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PHOSPHORUS LOADING TO LAKES OF SUWAŁKI LANDSCAPE PARK (NORTH-EASTERN POLAND) AND ITS RELATION TO LAKE TROPHY INDICES

ABSTRACT: Annual total-P input (TP) to 20 lakes of Suwałki Landscape Park (SLP) with a fluvial inflow, surface runoff and precipitation has been estimated. In most cases, the annual TP input is lower than the dangerous one acc. to Vollenweider's (1976) criteria, whereas the weight ratio TN:TP points to stimulation of the phosphorus deficit. A relatively high correlation has been found between the annual load expressed in TP per lake surface unit and TP concentration in surface layers in summer. TP concentration in surface layers does not determine the variation of water transparency (SD) and chlorophyll a concentration with sufficient accuracy, whereas the relation between the latter two trophic parameters and algal biomass is high. For the majority of lakes, and practically for all mesotrophic and deep lakes, regressions of SD or TP vs. chlorophyll found for different groups of Masurian lakes, do not apply. The values of these parameters are much lower than they should be according to these models at relevant TP concentration. A conclusion has been drawn about the low bioavailability of TP supplied and present in SLP lakes, and thus the slower eutrophication rate of SLP lakes. This conclusion is convergent with results of previous investigations (Hillbricht-Ilkowska 1990).

KEY WORDS: phosphorus load, lakes, trophy parameters, Suwałki Landscape Park.

1. INTRODUCTION

In all considerations of lakes in danger of advanced eutrophication it is necessary to estimate the phosphorus input from external sources, i.e., with fluvial inflow, surface runoff, point sources (wastes discharge), precipitation and ground waters. This estimation is fundamental for qualifying the lake in a proper category of endangering (Hillbricht-Ilkowska 1989) depending whether the actual load is greater or equal to the so-called permissible load, i.e., such – which according to Vollenweider (1976) criteria – does not stimulate algal blooms.

Estimation of the actual phosphorus load is also a starting point for finding relations between P input to the lake and its concentration in lake waters, on one hand, and relation between P concentration in waters and eutrophication symptoms, on the other hand, such as chlorophyll a concentration, algal biomass or water transparency measured with Secchi disc.

These relations are being frequently investigated in world limnology and of different countries and are distinctly stimulated by Vollenweider's (1968, 1976, 1989) research. There are many mathematical models usually in the form of simple regressions or correlations among these parameters. These relations provide quantitative information on the rate of reaction of a lake or a particular group of lakes to the input of eutrophying element such as phosphorus, providing thus grounds for all kinds of recultivation treatments based on elimination or inactivation of this element.

Much has been written on this subject in world literature (review in Henderson-Sellers and Marland 1987), and some of these relations have been checked or formulated for Polish lakes by Uchmański and Szeligiewicz (1988) and Zdanowski (1982). The lakes analysed by these two last sources do not contain the lakes of the Suwałki Landscape Park (SLP), although regressions given by these authors are based on a great number of different lakes from various regions of Poland (from several tens to almost two hundreds).

The aim of the present paper is: to estimate the total P (TP) input from various external sources to SLP lakes (description of lakes and their trophic state is Hillbricht-Ilkowska and Wiśniewski 1993), to determine the lakes endangering category and to find relations between external phosphorus input and its concentration in lakes in summer, as well as relation between TP concentration in surface layers and such typical trophic parameters as transparency (SD), chlorophyll a concentration and biomass of algae determined also for the summer period.

These relations shall be analyses with consideration to: (1) whether annual TP input may sufficiently determine TP concentration in the lake in summer; (2) whether relations among trophic parameters are similar to those established for other lakes; particularly, whether regressions observed for other groups of lakes can be used for determining the trophy of Suwałki lakes with a satisfactory accuracy.

Analytical methods of determining total phosphorus (TP), total nitrogen (TN), chlorophyll a, biomass of algae (Simm, unpubl. material) are given in the paper by Hillbricht-Ilkowska and Wiśniewski (1993).

2. ESTIMATION OF ACTUAL, PERMISSIBLE AND DANGEROUS PHOSPHORUS LOADS AND THE STATE OF LAKE ENDANGERING

External phosphorus sources for the lake are following: point sources (i.e., direct wastes discharge to the lake), surface runoff from the watershed in the form of streams and through the direct contact with the lake's shoreline, precipitation (dry and wet), and underground waters.

The preliminary estimation of TP input with waters from the watershed and also with the precipitation for thirteen mesotrophic lakes of the SLP region (i.e. having: SD $\geq$ 2.5 m, TP $\leq$ 0.050 mg $\cdot$ l^{-1}, chlorophyll a $\leq$ 5 μg $\cdot$ l^{-1}, summer period, surface layers) made by Hillbricht-Ilkowska (1990) show that for the majority of these lakes (including the biggest and/or the deepest ones as e.g., lake Hańcza) annual TP input in g $\cdot$ m^{-2} (lake surface) does not exceed permissible values estimated after Vollenweider (1968), i.e., taking into consideration the average lake depth.

These estimations for mesotrophic lakes made by Hillbricht-Ilkowska (1990) were recalculated i.e., including water exchange parameter according to the data of Bajkiewicz-Grabowska (1993). Also TP input for other, i.e., meso-eutrophic or eutrophic lakes was estimated. Such estimations were made altogether for 20 SLP lakes, for which detailed trophic characteristics and morphometric data can be found in the paper by Hillbricht-Ilkowska and Wiśniewski (1993). Data on the exchange of water in lakes (Bajkiewicz-Grabowska 1993) allowed to estimate the permissible loads not only on the basis of mean lake depth (Vollenweider 1968) but also on the time of water retention (Vollenweider 1976).

However, these estimations include the following assumptions, which generally cause that the estimated phosphorus input: (1) takes into consideration only surface areal input. This is: runoff from direct lake watershed with streams supplying it and precipitation (dry and wet together). The possible input from not controlled and not recorded point sources, like waste discharge directly to the lake was not taken into consideration as well as the underground supply. However, it should be added that most lakes such as: Hańcza, Szelment Wlk., Szelment Mł. are not waste receivers (Cydzik et al. 1982) introduced directly to the lake; (2) is based on measurements of TP concentrations and flow in summer (August) and then extrapolated for the 10-month period (excluding ice period). Thus the values received should be treated as underestimated and even "minimal" ones of the annual phosphorus input from lake watershed and precipitation. They do not take into consideration the seasonal increase in discharge and runoff, which can be quite significant in the thawing period, as well as shortlasting increases after storm rains. Acc. to studies of Hillbricht-Ilkowska et al. (1983) on the

Masurian Lakeland about 50% of annual phosphorus load reaches the lake between April and May.

For each lake the following were calculated separately: (1) river inflow (for lakes supplied by the Szeszupa, Szelmentka and Czarna Hańcza waters) as a product of TP concentration and flow; (2) input from the direct lake watershed as a product of surface runoff unit estimated in Hillbricht-Ilkowska (1993) for lakeside, small stream watersheds and the area of direct lake watershed. The areas without surface runoff (land depressions) (acc. to data of Bajkiewicz-Grabowska 1993) were not included into the lake watershed active in runoff.

The TP input with precipitation has been assumed as 0.05 g TP $\cdot$ m^{-2} (lake surface) per year acc. to data of Goszczyńska (1983). This is an average value for the Masurian Lakeland for wet and dry precipitation together and generally close to the average value for agricultural, non-urban areas in Europe (Goszczyńska 1983). The above estimations of annual "minimal" TP input with surface runoff and precipitation were compared with permissible and dangerous TP load values acc. to criteria of Vollenweider (1976).

The permissible TP (L_{TP}) load was estimated according to the equation:

$$L_{TP}=20qs \ / \ 1+\sqrt{z(q\ s)}$$

where: L_{TP} = annual TP load in mg $\cdot$ m^{-2} (lake surface) per 1 year, qs = hydraulic load (m $\cdot$ y^{-1}), i.e., product of mean depth and annual flushing rate (ratio of annual outflow to lake volume), z = mean depth (m).

The qs value was calculated for each lake acc. to data of Bajkiewicz-Grabowska (1993) for the annual rate of lake water exchange and its mean depth (see Hillbricht-Ilkowska and Wiśniewski 1993). A dangerous load, i.e., the load accelerating the eutrophication was taken as a double permissible value.

The assessed "minimal" annual TP load received by the 20 lakes from areal sources and precipitation was compared with values of permissible and dangerous load, in order to determine the so-called endangering categories (Hillbricht-Ilkowska 1989) when:

Cat. I – actual load is smaller than permissible;

Cat. II – actual load is bigger than permissible, but smaller than the dangerous one;

Cat. III – actual load is equal or bigger than the dangerous one.

In over half (12) of the 20 lakes analysed here, an actual annual load is smaller than the permissible one, in the other 5 – the load i s equal or greater than the permissible one, but smaller than the dangerous one; these are lakes of I or II category of endangering (Table 1, Fig. 1). Among them are some deep lakes like; Hańcza, Kamenduł, Perty, Kojle and Jaczno, with low flushing rate, narrow direct watershed (active in surface runoff) and small values of areal runoff

Table 1. Estimated annual actual TP load (surface runoff, fluvial inflow, precipitation) and its permissible values (g · m^{-2} lake surface) acc. to Vollenweider criteria (Vollenweider 1976) for SLP lakes*

River Lakes**	No.	TP load ($g \cdot m^{-2}$ lake surface per year) actual	TP load ($g \cdot m^{-2}$ lake surface per year) permissible	Categories of endangering***	TN:TP weight ratio in all sources
Szelmentka					
Szelment Wielki	(1)	0.47	0.12	III	15
Szelment Mały	(2)	0.76	0.59	II	6
Iłgieł	(3)	9.45	4.67	III	4
Kupowo	(4)	1.75	2.66	I	7
Szeszupa					
Gulpin	(5)	5.05	5.18	II	9
Okrągłe	(6)	0.95	1.77	I	22
Krajwelek	(7)	1.32	4.31	I	25
Przechodnie	(8)	0.65	1.30	I	16
Postawelek	(9)	3.95	14.79	I	25
Pobondzie	(10)	0.65	2.65	I	18
Kamenduł	(11)	0.12	0.50	I	30
Jaczno	(12)	0.07	0.33	I	19
Perty	(13)	0.06	0.14	I	22
Kojle	(14)	0.05	0.15	I	22
Szurpiłówka					
Szurpiły	(15)	0.35	0.16	II	19
Jeglówek	(16)	0.45	0.12	III	21
Kopane	(17)	0.55	0.54	II	23
Udziejek	(18)	2.45	1.28	II	24
Czarna Hańcza					
Hańcza	(19)	0.057	0.26	I	21
Jegliniszki	(20)	0.054	0.25	I	21

*Morphometric, hydrological and trophic data including locality of particular lakes in river watersheds – see Hillbricht-Ilkowska and Wiśniewski (1993); **Lake number (in brackets), locality and its watersheds (see Hillbricht-Ilkowska (1993) (Fig. 1) and Hillbricht-Ilkowska and Wiśniewski (1993) (Fig. 1); ***Categories of endangering I–III (after Hillbricht-Ilkowska 1988) acc. to ratio of actual load to the permissible and (twice bigger) the dangerous one see the text.

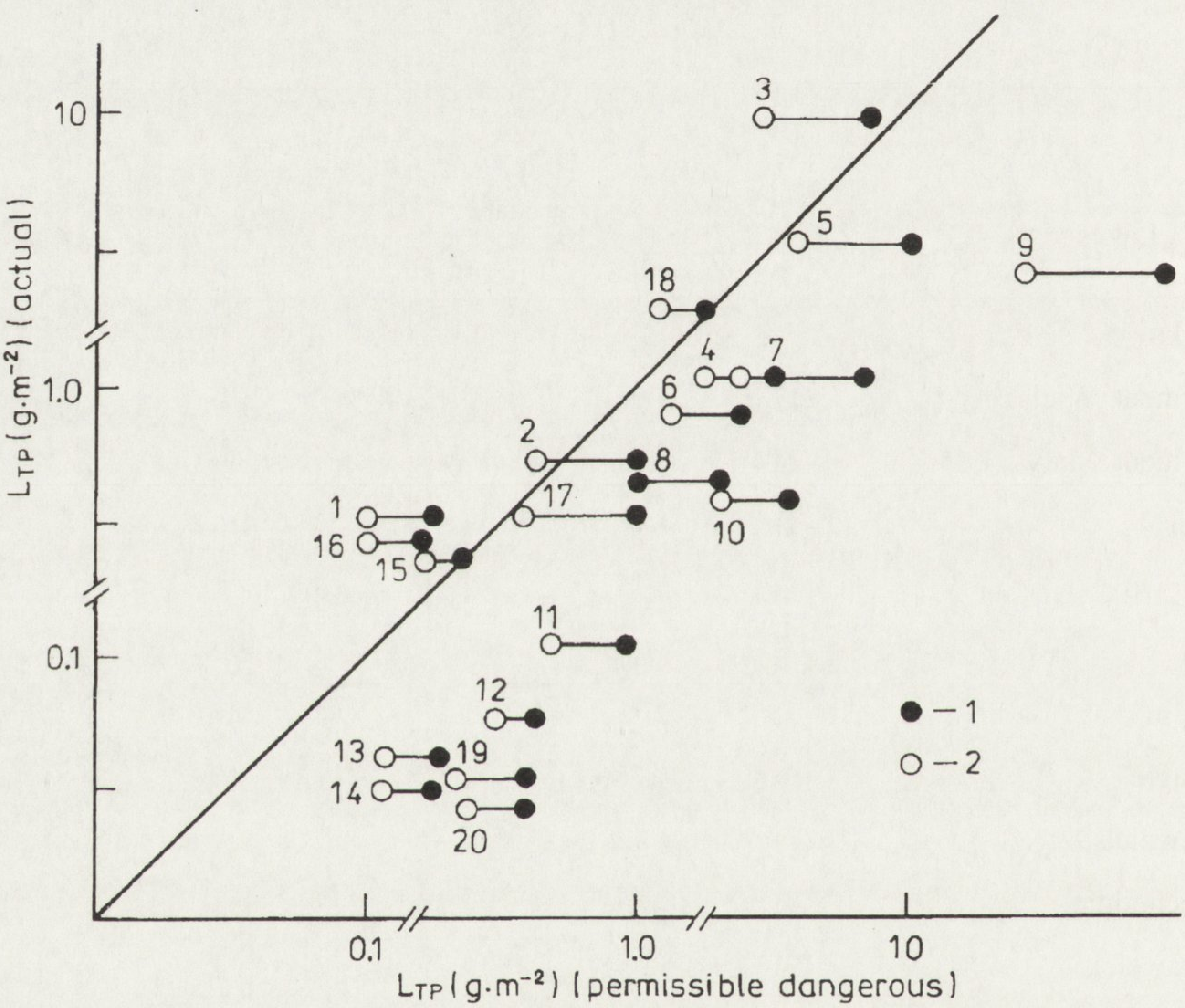

Fig. 1. Actual annual TP load (surface runoff, fluvial inflow and precipitation) (L_{TP}) (in g · m^{-2} lake surface) vs permissible (1) and dangerous (2) loads estimated according to Vollenweider (1978) for 20 SLP lakes (lake number – see Table 1)

(Hillbricht-Ilkowska 1993). The annual TP load reaching these lakes is usually lower than 1 g · m^{-2} (lake surface) but the input with precipitation consists a considerable part (50–70%) of the total load. Some shallow and/or strongly flow-through lakes also belong to lakes of I or II category. These are: Szelment Mł., Kupowo, Gulbin, Okrągłe, Pobondzie, Kopane, Udziejek, Jegliniszki, Krajwelek, Przechodnie and Postawelek (Table 1). However, in these lakes the load carried by the river is high (up to 2–3 g · m^{-2} lake surface per 1 year) and the permissible as well as dangerous (Fig. 1), loads are high because of the high flushing rate of these lakes. Three lakes – Szelment Wlk., Iłgieł in the Szelmentka watershed and Jeglówek in the Szurpiłówka watershed belong to the III category of endangering; the load from direct watershed and brought with rivers exceeds considerably the assessed dangerous load for these lakes (Table 1, Fig. 1).

The analysis of the pool of 20 lakes (Fig. 1) confirms the general conclusion made for mesotrophic lakes only (Hillbricht-Ilkowska 1990), that the majority of lakes within SLP and its buffer zone are endangered by TP load from areal sources and precipitation at a moderate degree as related to their natural capacity determined by depth and flow-through regime. Thus they differ basically from the Masurian lakes (Hillbricht-Ilkowska 1989), the majority of which belong to the III category of endangering. However, one should remember that the above analyses are based on underestimated TP loads reaching the lake. Taking into consideration all possible sources and their seasonal variability may result in placing the majority of lakes in a higher category of endangering.

The range of TN:TP weight ratio in all analysed here input sources of these elements (river tributaries, runoff, precipitation) is 15–25. The exception are flow-through lakes of the Szelmentka, where TN:TP ratio is below 10 (Table 1). It seems that TN:TP ratio in all external sources is slightly higher than calculated only for surface runoff itself (based on different lakeside small streams watersheds), where it was about 15 (Hillbricht-Ilkowska 1993).

Thus, it can be said that in the majority, the proportions of these two elements of lakes in the input from watershed and precipitation, should stimulate the phosphorus deficit in relation to nitrogen.

3. RELATIONS BETWEEN ACTUAL LOAD OF TOTAL PHOSPHORUS AND ITS CONCENTRATION IN SURFACE LAYERS OF SLP LAKES IN SUMMER

The annual TP input to 20 SLP lakes estimated in the previous chapter is a sum of: river inflow, surface runoff from the direct watershed and precipitation. It is an underestimated value of annual load, as already mentioned. However, a question arises whether this under–estimated value may to some extent determine TP concentrations ($mg \cdot l^{-1}$) of surface layers in summer. Therefore, the regression was estimated between TP concentration in August (surface layers) and annual input expressed in: (1) 10^6 mg per lake; (2) $g \cdot m^{-2}$ lake surface; (3) $g \cdot m^{-3}$ lake volume.

For all these relations ANOVA (Table 2) has shown a statistically significant relation, which was the strongest (r^2=49%, p=0.0006) for relation between TP concentration in lake (surface, summer) and the annual input expressed in g per lake area unit. Thus, for the analysed group of lakes the best "predictor" of surface TP concentration in summer is the annual input from external sources expressed in g of TP per m^2 of lake area. This relation takes the form of:

$$TP = 0.035 \text{ (s.e. } \pm 0.009) + 0.015 \text{ (s.e. } \pm 0.003) L_{TP}$$

n = 20, r = 0.7,
where: TP – TP concentration in surface layers in summer in $mg \cdot l^{-1}$, L_{TP} – TP input to the lake from the above mentioned sources in $g \cdot m^{-2}$ per year.

Table 2. Statistical analysis (ANOVA) of regression (y = a + bx) between TP (y) concentration (summer, surface layers, in mg · l^{-1}) and the differently expressed annual TP input (x) from external sources (fluvial inflow, surface runoff, precipitation) for 20 SLP lakes

Annual TP input in:	Intercept (a) (s.e.)	Slope (b) (s.e.)	N	r^2 (%)	P	r
10^6 mg per lake	0.039 (0.012)	0.00005 (0.00002)	20	28.8	0.0015	0.54
g · m^{-3} of lake volume	0.039 (0.011)	0.047 (0.015)	20	35.1	0.0059	0.59
g · m^{-2} of lake surface	0.035 (0.009)	0.015 (0.003)	20	48.7	0.0006	0.70

4. RELATIONS AMONG TROPHIC PARAMETERS OF SLP LAKES

The relations among the following values were determined: phosphorus concentration, water transparency (SD), chlorophyll a concentration and algal biomass (Fig. 2); in order to find to what extent the basic trophic parameters such as TP concentration (in surface layers in summer) can be a good "predictor" of other trophic parameters. Values of particular parameters are given in Hillbricht-Ilkowska and Wiśniewski (1993, Table 3).

The statistical analysis (ANOVA) and constants of log-log regressions shown in Table 3 for different pairs of trophic parameters indicates that all six relations are statistically significant, but the lowest r^2 (coefficient of determination) and probability was found for the relations in which TP concentration is the independent variable. It means that this parameter is relatively the weakest "predictor" for transparency, chlorophyll a concentration and algal biomass, whereas the transparency and chlorophyll a values indicate a very strong interdependence and dependence on algal biomass as proved by very high determination coefficients (r^2) and high probability level (Table 3).

This means that much of the SD variability is determined by the algal biomass and chlorophyll a concentration. A statistically high significance is also displayed by the arithmetical regression between following parameters.

Chlorophyll a and algal biomass: chl a (μg · l^{-1}) = 6.292 + 2.977 biomass (mg · l^{-1}, wet weight);
$n = 22$, $r^2 = 43.7\%$, $p = 0.0008$, $r = 0.66$.

Biomass and transparency: SD (m)=4.156–0.406 biomass (mg · l^{-1});
$n = 22$, $r^2 = 38.7\%$, $p = 0.002$, $r = -0.62$.

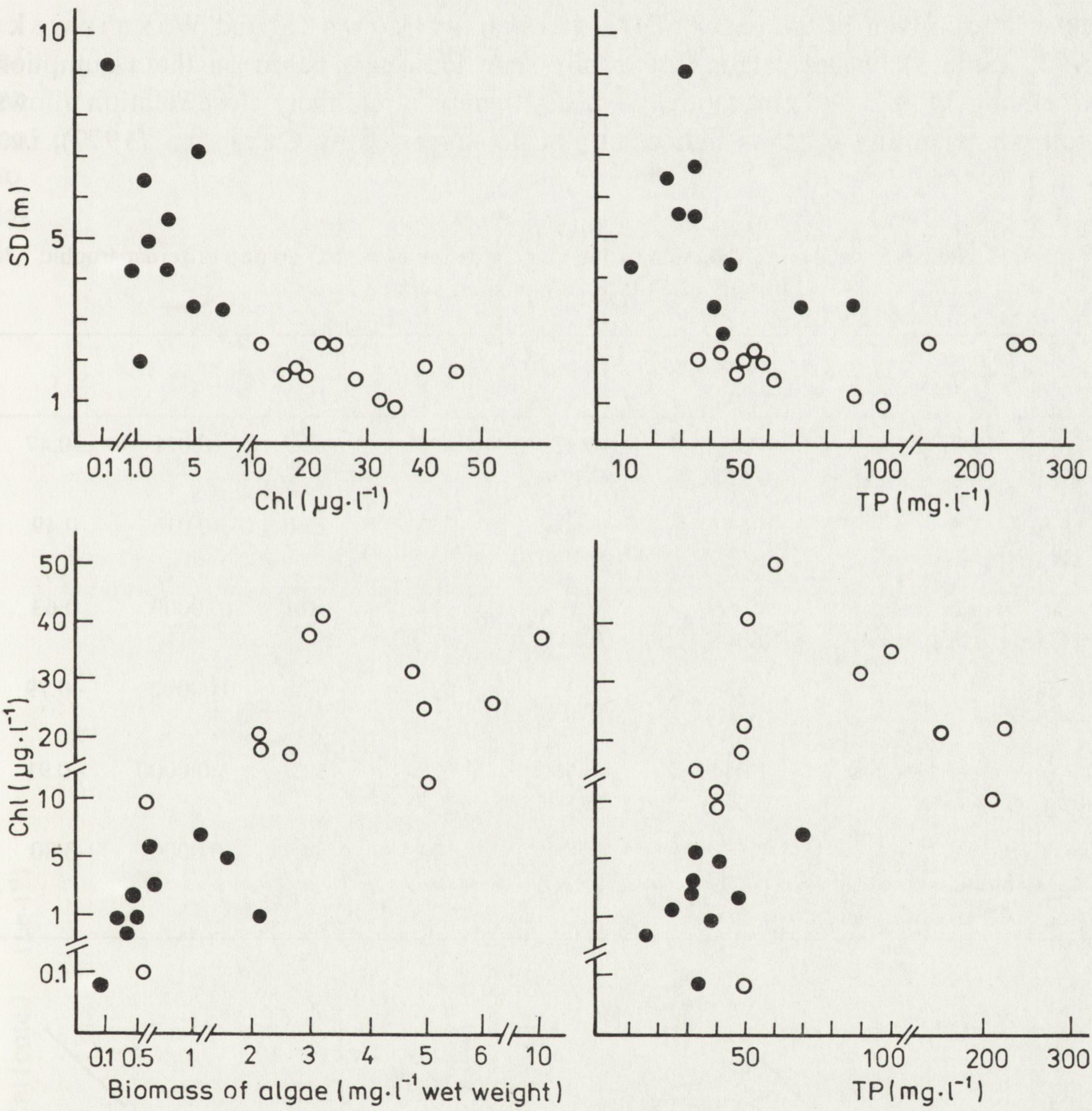

Fig. 2. Inter-correlations between four trophic parameters for 25 SLP lakes: TP concentration (mg · l^{-1}), SD (m), chlorophyll a concentration (μg · l^{-1}), algal biomass (mg · l^{-1} wet weight), (values for summer, surface layers)
Areas: dark – deep mesotrophic lakes, light – other lakes

Chlorophyll and transparency: SD (m)=4.582–0.101 chlorophyll (μg · l^{-1}); n = 21, r^2 = 47.4%, p = 0.0006, r = –0.69.

It is interesting to compare the probability with which the trophic parameters of SLP lakes can be estimated also on the basis of "TP-SD-chl" regressions calculated for other groups of lakes. Thus, these parameters are compared with values according to the regressions found by Uchmański and Szeligiewicz (1988) for several tens of Polish lakes, and by Zdanowski (1982) for 195 different Polish lakes. Also different indices of trophy state invented by Carlson (1977) are compared.

In the latter, given in the paper of Hillbricht-Ilkowska and Wiśniewski (1993, Table 3), the calculation of trophy state indices is based on the assumption that among TP, SD and chlorophyll a values there is a relatively close relation allows a full compatability of these indices at a scale suggested by Carlson (1977), i.e., from 1 to 100.

Table 3. Statistical analysis (ANOVA) of log-log regression (y=a+bx) among different trophic parameters of SLP lakes (summer, surface layers)

Y, X	Intercept (a) (s.e.)	Slope (b) (s.e.)	N	r^2 (%)	P	r
SD (m), TP (mg · l^{-1})	–0.334 (0.525)	–0.433 (0.174)	23	22.7	0.021	–0.47
Chl (µg · l^{-1}) TP (mg · l^{-1})	5.611 (1.520)	1.306 (0.498)	23	25.0	0.016	0.49
Algal biomass (mg · l^{-1}) TP (mg · l^{-1})	4.065 (1.043)	1.333 (0.347)	24	40.1	0.0009	0.63
SD (m), chl a (µg · l^{-1})	1.538 (0.36)	–0.315 (0.055)	21	62.8	0.00002	–0.79
SD (m), algal biomass (mg · l^{-1})	1.044 (0.058)	–0.401 (0.041)	22	82.7	<0.0000	–0.91
Chl a (mg · l^{-1}), Algal biomass (mg · l^{-1} wet weight)	1.558 (0.235)	1.001 (0.165)	21	64.7	0.00001	0.80

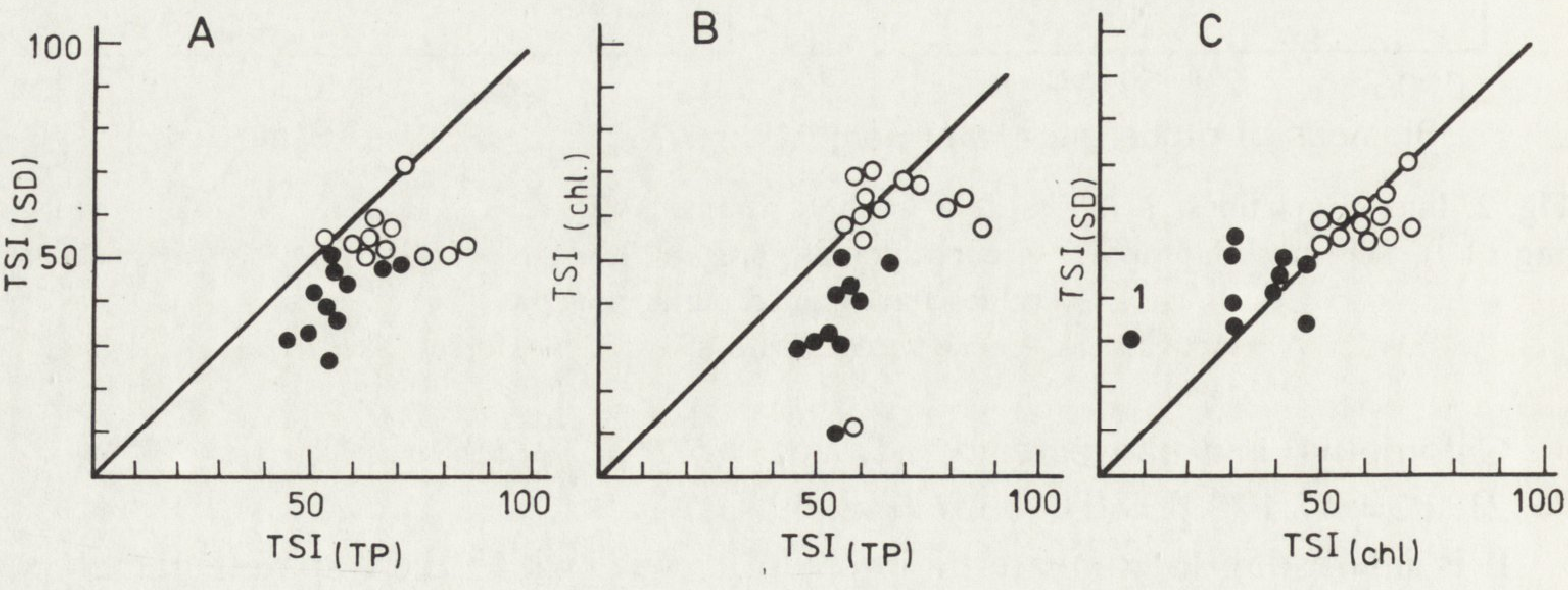

Fig. 3. Intercorrelation between pairs (A, B, C) of T(rophic), S(tate), I(ndex), acc. to Carlson (1977) based on total phosphorus (T_P), transparency (SD) and chlorophyll a concentration (Chl) (summer, surface layers) for 25 SLP lakes
Areas: dark – deep mesotrophic lakes, light – other lakes, 1 – lake Hańcza

The graphic presentation of Carlson's trophic indices (Fig. 3) shows that values of the index based on TP (TSI_{TP}) measurements are usually higher than indices based on SD (TSI_{SD}) or chlorophyll (TSI_{chl}). The relevant data in Figure 3 (A and B) are not arranged around the diagonal, but show – as a group of all 25 lakes – a tendency to a lower chlorophyll a concentration and greater transparency that should occur in lake – according to Carlson model – at given TP concentration. In other words, these is "too much" phosphorus in summer in the surface layers of lakes in relation to other

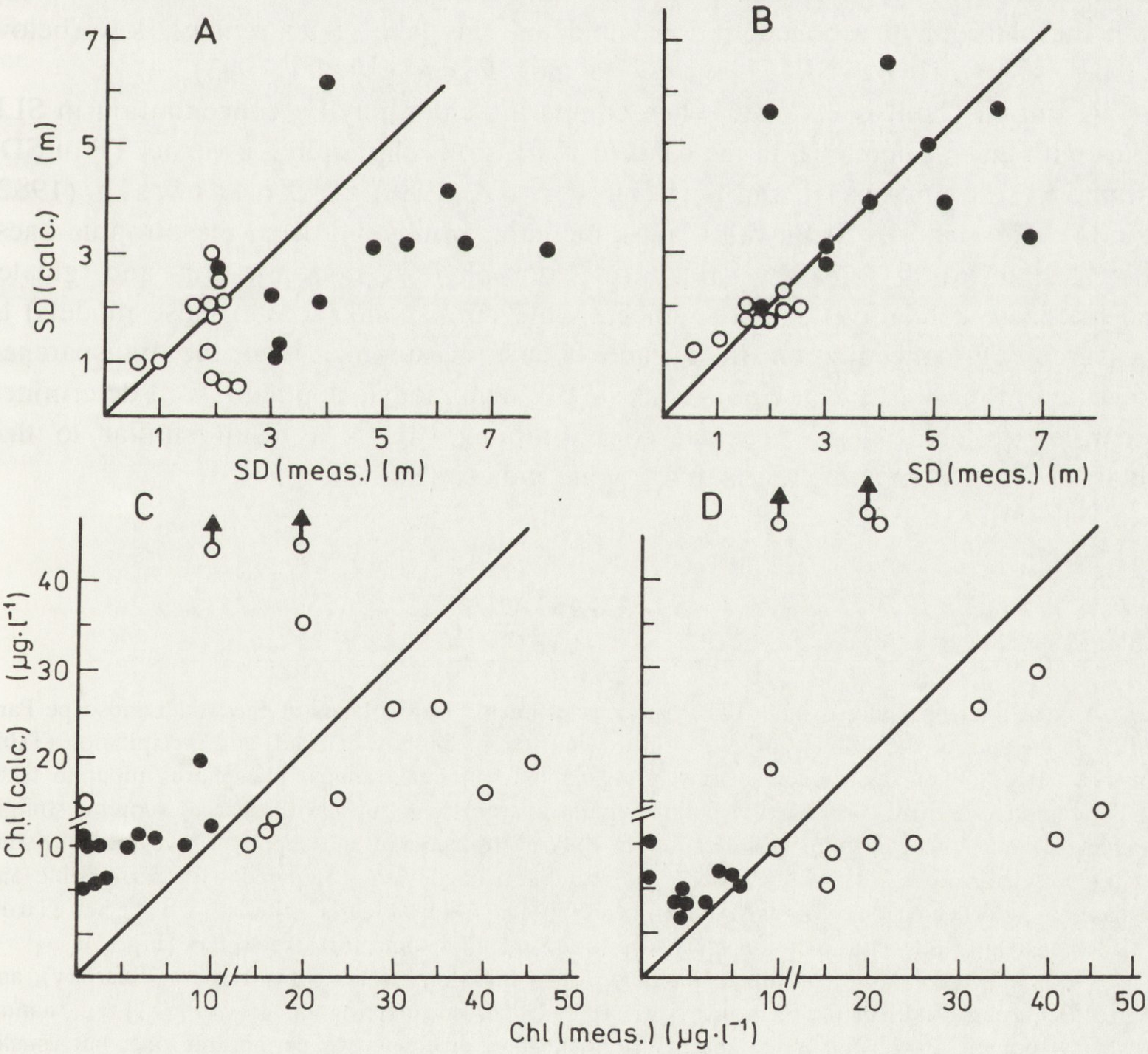

Fig. 4. The values of SD (m) and chlorophyll a concentration ($\mu g \cdot l^{-1}$ measured (meas.) summer, surface layers) in 23–25 lakes vs the values calculated (calc.) on the basis of different relations to phosphorus found for other groups of Polish lakes

Areas: dark – deep mesotrophic lakes, light – other lakes A–SD(m) = $\frac{127.35}{TP\ 1.09}$ Uchmański and Szeligiewicz (1988), B-log SD = 0.74–0.39 log Chl Zdanowski (1982), C-log Chl = 0.792 log TP–0.172 Uchmański and Szeligiewicz (1988), D-log Chl = 1.428 log TP–1.387 Zdanowski (1982) for n=195 eutrophication parameters connected with it as transparency or chlorophyll a concentration. It seems that this in consistency of Carlson's indices $TSI_{(TP)}$ versus $TSI_{(SD)}$) and versus $TSI_{(chl)}$) is especially significant in the case of deep, dimictic lakes, which display characters of mesotrophy (Fig. 3) as shown by Hillbricht-Ilkowska and Wiśniewski (1993). Whereas, $TSI_{(chl)}$ versus $TSI_{(SD)}$ values display a high correlation. An exception is lake Hańcza, less transparent than it could be expected acc. to chlorophyll a concentration consistently with Carlson model. It means that, water transparency in this lake in summer is not connected mostly with the chlorophyll a concentration which in this lake is extremely low (below 0.1 $\mu g \cdot l^{-1}$) (Hillbricht-Ilkowska and Wiśniewski 1993).

A similar result is obtained when comparing chlorophyll a concentration in SLP lakes with those calculated on the basis of regression "chlorophyll a versus TP or SD" formed by Uchmański and Szeligiewicz (1988) and Zdanowski (1982) (Fig. 4). The majority of Suwałki lakes, including almost all deep, mesotrophic ones, shows significantly smaller values of chlorophyll a concentration and greater transparency in relation to those which should correspond (acc. to these models) to measured TP concentration in surface layers, in summer. But the transparency measured in these lakes may be – consistently with models applied – well determined according to chlorophyll a actual concentration. This is a result similar to that obtained when comparing Carlson's trophic indices (Fig. 3).

5. SUMMARY

Annual total phosphorus input (TP) has been estimated for 20 lakes of Suwałki Landscape Park (SLP) as the sum of the fluvial inflow, surface runoff (from direct watershed) and precipitation (Table 1). The values obtained characterise most probably the "minimal" annual phosphorus input to lakes of the region examined, because the possible point sources (e.g. sewage discharge) running straight into lakes were not taken into consideration as well as the underground supply. However, no visible sewage discharge to lakes was observed. The values obtained were compared with permissible and dangerous loads calculated for each lake according to Vollenweider's criteria (Vollenweider 1976), i.e., taking into consideration mean depth and retention time for lake waters (Fig. 1).

The majority of lakes examined, including deep mesotrophic lakes (as Hańcza, Szurpiły), and high flow-through lakes of the Szeszupa river are in I or II endangering category (Fig. 1), i.e., annual TP load from the above mentioned sources is smaller and/or equals the permissible one, but usually less than the dangerous one. This allows to present a careful conclusion that probably the majority of SLP lakes are endangered by TP input from areal sources, moderately. This makes it basically different from the region of Great Masurian Lakes, where the lakes generally belong to a III endangering category (i.e., TP load is equal or higher than dangerous). The TN:TP weight ratio (in all input sources) in the majority of lakes remains within 15–25, i.e., values stimulating phosphorus deficit as related to nitrogen (Vollenweider 1989) (Table 1).

A correlation was looked for between annual TP input from the above mentioned sources and TP concentration in surface layers in summer. The relatively strongest correlation ($r=0.7$, $p=0.0006$) was observed between an input expressed in g TP per lake surface unit and TP concentration is surface lake water in summer (Table 2).

Determined were the interrelations (in summer, surface – layers) between the following trophic parameters: TP concentration, water transparency, chlorophyll a concentration and algal biomass

(Fig. 2, Table 3). It was also analysed whether the relations described by Carlson (1977) for other lakes (Fig. 3), and for Polish lakes (mostly Masurian Lakeland) (Fig. 4) by Uchmański and Szeligiewicz (1988) and Zdanowski (1982) can be applied to SLP lakes.

It has been found that TP concentration (summer, surface layers) does not explain much of the variation of transparency and chlorophyll a concentration (r=–0.47 and 0.49, respectively, at p=0.021 and 0.16 for the log-log functions, Table 3), although it correlates slightly better with algal biomass (r = 0.63, p = 0.0009, Table 3). However, water transparency of lakes is correlated strongly both with algal biomass (r = –0.91, p<0.000, Table 3) and chlorophyll (r = –0.79, p = 0.00002, Table 3), and the two last parameters with one another (r = 0.8, p = 0.00001, Table 3). Only in lake Hańcza the transparency is lower than should be expected, considering the chlorophyll a concentration (Fig. 3). The relation "water transparency – chlorophyll a" observed for other lake groups can be also used for SLP lakes (Fig 3 and 4).

Nevertheless, for the majority of lakes and almost for all the 12 deeper mesotrophic lakes, regressions "SD vs TP" or "chlorophyll vs TP" observed for other lake groups (including Masurian Lakes) (Fig 3 and 4) do not apply. The parameters being an eutrophication symptoms such as SD or chlorophyll a concentration are distinctly lower than they should be at a relevant TP concentration, consistently with these models.

It is consistent with results of investigations on the watershed and chemistry of inflowing waters described by Hillbricht-Ilkowska (1993). The rate of reaction of lakes of the examined area to eutrophication is weaker and slower in relation to other lake groups, because the amount of phosphorus reaching and present in the lakes is not directly available to pelagic producers, most probably being absorbed on mineral particles. The direct result of this is that chlorophyll a concentration and water transparency in SLP lakes are generally lower than judging by total phosphorus concentration.

6. POLISH SUMMARY

Oceniono szacunkową roczną dostawę fosforu ogólnego (TP) z dopływem rzecznym, spływem powierzchniowym (ze zlewni bezpośredniej) oraz z opadem, dla 20 jezior Suwalskiego Parku Krajobrazowego (SPK) (tab. 1). Wartości otrzymane charakteryzują najprawdopodobniej "minimalną" roczną dostawę fosforu do jezior badanego rejonu, ponieważ nie uwzględniono ewentualnych źródeł punktowych (np. ścieków z gospodarstw) odprowadzanych bezpośrednio do jezior ani zasilania gruntowego. Otrzymane wartości porównano ze skalkulowanymi dla każdego jeziora ładunkami dopuszczalnymi i niebezpiecznymi wg kryteriów Vollenweidera (Vollenweider 1976), tj. uwzględniając średnią głębokość i czas retencji wód jeziora (rys. 1).

Większość badanych jezior, w tym głębokie jeziora mezotroficzne (jak Hańcza, Szurpiły), jak też silne przepływowe jeziora rzeki Szeszupy wykazują I lub II kategorię zagrożenia (rys. 1), tzn. roczny ładunek fosforu całkowitego z powyższych źródeł jest mniejszy i/lub równy dopuszczalnemu, ale z reguły mniejszy niż niebezpieczny. Upoważnia to do sformułowania ostrożnego wniosku, że prawdopodobnie większość jezior SPK jest zagrożona dostawą fosforu ze źródeł obszarowych w stopniu umiarkowanym, co różni je zasadniczo od rejonu Wielkich Jezior Mazurskich, które wykazują z reguły III kategorię zagrożenia (tzn. ładunek fosforu całkowitego) jest równy lub większy niż niebezpieczny). Również o umiarkowanym zagrożeniu postępem eutrofizacji prawdopodobnie świadczy wartość wagowego stosunku azotu całkowitego do fosforu całkowitego (we wszystkich źródłach zasilania łącznie). Dla większości jezior kształtuje się on w granicach 15–25, tzn. wartości stymulujących deficyt fosforu w stosunku do azotu (Vollenweider 1989) (tab. 1).

Poszukiwano korelacji pomiędzy roczną dostawą fosforu ze źródeł jak wyżej a jego stężeniem w warstwach powierzchniowych w okresie letnim. Stosunkowo najsilniejszą korelację (r = 0,7, p = 0,0006) stwierdzono pomiędzy dostawą wyrażoną na jednostkę powierzchni jeziora a stężeniem fosforu w wodzie powierzchniowej jeziora w okresie letnim (tab. 2). Zależność ta może być wykorzystana do szacunkowego prognozowania średnioletniego stężenia fosforu w warstwach powierzchniowych jezior badanego regionu.

Określono wzajemne zależności pomiędzy wartościami (okres letni, warstwy powierzchniowe) następujących wskaźników trofii: stężenie fosforu całkowitego, przezroczystość wód, zawartość chlorofilu a w wodzie i biomasa glonów (rys. 2, tab. 3). Oceniono także, w jakim stopniu te zależności, opisane dla innych grup jezior przez Carlsona (1977) (rys. 3) oraz jezior polskich (głównie Poj. Mazurskie, rys. 4) wg Uchmańskiego i Szeligiewicza (1988) i Zdanowskiego (1982), mogą być zastosowane dla jezior SPK.

Stwierdzono, że stężenie fosforu całkowitego (okres letni, warstwy powierzchniowe) w słabym stopniu wyjaśnia zmienność takich objawów eutrofizacyjnych, jak przezroczystość i zawartość chlorofilu (odpowiednio r = –0,47 i 0,49 przy p = 0 ,021 i 0,16 dla funkcji log-log, tab. 3), chociaż nieco lepiej koreluje z biomasą glonów (r = 0,63, p = 0,0009, tab. 3). Natomiast przezroczystość wód badanych jezior jest silnie skorelowana z biomasą glonów (r = –0,91, p = 0,0000, tab. 3) i z chlorofilem (r = –0,79, p = 0,00002, tab. 3), jak również dwa ostatnie wskaźniki pomiędzy sobą (r = 0,8, p = 0,00001, tab. 3). Tylko w jez. Hańcza przezroczystość jest mniejsza w stosunku do tej, jakiej należy się spodziewać wg zawartości chlorofilu (rys. 3). Zależność przezroczystość wód–chlorofil, stwierdzona dla innych grup jezior, może być stosowana również dla jezior SPK (rys. 3 i 4).

Natomiast dla większości jezior w tym praktycznie dla wszystkich 12 głębszych jezior mezotroficznych nie stosują się regresje: widzialność krążka Secchiego a fosfor całkowity lub chlorofil a fosfor całkowity stwierdzone dla innych grup jezior (w tym Wielkich Jezior Mazurskich) (rys. 3 i 4) w tym znaczeniu, że wartości wskaźników będących objawem eutrofizacji, jak widzialność krążka Secchiego czy zawartość chlorofilu są zdecydowanie niższe od tych, jakie zgodnie z tymi modelami winny mieć miejsce przy odpowiednim stężeniu fosforu.

Może to wskazywać na bardzo ważną okoliczność, spójną z wynikami badań zlewni i chemizmu wód zasilania opisanych w pracy Hillbricht-Ilkowska (1993). Tempo reakcji jezior badanego obszaru na eutrofizację jest słabsze i powolniejsze w stosunku do innych grup jezior, ponieważ część fosforu dostającego się i obecnego w jeziorach nie jest dostępna bezpośrednio producentom pelagicznym, będąc najprawdopodobniej związana z cząstkami mineralnymi. Bezpośrednim skutkiem takiej sytuacji jest to, że zawartość chlorofilu, a w konsekwencji i przezroczystość wód, jest w jeziorach SPK na ogół niższa, niżby to wynikało z wartości stężenia fosforu całkowitego.

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