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PHYTOPLANKTON AND THE PHYSICOCHEMICAL BACKGROUND IN AN ASSESSMENT OF THE ECOLOGICAL AND TROPHIC CONDITIONS IN VENDACE-TYPE LAKES*

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Abstract

This study focused on the phytoplankton and environment relationships as well as on the ecological and trophic conditions of lakes inhabited by coregonid fish. Studies were carried out in deep and stratified vendace-type lakes called Lake Pluszne and Lake Łańskie (the Olsztyn Lake District, north-eastern Poland) in 2007-2008. Ecological and trophic conditions were determined on the basis of the phytoplankton multi-metric PMPL and Trophic State Index. Both lakes were characterized by a similar thermal and mictic regime, with the occurrence of hypolimnetic oxygen deficits. They were classified as hydrocarbonate-calcium type and medium-sized eutrophicated water bodies. According to the integrated trophy assessment, proposed in this research, the final Trophic State Index TSI_{AV} indicated meso-eutrophy of both lakes, although the phytoplankton-based PMPL indicated that the ecological potential in Lake Łańskie was good and less than good - due to large cyanobacteria biomasses - in Lake Pluszne. The actual loads of phosphorus and nitrogen significantly exceeded permissible levels, especially in Lake Łańskie (5-fold at the most of the P content), at similar morphometric and sedimentation conditions in both lakes. However, more intensive water-exchange rate and more favorable conditions for phosphorus runoff in Lake Łańskie could limit the phytoplankton growth, especially cyanobacteria. Summing up, better oxygen conditions and less abundant phytoplankton suggested that Lake Łańskie had more suitable conditions for coregonids during the surveyed period than Lake Pluszne, where the vendace biomass has recently decreased drastically.

Keywords: water quality, ecological status, trophic state, phytoplankton biomass, cyanobacteria, coregonids.

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INTRODUCTION

Coregonids as the most valuable fish in lakes, but they are extremely sensitive to deteriorating environmental conditions, especially to dissolved oxygen deficits (Czerniejewski et al. 2004, Fiszer et al. 2012, Godlewska et al. 2014). Their main representatives are the planktivorous pelagic species: vendace *Coregonus albula* L. and common whitefish *C. lavaretus* L. It is assumed that the threshold of 1.5 mg O_2 dm^{-3} is an absolute limit for these species (Godlewska et al. 2014), and below it massive fish deaths may occur. Moreover, *C. albula* was described as an indicator species (Garcia et al. 2006), typical of mesotrophic lakes, which responds negatively to the effects of progressive eutrophication. Consequently, the natural spawning and feeding (poor crustacean zooplankton resources) conditions for coregonids are limited.

Phytoplankton is responsible for half of the global oxygen production and it is the main oxygen producer in lake ecosystems. It is a very sensitive biological indicator, reacting rapidly and adapting to certain changes in an aquatic ecosystem. Many aquatic organisms are aerobes, thus their vertical distribution or even reproductive activities, especially of coregonids, may be limited because of oxygen deficits or completely anaerobic conditions (Borowiak et al. 2011).

Studies on the vendace population in Lake Pluszne completed by Godlewska et al. (2014) in 2001-2012 revealed a distinct decrease of this fish biomass, especially since 2007, when it fell from *ca* 155 (in 2007) to 5 kg ha^{-1} (in 2012). This finding was explained as resulting from the detected unfavorable temperature and oxygen conditions ("temperature-oxygen squeeze" for living space), mainly caused by increased eutrophication. The aim of the current study has been to assess the phytoplankton living in Lake Pluszne and Lake Łańskie in relation to the physicochemical variables, and to identify ecological and trophic conditions in the two lakes as natural living habitats of some coregonids.

MATERIAL AND METHODS

Studies on phytoplankton and environmental conditions were carried out in two vendace-type lakes (Lake Pluszne and Lake Łańskie), where planktivorous coregonids *C. lavaretus* and *C. albula* dominated the fish fauna. These lakes are located in the Olsztyn Lake District (north-eastern Poland). The water-flow direction in both lakes is the following: the Świerkocin Canal – Lake Pluszne – the Swaderki Canal – Lake Poplusz Wielki – the Swaderki Canal – the Marózka River – Lake Pawlik – the Marózka River – Lake Święte – the Marózka River – the Łyna River – Lake Łańskie – the Łyna

River. The data provided by LOSSOW et al. (2006) indicate that the water-flow in Lake Łańskie is much higher than in Lake Pluszne. Both lakes are deep and stratified, and belong to class 5a (Lake Pluszne) and 6a (Lake Łańskie) according to the Polish abiotic typology (MS 2005), and to LC-B1 type of lakes (lowland, stratified, shallow, calcareous) according to the *Commission Decision ...* (2013) – Table 1.

Table 1

The characteristics of the lakes

Features	Lake Pluszne	Lake Łańskie
Geographic coordinates	53.59317 N 20.40331 E	53.59513 N 20.48322 E
Surface area (km^2)	9.033	10.423
Maximal depth (m)	52.0	53.0
Mean depth (m)	14.9	16.0
Volume (10^3 m^3)	134,913.3	168,047.3
Theoretical reach of mixing* (m)	8.2	8.4
Hydraulic load (m yr^{-1})	0.91	6.91
Mictic type	dimictic	dimictic
Abiotic type**	5a	6a
Central Baltic GIG lake type***	L-CB1	L-CB1
Classification of water body****	NWB	HMWB
Fishing type	vendace	vendace

* calculated as $E = 4.4 \sqrt{D}$, where D – the average effective length of the lake;
** according to Polish abiotic typology (MS 2005);
*** according to Commission Decision (2013), L-CB1 – lowland, stratified, shallow, calcareous;
**** according to Water Framework Directive (EC 2000) NWB – Natural Water Body, HMWB – Heavily Modified Water Body;

Phytoplankton samples were collected during two growing seasons (April-November) in 2007 and 2008. In spring and autumn, integrated samples were taken at the deepest site, from the 0-5 m water column, whereas in summer they were obtained from the epilimnion and metalimnion. The phytoplankton was analysed according to standard methods (CEN 2006). Water samples for physicochemical analyses were taken in parallel to phytoplankton samples. The temperature and dissolved oxygen concentration were simultaneously measured with a YSI oxygen probe (model 58) and the transparency was assessed using Secchi disk visibility tests. The water reaction was measured with an HI 22 pH-meter (Hanna Instruments) and electrolytic conductivity was determined with a Digitalmeter DIGI 610 conductometer. The $N\text{-}NO_3^-$ concentration was measured using high performance liquid ion chromatography on an HPLC Shimadzu apparatus (Prominence system). Total phosphorus (after mineralization) and phosphates and $N\text{-}NH_4^+$ were analysed colorimetrically on a Shimadzu UV 1601 spectrophotometer. In turn, total nitrogen and $N\text{-}NO_2^-$ concentrations were analysed on an Epoll ECO 20 spectrophotometer. The concentration of chlorophyll *a* was determined with the Lorenzen method (1967, PN-86/C-05560.02). All chemical analyses were performed according to *Standard Methods* … (1999).

The Polish phytoplankton-based method (Phytoplankton Metric for Polish Lakes, PMPL) was used to assess the ecological status of the lakes. The PMPL comprises three partial metrics: chlorophyll *a* (MC), total biomass (MTB) and biomass of cyanobacteria (MBC) (Napiórkowska-Krzebietke et al. 2012, Phillips et al. 2014). The trophic state of the lakes was determined using Trophic State Index (TSI), based on the Secchi disk visibility (SDV), total phosphorus (TP) and chlorophyll *a* (Chl-*a*) (Carlson 1977), total nitrogen (TN) (Kratzer, Brezonik 1981) and total organic carbon (TOC) (Dunalska 2011). The original Carlson's TSI consists of three partial components: TSI_{SD}, TSI_{TP} and TSI_{Chl} calculated for summer variables. In this paper, the final TSI_{AV}, i.e. an average value including also TSI_{TN} and TSI_{TOC}, was derived as follows:

$$TSI_{AV} = (TSI_{SD} + TSI_{TP} + TSI_{Chl} + TSI_{TN} + TSI_{TOC})/5$$

The values of real nutrient loads (calculated from literature data, Lossow et al. 2006) in these lakes were compared with the Vollenweider's (1976) critical values: the permissible and dangerous loads of phosphorus and nitrogen. A coefficient of variation was applied to compare the degree of the physicochemical parameters variation in both lakes. The statistically significant changes of total phytoplankton and cyanobacterial biomasses and environmental variables were tested with the U Mann-Whitney test by comparing two independent groups (StatSoft, Inc.), assuming a significance level of 0.05. The *R*-Spearman correlation was used to determine the relationship between selected phytoplankton and environmental parameters.

RESULTS AND DISCUSSION

Physicochemical background

In 2007-2008, the lakes Pluszne and Łańskie were characterized by a similar thermal and mictic regime with a similar theoretical mixing reach (Table 1). The water column was well-mixed and oxygenated in spring (Figure 1). The average dissolved oxygen concentration in the whole water column was 14.8 mg dm^{-3} (oxygen saturation 117%) in Lake Pluszne and 13.3 mg dm^{-3} (oxygen saturation 105%) in Lake Łańskie. In summer, the epilimnion (thick for 4 m in June to 8 m in August) of both lakes was also well-oxygenated (over 100%). In Lake Pluszne, the thickness of the metalimnion ranged from 4 to 6 m with the maximal thermal gradient of 3.5°C m^{-1}, whereas in Lake Łańskie the metalimnion was from 3 to 7 m thick and the gradient reached 3.7°C m^{-1}. The dissolved oxygen concentration decreased down to 2.0 mg dm^{-3} (Lake Łańskie) or below 1.0 mg dm^{-3} (Lake Pluszne) in August.

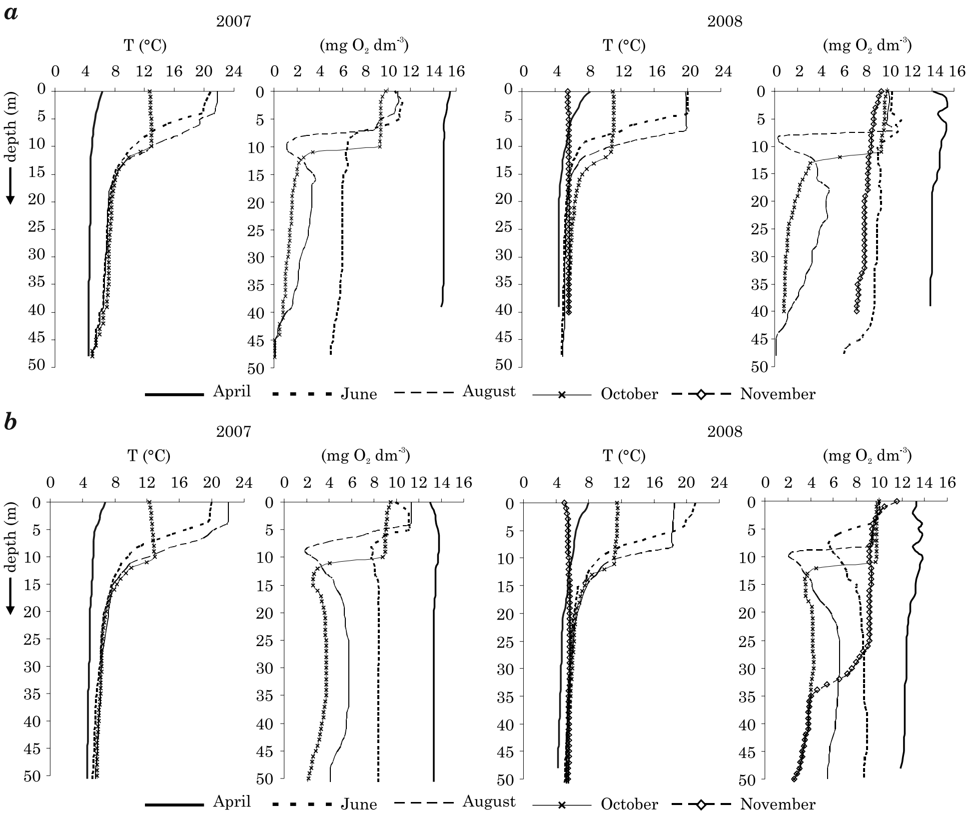

Fig. 1. Thermal and oxygen conditions in Lake Pluszne (*a*) and Lake Łańskie (*b*) in 2007-2008

Thus, the metalimnetic oxygen minimum referred to as a negative heterograde oxygen curve was recorded, which is typical of mesotrophic lakes (ZDANOWSKI et al. 2006). Similar, low oxygen concentrations in the metalimnion of Lake Łańskie had been observed in previous years (PYKA et al. 2006). The voluminous (*ca* 50% of the total lake's volume) and cold hypolimnia of both lakes had different oxygen conditions. It was only in Lake Pluszne that the dissolved oxygen concentration decreased even to trace amounts of oxygen at the bottom (August 2008). Nevertheless, hypoxia (i.e. <50% oxygenation), which occurs frequently in many freshwaters (NÜRNBERG 2004, NAPIÓRKOWSKA-KRZEBIETKE et al. 2012, NORTH et al. 2014), was observed in the hypolimnion of both lakes, The AHOD (areal hypolimnetic oxygen deficit) measured for both lakes considerably exceeded the values typical of mesotrophy or even eutrophy in Lake Pluszne in 2007 – Figure 2 (HUTCHINSON 1957, citied by ZDANOWSKI et al. 2006 and STAWECKI et al. 2013).

The pH in the surface waters of the lakes was alkaline and relatively stable (Table 2). Analogously, the electrolytic conductivity varied over a small range, reaching 282 μS cm^{-1} on the surface and 352 μS cm^{-1} near the

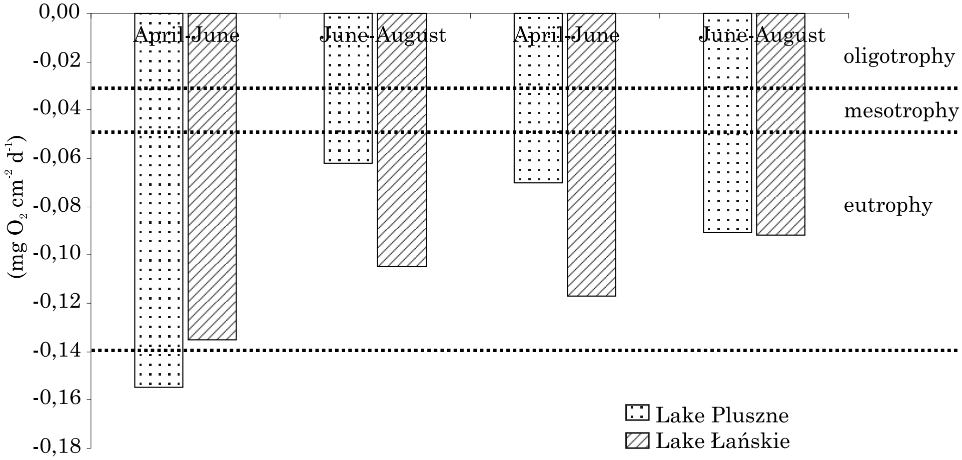

Fig. 2. Areal hypolimnetic oxygen deficit in Lakes Pluszne and Łańskie in spring (April-June) and summer (June-August) in 2007-2008, the dotted lines indicated oxygen deficit below 0.033 mg O_2 cm^{-2} d^{-1}; between 0.033 and 0.050 mg O_2 cm^{-2} d^{-1} and between 0.050 and 0.140 mg O_2 cm^{-2} d^{-1} typical of oligo-, meso- and eutrophy, respectively (according to HUTCHINSON 1957, citied by ZDANOWSKI et al. 2006)

bottom. Lake Pluszne and Lake Łańskie presented hydrocarbonate-calcium-type salinity, typical of the harmonic type of lakes in the European Lowland (MARSZELEWSKI 2005 cited by PYKA et al. 2007). The mean Chl-*a* content of 12.3 µg dm^{-3} – 2007 and 10.1 µg dm^{-3} – 2008 (Table 2) in Lake Pluszne indicated the fourth or third water quality class, moderate or poor ecological status (*Regulation* ... 2011). In Lake Łańskie, the chlorophyll concentration was typical of the second water quality class, i.e. good ecological potential. By analogy, the mean values of Secchi disk visibility (2.4 m and 2.1 m in both years) were typical of waters with a less than good ecological status in Lake Pluszne, whereas in Lake Łańskie (3.1 m and 2.8 m) they indicated at least good ecological potential. The total phosphorus and nitrogen enrichment of both lakes, as characteristic for medium-sized eutrophicated waters (ZDANOWSKI 1982, KUFEL 2001), reflected worse than good ecological status/potential (*Regulation* ... 2011). According to LOSSOW et al. (2006) and TEODOROWICZ et al. (2006), both lakes were directly or indirectly loaded with nutrients, thus playing the role of nutrient traps. Regarding nutrient variations, the highest CV was noted in the case of nitrates. Up to 209.6% in the surface layer of Lake Pluszne and up to 169.1% in the surface layer of Lake Łańskie indicated very high dispersion of nitrate concentrations. The mean concentration of total organic carbon in summer was 5.9 mg dm^{-3} in Lake Pluszne and 4.7 mg dm^{-3} in Lake Łańskie.

Phytoplankton background

During the growing seasons of 2007 and 2008, the total phytoplankton formed biomass equal 1.4-22.7 mg dm^{-3} in Lake Pluszne, and statistically

Table 2

Variability (mean, ±SD, CV) of physicochemical parameters in Lake Pluszne and Lake Łańskie in 2007-2008

Variables		pH	EC ($\mu S\ cm^{-1}$)	$N\text{-}NH_4^+$ (mg dm^{-3})	$N\text{-}NO_2^-$ (mg dm^{-3})	$N\text{-}NO_3^-$ (mg dm^{-3})	TN (mg dm^{-3})	$P\text{-}PO_4^{3-}$ (mg dm^{-3})	TP (mg dm^{-3})	Chlorophyll ($\mu g\ dm^{-3}$)
Lake Pluszne	2007	8.3 ± 0.5	240 ± 33	0.04 ± 0.02	0.004 ± 0.001	0.06 ± 0.12	0.81 ± 0.15	0.030 ± 0.021	0.094 ± 0.035	12.3 ± 5.8
	2008	8.3 ± 0.5	251 ± 20	0.05 ± 0.03	0.004 ± 0.001	0.05 ± 0.10	0.99 ± 0.10	0.021 ± 0.009	0.128 ± 0.016	10.1 ± 2.4
	CV (%)	5.5	10.6	49.4	30.8	209.6	16.6	63.4	26.9	37.8
Lake Łańskie	2007	8.2 ± 0.2	313 ± 25	0.04 ± 0.02	0.004 ± 0.002	0.05 ± 0.07	0.65 ± 0.09	0.028 ± 0.018	0.105 ± 0.025	10.7 ± 2.5
	2008	8.2 ± 0.4	331 ± 10	0.06 ± 0.07	0.003 ± 0.002	0.07 ± 0.13	0.85 ± 0.06	0.033 ± 0.024	0.156 ± 0.020	9.4 ± 5.8
	CV (%)	3.7	6.3	92.6	62.1	169.1	16.8	66.9	26.4	41.9

EC – electrolytic conductivity, TN – total nitrogen, TP – total phosphorus, CV – coefficient of variation

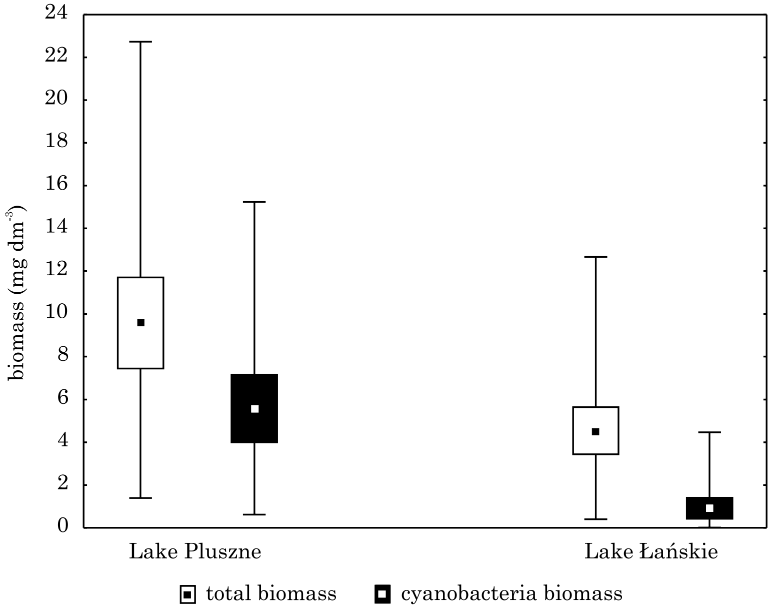

Fig. 3. Total phytoplankton biomass and cyanobacterial biomass (mean, mean±standard error, min-max) in Lakes Pluszne and Łańskie during the growing seasons in 2007 and 2008

significantly smaller biomass (0.4-12.7 mg dm^{-3}, U = 41.00, p = 0.016) in Lake Łańskie (Figure 3). The maximal values of the total biomass of phytoplankton in both lakes exceeded eutrophy and bloom thresholds (HEINONEN 1980, OLIVER, GANF 2000, NAPIÓRKOWSKA-KRZEBIETKE, DUNALSKA 2015). In Lake Pluszne, cyanobacteria were the main biomass contributor, forming statistically significantly higher biomass than in Lake Łańskie (U = 13.00, p = 0.001). The cyanobacterium dominants were species from the genera *Limnothrix*, *Planktolyngbya, Pseudanabaena* and *Aphanizomenon*, including toxin-producing *A. gracile* (Lemm.) Lemm. (KOBOS et al. 2013). The phytoplankton in Lake Łańskie was co-dominated by diatoms, chrysophytes and cryptophytes in 2007, but a distinct domination of cyanobacteria was recorded in 2008.

Ecological and trophic state of the lakes

The final multi-metric PMPL indicated a poor ecological status of Lake Pluszne (Table 3). The PMPL value was 3.48 in the first year and 3.53 in the second year of the research, which – according to HUTOROWICZ et al. (2011) – was close to the mid-range of that class, and could be the most reliable assessment. Partial assessments provided by the MC, MTB and MBC were not as consistent. The lowest values were achieved from the MC metric concerning Chl-*a*, which indicated a good ecological status. However, the high MBC metric value corresponded to a bad status and finally resulted in a worse

Table 3

Phytoplankton-based ecological status assessment of Lakes Pluszne and Łańskie

Lake	Year of study	MC	MTB	MBC	PMPL	Ecological status*/ potential**
Pluszne	2007	1.85	3.58	5.00	3.48	poor
	2008	1.65	3.94	5.00	3.53	poor
Łańskie	2007	1.69	1.90	0	1.20	good
	2008	1.48	2.70	1.20	1.79	good

MC – metric chlorophyll *a*, MTB – metric total biomass, MBC – metric biomass of cyanobacteria, PMPL – multi-metric Phytoplankton Metric for Polish Lakes,
* Lake Pluszne, ** Lake Łańskie; the metric thresholds of 1, 2, 3, 4 (according to NAPIÓRKOWSKA-KRZEBIETKE et al. 2012) for the high/good, good/moderate, moderate/poor, poor/bad ecological status, respectively

assessment based on the PMPL. Lake Łańskie had good ecological potential and the results of its assessment were more stable. Thus, only this lake met the WFD-required target of having at least good ecological status or potential.

Another partial assessment indicator, TSI_{TP} (Table 4), implicated slightly more eutrophicated waters, probably due to large P-amounts in the form unavailable to phytoplankton that are recorded in some Masurian lakes (PYKA et al. 2007). The CARLSON's TSI (1977) as an average of TSI_{SD}, TSI_{Chl} and TSI_{TP} indicated the near-eutrophy of the surveyed lakes. The schemes of CARLSON (1977) and KRATZER and BREZONIK (1981) aggregated by CARLSON and SIMPSON (1996) into one procedure and now also combined with TSI_{TOC} proposed by DUNALSKA (2011) were applied to calculate the final Trophic State

Table 4

The combined TSI-based trophic state assessment of Lake Pluszne and Lake Łańskie (June-August in 2007-2008)

Lake	Year of study	TSI_{SD}	TSI_{Chl}	TSI_{TP}	TSI_{TN}*	TSI_{TOC}**	TSI***	TSI_{AV}****	Trophic state*****
Pluszne	2007	54	53	75	53	48	61	57	meso-eu
	2008	54	54	75	55	48	61	57	meso-eu
Łańskie	2007	52	54	73	48	46	60	55	meso-eu
	2008	53	48	77	52	44	59	55	meso-eu

* according to KRATZER, BREZONIK (1981);
** according to DUNALSKA (2011);
*** the CARLSON's (1977) TSI as averaged value obtained from TSI_{SD}, TSI_{Chl} and TSI_{TP};
**** TSI_{AV} as averaged value obtained from TSI_{SD}, TSI_{Chl}, TSI_{TP}, TSI_{TN} and TSI_{TOC};
TSI thresholds:
40, 50 and 60 for mesotrophy, meso-eutrophy and eutrophy (CARLSON 1977);
50 and 70 or 75 for meso-/eu- and eu-/hypereu-trophy (CARLSON, SIMPSON 1996, HÅKANSON, BOULION 2001);
52, 59 and 63 for oligo-/meso-, meso-/eu- and eu-/supereu-trophy (TOLEDO et al. 1983, cited by AFFONSO et al. 2011);
***** own proposal based on TSI_{AV} and classification system given by CARLSON (1977)

Index TSI_{AV}. This approach is suggested by the authors as a new integrated assessment of trophic conditions. The above combination of several methods allowed us to obtain a more suitable multivariable index. This new, TSI_{AV}--based assessment of both lakes (55, 57; Table 4) corresponded well with eutrophy defined by Carlson, Simpson (1996) and Håkanson, Boulion (2001) or even mesotrophy proposed by Toledo et al. (1983, cited by Affonso et al. 2011). Furthermore, by adopting the classification system given by Carlson (1977), both lakes can be finally assessed as meso-eutrophic waters based on the TSI_{AV}. In relation to the possible attributes given by Carlson and Simpson (1996) for northern temperate lakes, anoxic hypolimnia, loss of salmonids and occurrence of warm-water fish with the domination of bass in the meso- and eutrophic lakes could be excepted (by TSI 40-50 and 50-60).

Phytoplankton against the physicochemical variables

The phytoplankton and environmental variables reveal highly varied interrelations (Napiórkowska-Krzebietke et al. 2013, Napiórkowska-Krzebietke, Hutorowicz 2015). In our studies, significant and positive correlations were detected between the total biomass and the concentrations of dissolved oxygen, total nitrogen and total organic carbon and pH (Table 5). However,

Table 5

The *R*-Spearman correlation coefficient* between selected phytoplankton and environmental parameters

Parameters	T	DO	SDV	pH	EC	TN	TP	$P\text{-}PO_4^{3-}$	TOC
TB	n.s.	0.421	-0.648	0.700	-0.513	0.454	n.s.	-0.466	0.498
BCy	n.s.	n.s.	n.s.	n.s.	-0.639	0.616	n.s.	-0.459	0.648
Chl-*a*	n.s.	n.s.	-0.477	0.494	-0.442	n.s.	n.s.	n.s.	n.s.

* statistically significant correlation, $p < 0.05$, n.s. – not significant, $n = 28$, TB – total biomass, BCy – cyanobacteria biomass, Chl-*a* – chlorophyll *a*, T – temperature, DO – dissolved oxygen, SDV – Secchi disk visibility, EC – electrolytic conductivity, TN – total nitrogen, TP – total phosphorus, TOC – total organic carbon

negative correlations were recorded with electrolytic conductivity, phosphates and Secchi disk visibility. Cyanobacterial biomass revealed that analogous significant relations likewise were significant but only with the TN, TOC, EC and PO_4-P. Although chlorophyll *a* is used as an equivalent of phytoplankton biomass (e.g. approved in *Regulation* ... 2011), its concentration is significantly correlated only with the SDV, pH and EC. The statistically non-significant relations between Chl-*a* and TN, TP or their mineral forms, were in contrast to the general thesis (e.g. Lewis, Wurtsbaugh 2008). Phosphorus is often found in a form unavailable to freshwater phytoplankton (Pyka et al. 2007, Napiórkowska-Krzebietke et al. 2013, Jekatierynczuk-Rudczyk et al. 2014).

The alkalinity of water in both lakes caused standard precipitation of bicarbonates and phosphorus binding on calcite. The co-precipitation process could balance the significant loads of phosphorus discharged into the lakes from the catchment and it could reduce its own resources directly available to phytoplankton in the epilimnion. This mechanism is characteristic of mesotrophic lakes and river-lake systems (Stawecki et al. 2003, Zdanowski et al. 2006). The phosphorus load supplied to Lake Łańskie (1.01 g P m^{-2}) was nearly one order of magnitude greater than in Lake Pluszne (0.10 g P m^{-2}). The real phosphorus loads were, thus, five- and two-fold higher than the permissible values proposed by Vollenweider (1976). By analogy, the real nitrogen load in Lake Łańskie (5.34 g N m^{-2}, i.e. exceeding two-fold its permissible load) was eight-fold higher than in Lake Pluszne (0.73 g N m^{-2}). The hydrological properties of Lake Łańskie, despite these high P and N loads, could retard eutrophication. Furthermore, the more intensive water flow in this lake created favourable conditions for the removal of phosphorus load, which could limit the risk of persistent phytoplankton blooms. In more stagnant Lake Pluszne, however, the conditions for phytoplankton growth (especially for cyanobacteria) were more favourable. Theoretically, better oxygen conditions and less abundant phytoplankton (good ecological potential) in Lake Łańskie should be more suitable for coregonids to maintain their population than in Lake Pluszne.

CONCLUSIONS

Lake Pluszne and Lake Łańskie were meso-eutrophic lakes according to the new, integrated trophy assessment (TSI_{AV}). The concentrations of TN and TP similarly indicated worse than good ecological status/potential of both lakes, but the real loads of phosphorus and nitrogen, as regards their permissible loads, were more distinctly exceeded in Lake Łańskie than in Lake Pluszne. Such findings as the summer cyanobacterial domination and relatively large total phytoplankton biomass (up to 23 mg dm^{-3}) in Lake Pluszne indicated its more advanced eutrophication stage. Consequently, the phytoplankton-based assessment indicated that Lake Łańskie had better water quality (i.e. good ecological potential) and – unlike Lake Pluszne – satisfied the WFD-required target of ensuring clean waters. Furthermore, the intensive water flow in Lake Łańskie could limit phytoplankton growth, especially cyanobacteria. Better oxygen conditions and good ecological potential in Lake Łańskie suggested that it had more suitable conditions for coregonids than Lake Pluszne during the analysed time period.

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