indicate a consistent eutrophic character concerning all three indices (Table 3 and 4).

3.2. MULTIANNUAL VARIABILITY OF TROPHIC STATE OF LAKES

Measurements of water transparency in lakes in the nineteen-thirties (Stangenberg 1936, 1937) compared with data obtained for the same lakes nowadays (Table 5) show a surprising lack of basic changes in Secchi disc readings over half a century. This concerns mostly deep mesotrophic lakes as Hańcza, Jeglówek, Szurpiły, Kamenduł, Perty, Szelment Wielki and some shallower ones like Wizajny and Jegliniszki (Table 5).

However, a decrease in transparency, slight but stable, is displayed by almost all flow-trough lakes of the Szeszupa river. This decrease is stronger the lower is the position of the lake in the river reach (Table 5). Also a double decrease in transparency is shown by lake Szelment Mały and this change is convergent with the changes in oxygen conditions in the hypolimnion. When comparing data on the percentage of oxygen saturation in the hypolimnion in 1975 (Cydzik et al. 1982) with data for 1985 (present paper) the following values (range for stations) for both Szelment lakes were obtained:

	Szelment Wielki	Szelment Mały
1975	48–52	44–46
1985	35–63	0.6–8

Table 4. Boundary values of various parameters assumed in trophic classification of water bodies and lakes by OECD 1982 (after Vollenweider 1989)

Trophic category	TP* (mg · m ⁻³)	Chlorophyll a (mg · m ⁻³)		SD (m)		Percent of oxygen saturation over the bottom (dependent of mean depth)
		mean-annual	maximal	mean-annual	minimal	
Ultra-oligotrophic	≤ 4.0	≤ 1.0	≤ 2.5	≤ 12.0	≤ 6.0	90
Oligotrophic	≤ 10.0	≤ 2.5	≤ 8.0	≤ 6.0	≥ 3.0	80
Mesotrophic	10–35	2.5–8	8–25	6–3	3–1.5	40–89
Eutrophic	35–100	8–25	25–75	3–1.5	1.5–0.7	40–0
Hypertrophic	≥ 100	> 25	> 75	< 1.5	< 0.7	10–0

*Mean annual value.

Table 5. Comparison of water transparency (Secchi disc readings in metres) of lakes of Suwałki Landscape Park, acc. to data of Stangenberg (1936, 1937) and present investigations (1983–1989)

Lake	1935–1936	1983–1985
Wiżajny	0.8	1.0
Jegliniszki	1.5	2.0 to the bottom
Hańcza	8.2	8.5
Czarne near Smolniki	2.8	2.3
Kamendul	3.0	2.7
Perty	3.6	4.2
Gulbin	1.7	1.9
Okągłe	2.0	1.75
Krajwelek	2.0	1.65
Przechodnie	2.7	1.5
Postawelek	3.2	1.6
Pobondzie	4.0	1.7
Jeglówek	1.5	2.0
Szurpiły (main part of the lake)	6.0	6.0
Kopane	3.1	3.0
Szelment Wielki	6.4	6.4
Szelment Mały	6.0	3.0
Ilgieł	2.3	2.25
Kupowo	2.9	2.1

This indicates an increasing oxygen consumption in the hypolimnion of Szelment Mały. In lake Szelment Wielki, in which SD did not change, probably since investigations of Stangenberg, the increase of oxygen consumption in the hypolimnion is not observed in the last 10 years.

Lake Hańcza because of its unique importance for Polish limnology was examined many times over last 60 years. The selected data characterizing the trophy of this lake is presented in Table 6, whereas Table 7 provides detailed data on concentration of nutrients in the surface and over the bottom layers in the last 7 years.

Table 6. Values of some trophy indices for waters of lake Hańcza in different years (July-August)

Indice	Year									
	1925	1931	1935	1955	1956	1957	1958	1973	1977 ⁷	1984 ⁸
Secchi disc readings (m)	7.5 ¹	6.5 ¹	8.2 ²	8.3 ³	7.9 ³	8.0 ³	5.5 ³			8–9
Phytoplankton biomass (mg · l ⁻¹ fresh wt)								2.0 ⁴		0.04–0.06
Chlorophyll a (µg · l ⁻¹)					3.0 ⁵ –1.5			1.6 ⁴	~0.01	
Seston (mg · l ⁻¹ dry wt)					0.15 ⁵ –0.24				0.01–1.05	
Changes in oxygen concentration in metalimnion ⁶		H ⁺¹	H ⁺³	H ⁺³	H ⁺³	H ⁺³	H ⁺³			
Conductivity (µS · cm ⁻¹)						160 ³		290–299	190–198	
Oxygen concentration over the bottom (mg · l ⁻¹)		9–10.35 ¹				10.0 ³	10.0 ³		9.4–9.6	5.0–8.0

¹Acc. to Koźmiński after Szczepański (1961), ²Acc. to Stangenberg (1936), ³Acc. to Szczepański (1961), ⁴Acc. to Spodniewska (1978), ⁵Acc. to Solski (1962), ⁶H – stratification of heterograde + type, increase of oxygen concentration in metalimnion, ⁷Acc. to Cydzik et al. (1982), ⁸present investigation.

Table 7. Concentrations ($\text{mg} \cdot \text{l}^{-1}$) of some nutrients forms in water of lake Hańcza in 1977* and 1984 (August)
Range of two-three stations

Nutrient	Surface waters		Over bottom waters	
	1977	1984	1977	1984
P-tot	0.02–0.136	0.034	0.03–0.05	0.016–0.032
P-PO ₄	0.016	0.012	0.003–0.016	0.012–0.016
N-tot	1.42	0.97–1.12	1.19–1.53	0.80–1.78
N-NO ₃	traces	0.05–0.07	0.23–0.27	0.15–0.16

*Acc. to Cydzik et al. (1982)

During that period no directional changes in SD are observed. Scarce data on chlorophyll, algal biomass and seston indicate rather a considerable random variability from year to year (Table 6). Metalimnetic oxygen maximum occurs permanently in this lake. Concentrations of different phosphorus and nitrogen forms (Table 7) do not show any directional changes both in the surface and near bottom layers. But in 1984 a considerable oxygen decrease was observed in the near bottom layer and in the lower part of hypolimnion of this deepest lake (Table 6) although later data (Zdanowski per. comm.) do not indicate a further decrease.

In the case of lake Hańcza we are probably dealing with first symptoms of eutrophication. According to the analysis of multiannual changes (also for almost half a century) of the trophic state of Great Masurian Lakes made by Gliwicz and Kowalczewski (1981) the first symptoms of eutrophication in deep lakes are at first occasional and then advancing oxygen losses in hypolimnion waters, although the indices concerning surface waters do not show any perceptible changes. In the case of lake Szelment Mały, few times shallower than lake Hańcza, we are dealing with parallel eutrophication changes both in the surface and deeper layers (Table 6 and 7).

The questions is, why lake Szelment Mały from all Suwałki lakes analysed show so consistent and coherent eutrophication changes. The Szelmentka on its section (about 100 m) between lakes Szelment Wielki and Szelment Mały (Fig. 1) receives sewage from the settlement Becejły. TP and TN concentration found at the outlet of this river to lake Szelment Mały is high and the phosphorus load equals $0.76 \text{ g} \cdot \text{m}^{-2}$ of lake surface, which is higher than the permissible load according to Vollenweider's criteria (Hillbricht-Ilkowska 1993). Lake Szelment Mały seems a good example of anthropogenous acceleration of eutrophication caused by

sewage inflow from point sources of pollution to the river, flowing directly to the lake.

Through-flow lakes, of Szeszupa the river in which a decrease in transparency was observed, seem to undergo eutrophication due to areal surface runoff, including numerous dispersed sources of pollution in the watershed of this river due to farming and breeding (many pastures, driving the cattle across the river, scattered farms).

Other lakes apart from the already mentioned – do not display any symptoms of distinct eutrophication. One of the reasons of such situation suggested by Hillbricht-Ilkowska (1990b) in relation to deep mesotrophic lakes is probably the limited bioavailability of phosphorus, which reaches the lakes mostly sorbed on suspension as a result of high water and air erosion in that region (Smolska 1993).

3.3. TROPHIC AND CHEMICAL COMPOSITION OF SURFACE VERSUS OVER-BOTTOM WATER LAYERS IN LAKES

Chemical composition of surface and over-bottom water layers in the summer period, i.e., during high productivity and thermo-oxygen stratification may differ considerably. As regards nutrients it may show high accumulation, i.e., increased concentration in the over-bottom layer as a net result of sorption and desorption processes on water – sediments interface (controlled by redox potential), biological activity of benthic animals (Wiśniewski 1990), activity of microorganisms and other processes. Therefore, simple indices such as ratio of nutrients over the bottom to surface concentration (further on called accumulation index), or comparison of TN:TP weight ratios, contribution of dissolved forms of percent content of P in seston, may inform about the net direction of these processes, i.e., "losses" (sorption, biological uptake) and "supply" (release, desorption) under physical conditions over the bottom of lakes in summer period.

The ratio of values of electrical conductivity (EC) and the concentrations of Ca, Mg, Na, K and tot-Fe in over-bottom waters to surface lake waters analysed for the whole pool of data (N=12–20) show the following mean values: E – 1.05 (s.d. \pm 0.11), Ca – 1.09 (s.d. \pm 0.16), Mg – 1.01 (s.d. \pm 0.08), Na – 1.00 (s.d. \pm 0.13), K – 1.11 (s.d. \pm 0.14), tot-Fe – 0.90 (s.d. \pm 0.68). They indicate that the composition of over-bottom waters as regards the concentration of above components practically does not differ from surface waters. This is indirectly confirmed by a conclusion made by Hillbricht-Ilkowska (1993b) on the consistency of chemical composition of surface and over-bottom waters of lakes and of river supply.

Different result is obtained when comparing N and P concentration in over-bottom and in surface waters (Fig. 3). Indices of TP accumulation in over-bottom layer in the majority of lakes are differentiated (up to 10), whereas analogous indices of TN accumulation are mainly grouped within 0.8–2.0 (although

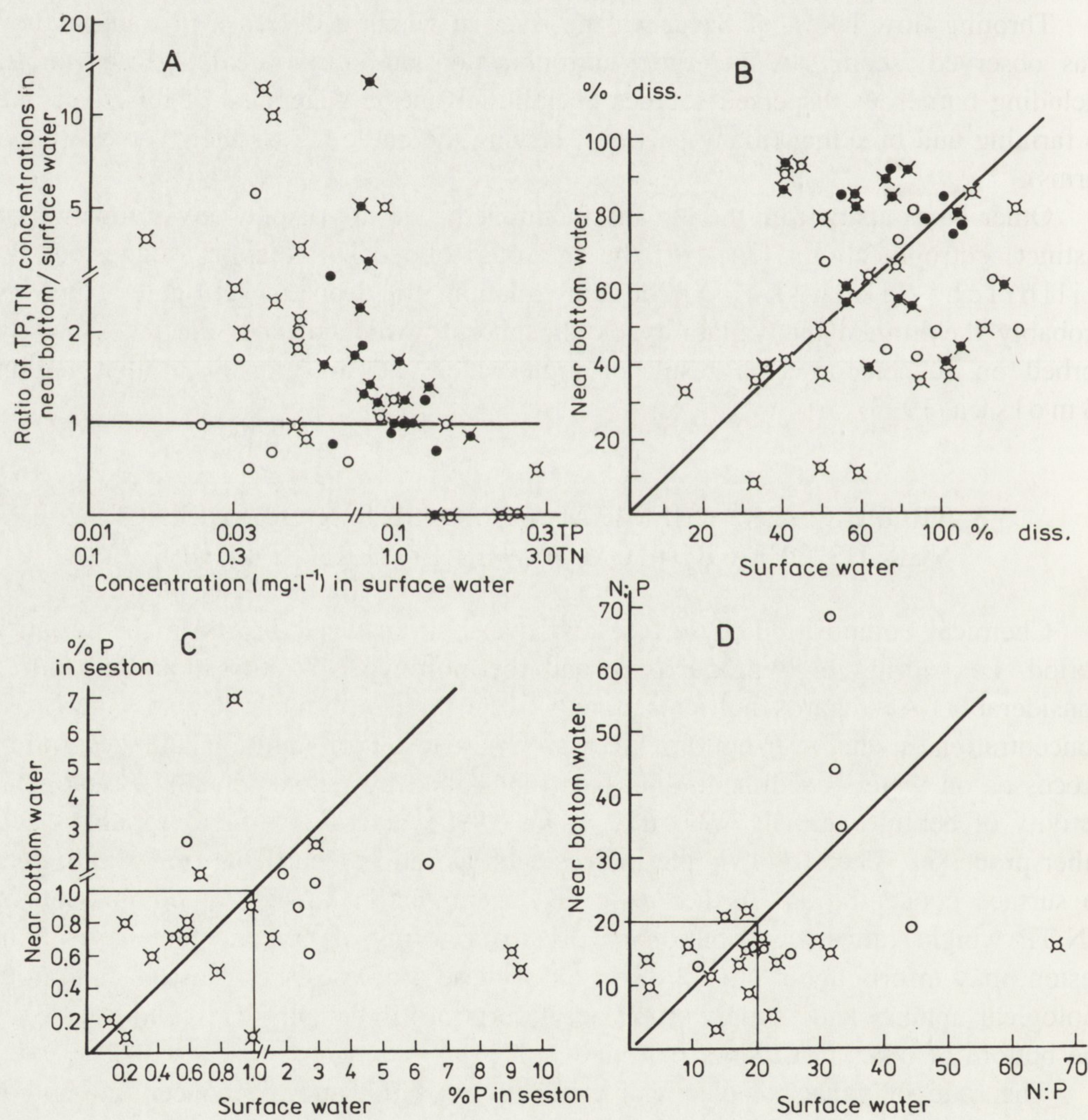


Fig. 3. Comparison of relations as regards nitrogen and phosphorus in surface water vs. the over-bottom water in lakes examined (August)

light rings are for TP, dark – for TN, crossed rings – lakes with oxygen deficit over the bottom, A – ratio of total phosphorus (TP) and total nitrogen TN concentration in over bottom to surface waters plotted against the concentration in surface waters, B – % contribution of phosphorus and nitrogen dissolved forms in their total concentration, C – % content of phosphorus in seston, D – TN:TP weight ratio

in three lakes they are as high as 3–15) (Fig. 3a). All lakes (except one) with TP accumulation index over 2.0 indicate simultaneously an oxygen deficit at the bottom, but there are many lakes with oxygen deficit at the bottom, where accumulation indices are mainly grouped within 1–2 and even less. The percent content of P diss. in TP is generally smaller in over-bottom layers (13 cases confirming versus 8 contradictory ones) than in surface ones. Analogous index for N does not display such a tendency (all points are rather evenly distributed along the diagonal in Fig. 3b). Generally the values of percent P dissolved over the bottom vary more (10–100%) in the analysed group of lakes as compared to analogous N diss. values (40–95%, but the majority of data are within the range 50–95%). Lakes with oxygen deficit do not show a separate tendency in these changes (Fig. 3c). The values of percentage P content in seston in surface and over-bottom layers also do not show any consistent trend. They are highly variable although in the majority of lakes the value of this parameter in over-bottom layers is less than 1.0%, whereas the range for surface layers is much broader: 0.1–10%. This may provide indirect information that in the majority of lakes phosphorus in over-bottom layers is most frequently connected with organic seston (resuspended sediments, and/or sedimentating particles).

The TN:TP weight ratio is generally smaller (14 cases confirming versus 7 contradictory ones) in the over-bottom layers and therefore this layer has more P as related to N. This tendency is convergent with the result of analysis of TP accumulation indices (Fig. 3d).

4. SUMMARY

In summer periods (August) of 1983–1986, studies were conducted over 25 lakes in Suwałki Landscape Park and its buffer zone. These lakes are connected with rivers: Szeszupa (together with the Szurpiłówka), Czarna Hańcza, Szelmentka and Pissa (Fig. 1, Table 1). Concentrations of different nitrogen and phosphorus forms and of other elements (Ca, K, Na, tot-Fe, Mg), chlorophyll, water transparency (Secchi disc) were measured as well as thermo-oxygen stratification (Table 1, Fig. 2a–d).

The lakes examined form a morphometrically and hydrologically diverse group of lakes (Table 1) containing deep lakes (including the deepest one in Poland – lake Hańcza: max. depth = 108.5 m), small, shallow, greatly flow-through (e.g. lakes of the Szeszupa river) and also the lakes of a low water exchange (Table 1).

The trophic classification of lakes suggested for Polish lakes (Table 2) and used all over the world (Table 4) was applied. The so-called indices of Carlson's trophy (Table 3) were also estimated. According to these classification systems the group of examined lakes has to be considered as mesotrophic or moderately eutrophic – there are no highly eutrophic or hypereutrophic lakes.

The most valuable as regards water purity and trophy i.e. showing consistent mesotrophic characters (at least for few of several parameters compared) (Table 3), are lakes: Szelment Wielki, Szelment Mały, Jeglówek, Szurpiły, Kamendul, Jaczno, Kojle, Perty and unique, α -mesotrophic lake Hańcza of the highest transparency, lowest chlorophyll concentration and phytoplankton biomass (Table 3). To this group also belong two shallower lakes Boczniew and Jegliniszki, connected (directly and indirectly) with lake Hańcza and lake Kluczysko directly connected with lake Szurpiły (Table 3). Some of these lakes, and especially four small but deep lakes: Perty, Kamendul, Jaczno

and Kojle, show either a lack of oxygen in the hypolimnion and over the bottom, or a temporary decrease (heterograde) of oxygen in the metalimnion. Shallow, small and flow-through lakes of the upper Szeszupa and of lower section of the Szelmentka are relatively more eutrophic whereas two shallow lakes Wizajny and Wistuć (beyond SLP and with agricultural surroundings) are the most eutrophic (Table 3). Measurements of water transparency made in the middle of nineteen-thirties compared with present data (Table 5) show that in the majority of lakes, and especially mesotrophic ones, this trophy index does not change basically. Still, a slight but consistent decrease in Secchi disc transparency is shown by flow-through lakes of the Szeszupa and it is greater the lower is their position in the river course. Lake Szelment Mały shows also an almost double decrease in transparency and this change is convergent with the decrease of oxygen concentration in the hypolimnion. In lake Hańcza, despite a constantly recorded oxygen maximum in the metalimnion, a tendency to oxygen decrease over the bottom was recorded in the last ten years (Table 6 and 7) and lack of directional changes of the remaining trophy indices.

The above comparison of trends of multiannual changes of SLP lakes (limited however by the quality and quantity of archival data) allow to conclude that the eutrophication rate of the whole group of lakes is moderate and mostly due to the effect of non-point sources (surface runoff from arable land, supply with erosion products). The slight decrease in transparency of flow-through lakes of the upper Szeszupa seems to provide that information. Whereas lake Szelment Mały displaying the greatest eutrophication symptoms in the last few decades, is an example of lake on that area under constant influence of point source of sewage from the urban settlement which are released almost straight to the lake. Almost in all lakes the TN:TP weight ratio in surface waters in summer (Table 3) is equal or over 20 which means a relative phosphorus deficit. On one hand, this indicates a circumstance favourable for maintaining the mesotrophic state of the lake, but also shows a possibility of fast reaction of the lake to an increased phosphorus supply from external sources.

The potential sensitivity of lakes on that area to an increased phosphorus supply is also proved by comparing the concentration of nutrients in the over-bottom layers as related to surface ones (Fig. 3). TP accumulation indices are over 1 in the majority of lakes, although they vary greatly (Fig. 3). The contribution of dissolved form in TP is usually smaller and percent of P in the seston is slightly greater in over bottom layers comparing with surface layers. Generally this situation may provide information about the existence – even in lakes without oxygen deficit – of internal supply in this element in summer.

5. POLISH SUMMARY

W okresach letnich (sierpień) 1983–1986 przeprowadzono badania 25 jezior SPK i jego otuliny powiązanych z rzekami: Szeszupą (na obszarze SPK) wraz z Szurpiłówką, Czarną Hańczą, Szelmentką i Pissą (rys. 1, tab. 1). Dokonano pomiarów stężenia różnych form azotu i fosforu oraz innych pierwiastków, chlorofilu, przezroczystości wód (widzialność krążka Secchiego) oraz stratyfikacji termiczno-tlenowej (rys. 2a–d, tab. 1).

Badane jeziora stanowią bardzo różnorodny pod względem morfometrycznym i hydrologicznym zbiór jezior (tab. 1), są wśród nich jeziora szczególnie głębokie, np. najgłębsze jezioro w Polsce – Hańcza (głębokość maksymalna 108,5 m) – rezerwat przyrody, oraz niewielkie i płytkie, zarówno silnie przepływowe (np. jeziora rzeki Szeszupy), jak i o niewielkiej wymianie wód (tab. 1).

Zastosowano klasyfikację troficzną jezior proponowaną dla jezior polskich (tab. 2) oraz stosowaną na świecie (tab. 4). Oceniono również wskaźniki trofii Carlsona (tab. 3). W świetle tych systemów klasyfikacyjnych, ogólnie rzecz biorąc, zbiór jezior badanego obszaru należy uznać za jeziora mezotroficzne lub umiarkowanie eutroficzne – brak jest jezior silnie eutroficznych, a tym bardziej hypereutroficznych.

Najcenniejsze pod względem czystości wód i trofii, tzn. wykazujące spójne cechy mezotrofii (przynajmniej w zakresie paru z kilku porównywanych parametrów) (tab. 3), są jeziora: Szelment

Wielki, Szelment Mały, Jegłówek, Szurpiły, Kamendul, Jaczno, Kojle, Perty oraz unikatowe, α -mezotroficzne jezioro Hańcza, o najwyższej przezroczystości, najniższej koncentracji chlorofilu i biomasy fitoplanktonu. Do tej grupy należą również dwa płytsze jeziora: Boczniew i Jegliniszki, powiązane (pośrednio i bezpośrednio) z jez. Hańcza i jez. Kluczyso powiązane pośrednio z jez. Szurpiły (tab. 3). Część tych jezior, a szczególnie 4 niewielkie, a głębokie jeziora: Perty, Kamendul, Jaczno i Kojle, wykazują jednakże bądź brak tlenu w hypolimnionie i nad dnem, bądź przejściowy spadek (heterograda ujemna) tlenu w metalimnionie.

Relatywnie najsilniejszy stopień eutrofizacji wykazują względnie płytkie, niewielkie i przepływowe jeziora górnej Szeszupy i dolnego odcinka rzeki Szelmentki, zaś najsilniejszy – dwa płytkie jeziora leżące poza SPK w otoczeniu rolniczym, Wiżajny i Wistuć (tab. 3). Z zestawienia pomiarów o przezroczystości wód jezior wykonanych w połowie lat trzydziestych z danymi współczesnymi (tab. 5) wynika brak zasadniczych zmian tego wskaźnika trofii w większości jezior, szczególnie w głębokich jeziorach mezotroficznych. Natomiast nieznaczny, choć konsekwentny spadek widzialności krążka Secchiego wykazują jeziora przepływowe rzeki Szeszupy i to tym silniejszy, im niżej są położone w biegu ciek. Również blisko dwukrotny spadek przezroczystości wykazuje jezioro Szelment Mały i zmiana ta jest zbieżna z kierunkiem zmian warunków tlenowych w hypolimnionie. W jez. Hańcza wykazano – mimo trwale notowanego maximum tlenowego w metalimnionie – tendencję do spadku tlenu nad dnem w ostatnim dziesięcioleciu (tab. 6 i 7) oraz brak kierunkowych zmian pozostałych wskaźników trofii.

Z powyższego porównania tendencji zmian wieloletnich jezior SPK (z konieczności ograniczonych jakością i ilością danych archiwalnych) można wysnuć ogólny wniosek, że tempo eutrofizacji całego zbioru jezior jest umiarkowane, głównie wiążące się z oddziaływaniem obszarowych źródeł tego procesu (spływ obszarowy z terenów użytkowanych rolniczo, dostawa z produktami erozji). Wydaje się, że informuje o tym nieznaczny spadek przezroczystości jezior przepływowych górnej Szeszupy. Natomiast jez. Szelment Mały, wykazujące najsilniejsze objawy eutrofizacji w ostatnich kilku dekadach, jest przykładem jeziora tego obszaru, które poddane jest stałemu oddziaływaniu źródła punkowego, jakim są ścieki z osady Becejły, praktycznie bezpośrednio odprowadzane do jeziora. W prawie wszystkich jeziorach stosunek TN:TP w wodach powierzchniowych w okresie letnim (tab. 3) jest równy lub wyższy niż 20, co oznacza względny deficyt fosforu. Okoliczność ta z jednej strony jest okolicznością sprzyjającą utrzymaniu mezotroficznego stanu jeziora, ale z drugiej strony wskazuje na możliwość szybkiej reakcji jeziora na wzmożoną dostawę fosforu ze źródeł zewnętrznych, jeśli by taka miała miejsce.

O potencjalnej wrażliwości jezior badanego obszaru na wzmożoną dostawę fosforu świadczą również wyniki porównania stężenia związków troficznych w warstwach naddennych w stosunku do warstw powierzchniowych (rys. 3). Wskaźniki kumulacji TP są w większości jezior większe niż 1, choć ogólnie bardzo zmienne (rys. 3), jak też na ogół najmniejszy jest udział formy rozpuszczonej, zaś nieco większy udział w sestonie. Ogólnie sytuacja ta może informować o istnieniu – nawet w jeziorach bez deficytu tlenowego nad dnem – wewnętrznego zasilania w ten pierwiastek w okresie letnim.

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