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Long-term changes in water quality and ecological status of lakes in the Wielkopolska National Park and its buffer zone with special reference to effectiveness of the lakes' protection

by

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Abstract

This paper evaluates water quality and ecological status of lakes located in the Wielkopolska National Park and its buffer zone. Changes in water quality were analyzed from 1974 to 2012 in order to assess the effectiveness of the protection strategies implemented on the studied lakes since 1957, i.e. the date when the park was established. The ecological status of the lakes was assessed with the use of macrophytes as well as hydromorphological and physicochemical analyses performed in 2012. Changes in water quality of the studied lakes within the last 40 years were analyzed based on available published and unpublished data, as well as field studies. All water bodies are characterized by advanced eutrophication. However, evaluation of the ecological status showed good status of the charophyte-dominated lakes, i.e. Lake Wielkowiejskie and Lake Budzyńskie. Lack of significant differences in physicochemical water qualities between the park and its buffer zone indicated that measures implemented to protect the water, particularly in the park, are ineffective. This study shows that more radical conservation measures are necessary to protect and improve the water quality, not only in WPN and its buffer zone but also in the whole catchment area.

Key words: Carlson index, macrophytes, physicochemical parameters, hydromorphology, alternative stable states

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Introduction

Eutrophication of water bodies is one of the most problematic issues in lake protection. High nutrient availability, specifically nitrogen and phosphorus, affects phytoplankton blooms and toxic cyanobacteria (particularly negative), and causes increases in blooms of gelatinous zooplankton and intensification of macrophyte growth, which consequently result in a decline of the lake biodiversity (Wiik et al. 2015; Yu et al. 2015). High phosphorus and nitrogen concentrations are of benefit to the fastest growing species, characterized by high biomass, which suppresses the slow growing or rare ones. On the other hand, reduced water transparency results in the inhibited growth of submerged macrophytes due to reduced light availability. The decay of algae requires oxygen, the deficiency of which is observed in the water column of deep eutrophic lakes. This, in turn, negatively affects fish and macroinvertebrate populations. In extreme cases, it causes fish death. Under anaerobic conditions, phosphorus is released from the bottom sediments, which accelerates the eutrophication process. Moreover, at the time of nitrogen-fixing cyanobacteria blooms, water is additionally supplied with nitrogen. Intensification of phytoplankton growth causes lake shallowing, and as a result of intensive development of macrophytes, lakes become overgrown with encroaching vegetation. These processes contribute to the disappearance of lakes (Choiński et al. 2014; Tao et al. 2015).

An increase in nutrient availability in the surface water occurs mostly due to human activities, industrial and/or domestic run-off, particularly from wastewater discharges, leakage from the sewage system or septic tanks, and contamination from agricultural sources (Aksever et al. 2015; Li et al. 2015). Agricultural activity is a major threat to the quality of surface and groundwater, mainly due to its spatial characteristics. Point sources can be more easily located and eliminated. On the other hand, spatial nature of non-point pollutants, combined with their considerable dispersion, make it difficult to locate the source and eliminate the pollutants.

The most effective way to protect lakes is to prevent their contamination. In the European Union, measures have been taken to prevent contamination of surface water with pollutants, particularly through implementation of the Water Framework Directive (European Commission Directive 2000) and Nitrates Directive (European Commission Council Directive 1991). Moreover, sources of pollutants are supposed to be effectively eliminated in catchment areas of lakes situated in protected areas such as national or landscape parks, and Natura 2000 sites. This particularly applies to areas subject to long-term protection.

The objectives of the study were 1) to evaluate the ecological status of the lakes located in the Wielkopolska National Park and its buffer zone, and 2) to assess changes in water quality of the studied water bodies from 1974 to 2012 as a manifestation of the effectiveness of the implemented protection strategy for water quality of the analyzed lakes.

Study sites

Wielkopolska National Park (*Wielkopolski Park Narodowy*, WPN) is located about 15 km from Poznań (central-west Poland). It is one of the oldest national parks in Poland, established in 1957 over an area of 5244 ha (Council of Ministers 1957). The current area of the park is 7584 ha. Its buffer zone covers 7256 ha (Council of Ministers 1996). Most of the park's area has been protected since 1934. This area is also protected by the Natura 2000 European Network. There are 11 lakes located in the park and five in the buffer zone (Fig. 1). The lakes were formed during the last Baltic glaciation, i.e. 10 thousand years ago. Most of the lakes are ribbon lakes, except for the terminal moraine Kociołek Lake. The biggest one is Lake Łódzko-Dymaczewskie (127 ha), and the deepest one is Lake Góreckie (16.8 m) (Table 1). Lake Trzcielińskie has a high disappearance rate. Currently, the lake is characterized by features of a pond: small area, depth of 0.3 m, and thick bottom sediments (Lawniczak, Rutkowski 2013) and it was not included in the present analysis.

Materials and methods

Assessment and classification of the ecological status of the lakes were carried out using biological parameters, such as a macrophyte determinant, supported by hydromorphological and physicochemical analyses. The ecological status based on macrophytes was determined using the ecological state macrophyte index (ESMI) (Ciecierska 2008). A vegetation survey was performed during the growing season of 2012, along transects located perpendicular to the shoreline, with a width of 30 m and a length determined by a depth of vegetation occurrence. A supplementary survey on macrophytes was carried out in 2013.

Hydromorphological conditions of the studied lakes were assessed using the Lake Habitat Survey method (Soszka, Skocki 2008), which includes

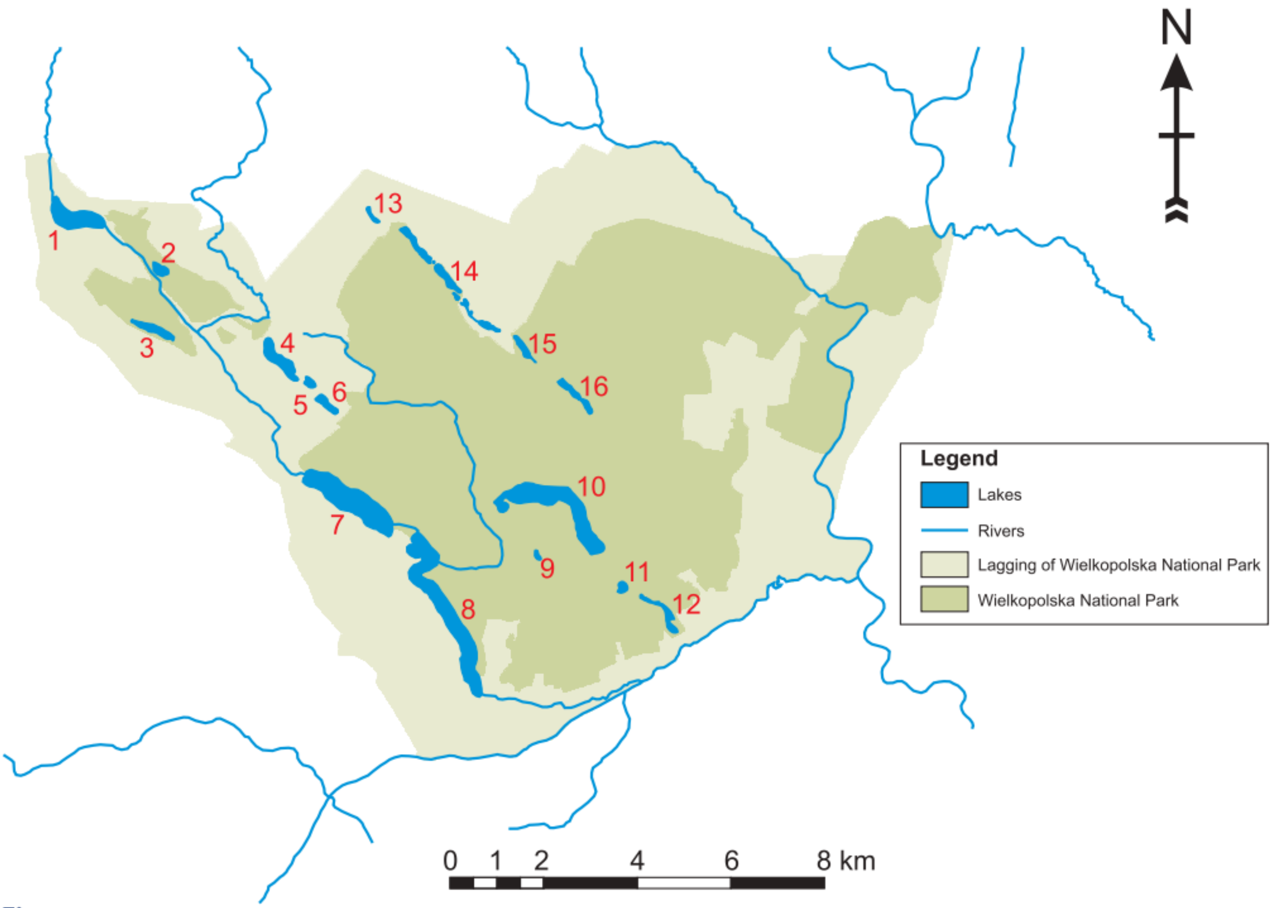

Figure 1

Location of the lakes in the Wielkopolska National Park and its buffer zone

Explanations: 1 – Tomickie, 2 – Trzcielińskie, 3 – Wielkowiejskie, 4 – Dębno, 5 – Bochenek, 6 – Lipno, 7 – Witobelskie, 8 – Łódzko-Dymaczewskie, 9 – Skrzynka, 10 – Góreckie, 11 – Kociołek, 12 – Budzyńskie, 13 – Konarzewskie, 14 – Chmęcicko-Rosnowskie, 15 – Małe, 16 – Jarosławieckie lakes

Table 1

Morphometric parameters of the studied lakes

Lake	Area (ha)	Volume (thou. m^3)	Coastline length (m)	Maximum depth (m)	Mean depth (m)	Location
Górecko-Budzyńska trough						
Góreckie[1]	99.8	8872.8	8190	16.8	8.8	WPN
Skrzynka[1]	1.7	33.5	575	3.3	2	WPN
Kociołek[1]	4.2	156.8	784	7.4	3.7	WPN
Budzyńskie[1]	13.5	224.7	2896	3.5	1.7	WPN
Witobelsko-Dymaczewska trough						
Tomickie[2]	38.7	429.5	3340	1.7	1.1	buffer zone
Wielkowiejskie[1]	15.4	260.3	8190	4.5	1.7	WPN
Witobelskie[1]	97.5	3550.6	5178	5.3	3.6	WPN
Łódzko-Dymaczewskie[1]	127	7473	9263	12.7	5.9	WPN
Rosnowsko-Jarosławiecka trough						
Konarzewskie[3]	2.5	88.5	988	6.8	3.5	buffer zone
Chomęcicko-Rosnowskie[1]	41.2	1902.8	7193	11.2	4.6	WPN
Małe[3]	6.6	116	1685	4.7	1.8	WPN
Jarosławieckie[1]	12.7	464.4	2327	6.2	3.6	WPN
trough of lakes Dębno-Lipno						
Dębno[3]	19	1470	2630	12.7	7.7	buffer zone
Bochenek[3]	3	139	825	7.6	4.6	buffer zone
Lipno[3]	7.8	321	1450	10.1	4.1	buffer zone

[1] – according to IMGW 2010; [2] – Ławniczak et al. 2011; [3] – Ławniczak et al. 2013

morphological conditions and the hydrological regime. The method is based on 10 sections (Hab-Plots) with a width of 15 m, within which the riparian, shore, and littoral zones were analyzed. Additionally, human pressures affecting the lakes, such as recreation (angling, swimming, motorboat sport, swimming), lake reclamation (e.g. dredging), fishery management, navigation, and others were recorded. Also, hydrological and geomorphological information was included. On the basis of two indices: the Lake Habitat Modification Score (LHMS) and the Lake Habitat Quality Assessment, the transformation of the lakes was assessed. LHMS values below 10 indicate a very good ecological status of lakes.

Water samples for chemical analysis were collected from the lakes in April and June/August 2012. Water temperature, dissolved oxygen and pH were measured in situ using a digital potentiometer (Elmetron CX-401), and conductivity using a potentiometer (Elmetron CC-551). Water samples for chemical analysis were collected from two layers: 30 cm below the surface and 60 cm above the bottom, always from the deepest part of the lake. Additional water samples were collected from different parts of three lakes characterized by elongated shape (Łódzko-Dymaczewskie, Góreckie and Chomęcicko-Rosnowskie). Two bottles were collected from each site. The first sample was filtered using Sartorius cellulose filters with a nominal pore size of 0.45 μm. The second one was not filtered for the determination of total phosphorus (P) and nitrogen (N). All samples were stored in the fridge and analyzed no later than 8 hours after the collection. Concentrations of soluble reactive phosphorus (amino acid method), total phosphorus (acid persulfate digestion method), nitrate (cadmium reduction method), ammonium (Nessler's method), nitrite (ferrous sulfate method), organic nitrogen (Kjeldahl's method), sulfates (colorimetric method), and chemical oxygen demand (COD; dichromate method) were determined using a HACH DR/2800 spectrophotometer (HACH 1992). Dissolved organic carbon (DOC) was measured with a HACH DR/400U spectrophotometer. Potassium concentrations were measured with flame emission spectroscopy, on a Sherwood Model 425. Chlorides, magnesium, and calcium were obtained with the titration method. Alkalinity was assessed with sulfuric acid to an end point of pH=4.5 using a pH analyzer (Elmetron CPI-551). Phytoplankton biomass was measured spectrophotometrically, based on chlorophyll a (Elbanowska et al. 1999). Visibility was determined using a Secchi disc.

Total assessment of the ecological status of the water was based on biological, hydromorphological and physicochemical water quality in relation to the Regulation of the Minister of the Environment of 22 October 2014 (Minister of the Environment 2014). Changes in water quality of the studied lakes within the last 40 years were analyzed based on available published and unpublished data (Brzęk 1948; Dąmbska et al. 1978; Dąmbska et al. 1981; Zerbe et al. 1994; Walna et al. 1996; Burchardt et al. 1999; Pułyk, Szulczyńska 1999; Siepak 2001; Owsianny 2003; Tybiszewska, Szulczyńska 2006). Four periods (1974, 1984, 1998, 2012) were chosen for the current study, for which most of the data were available. For the first three periods, data were obtained from archival materials, and for the fourth period – from a field survey. In the case of Lake Skrzynka, the hydrochemical dystrophy index (HDI) was calculated according to Górniak (2004, 2006) to assess the degree of water dystrophication. Surface water quality was assessed on the basis of the trophic status using Carlson's trophic state index (TSI) (Carlson 1977). The index is based on the content of chlorophyll a (Chl), total phosphorus concentrations (TP) in the water and Secchi depth visibility (SD). The mean values from the June-August period were used. Values of each indicator were calculated according to the following formulae:

$$TSI(Chl) = 9.81 \ln(Chl) + 30.6$$

$$TSI(SD) = 60 - 14.43 \ln(SD)$$

$$TSI(TP) = 14.43 \ln(TP) + 4.15$$

$$TSI = [TSI(Chl) + TSI(SD) + TSI(TP)]/n.$$

Based on the TSI values, the lakes are classified as oligotrophic (low productivity; TSI<40), mesotrophic (moderate productivity; TSI = 40-50), eutrophic (high productivity; TSI = 50 to 70) and hypereutrophic (very high productivity; TSI>70).

Statistical analyses

All statistical analyses were performed using Statistica (StatSoft, Poland) software. The data were transformed (square root or logarithmic) to assess the homogeneity of variance. Differences among the physicochemical parameters of water within the studied lakes were tested with analysis of variance (ANOVA) and Tukey's post hoc test. Principal component analysis (PCA) was employed to investigate differences between the lakes based on water quality parameters measured in 2012.

Results

Water quality of the lakes located in the Wielkopolska National Park and its buffer zone varied considerably. Based on the physical and chemical water quality parameters in the PCA diagram, the lakes form three groups. Lakes Lipno, Budzyńskie, Góreckie, Skrzynka, and Jarosławieckie are grouped in the right part of the diagram by positive values of PC1 and PC2 (Fig. 2). Positive values of PC1 and negative values of PC2 are recorded for lakes Bochenek, Dębno and Małe (particularly Lake Bochenek), which are discriminated by high values of phosphates, total phosphorus and high conductivity. Negative PC1 values are observed for lakes characterized by the worst water quality as compared to other studied water bodies. Only three lakes – Kociołek, Wielkowiejskie and Konarzewskie – are distinguished from the others. Lake Kociołek shows a negative correlation with PC2, and was distinguished by the lowest concentrations of nitrate and sulfates, and high ammonium content. Lake Konarzewskie differed the most from the other water bodies. It was characterized by the highest concentrations of alkalinity, phosphates, total phosphorus and calcium.

The first two principal components together explain 50.63% of the observed variation (Fig. 3). PC1 is most strongly correlated with the level of hardness, phosphates, total phosphorus and calcium content. PC2 is correlated with forms of nitrogen, although these correlations were not significant.

PCA was conducted to better understand the correlations between the measured properties. The PCA showed that some of the physicochemical parameters, such as SRP, TP, NH_4^+, and calcium were closely correlated (Fig. 3). On the other hand, oxygen saturation and pH revealed a negative correlation with these ingredients. These connections occur mostly through photosynthesis. Additionally, close relationships were determined between chlorides, sulfates, conductivity and COD (Fig. 3).

In 2012, water quality parameters varied between the studied lakes and within the sampling layers. Significant differences were determined for most of the studied parameters except the forms of nitrogen (Table 2). Larger differences occur between the lakes than among the sampling layers. These interactions

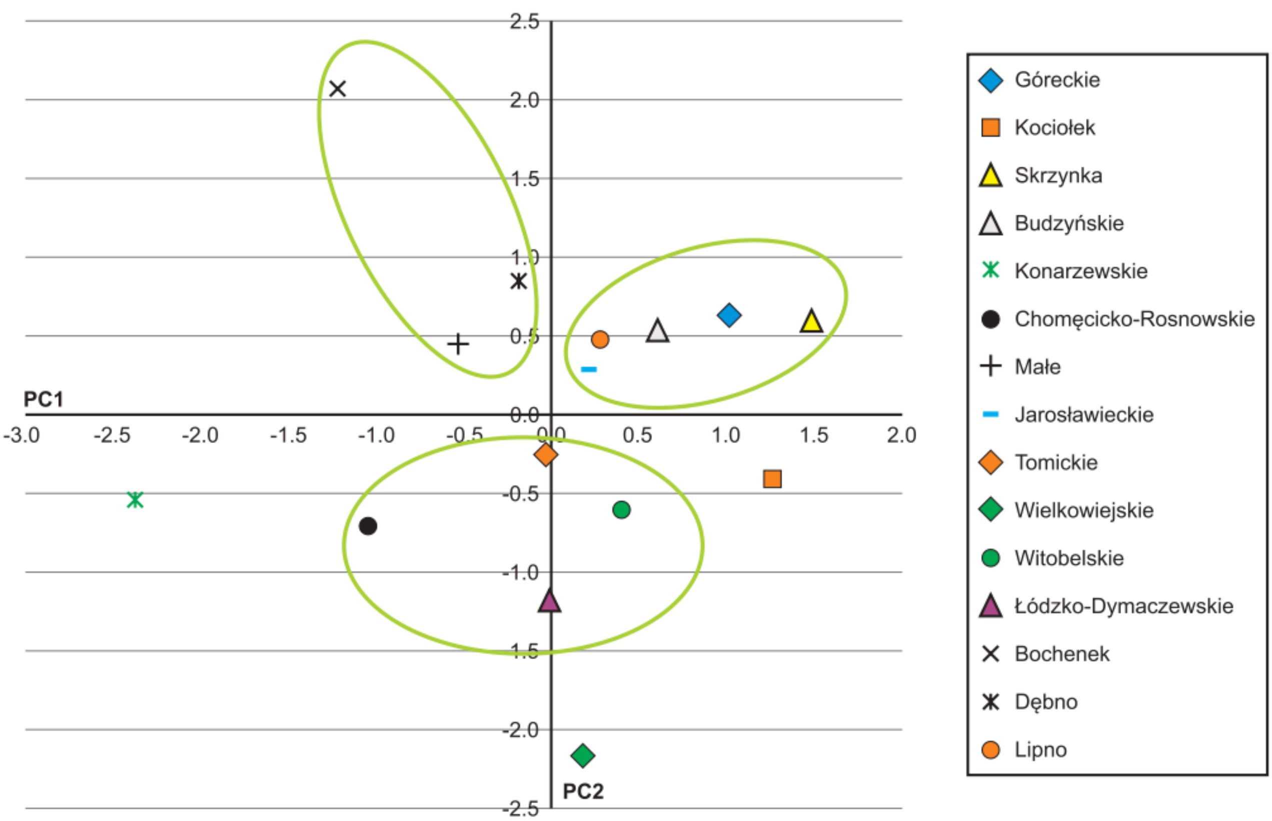

Figure 2

Distribution of the analyzed lakes in the Wielkopolska National Park and its buffer zone in the system of the first two principal components (PC1 and PC2) based on surface water parameters

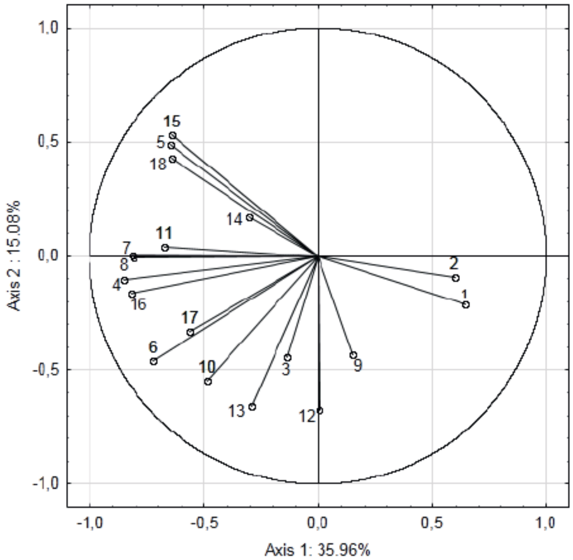

Figure 3

Correlations between the first two principal components PCA1 and PCA2 of physicochemical parameters of the studied lakes. Explanations: 1 – pH, 2 – oxygen conc., 3 – temp., 4 – hardness, 5 – conductivity, 6 – alkalinity, 7 – soluble reactive phosphorus, 8 – total phosphorus, 9 – nitrite, 10 – nitrate, 11 – ammonium, 12 – Kjeldahl nitrogen, 13 – total nitrogen, 14 – sulfates, 15 – chlorides, 16 – calcium, 17 – magnesium, 18 – COD

were generally smaller than the main effects (smaller *F* ratios in Table 2); significant differences were determined between the lakes and sampling layers in relation to concentrations of phosphorus, ammonium, COD and chlorides.

The highest values of phosphates and total phosphorus were measured during the summer in the hypolimnion of lakes Konarzewskie, Chomęcicko-Rosnowskie, Bochenek and Małe, indicated by the internal lake supply of nutrients. In Lake Konarzewskie, phosphates and total phosphorus concentrations were also high on the surface (Fig. 4, 5). The mean concentrations of bioavailable soluble reactive phosphates (SRP) ranged from 0.62±0.54 mg PO_4^{3-} dm^{-3} in spring to 0.35±0.18 mg PO_4^{3-} dm^{-3} in summer.

Generally, ammonium was depleted in the epilimnion, except for Lake Kociołek in summer. The highest ammonium concentrations were recorded in the sub-bottom of lakes Konarzewskie, Chomęcicko-Rosnowskie, Dębno and Bochenek; they varied between 2.5 and 2.7 mg NH_4^+ dm^{-3} (Fig. 6). Nitrate concentrations varied considerably among the lakes (Fig. 7). However, these differences were not statistically significant. The highest values were noted in lakes Łódzko-Dymaczewskie, Witobelskie, Wielkowiejskie and Tomickie in the surface water in spring, and ranged from 0.9 to 1.2 mg NO_3^- dm^{-3}. The largest differences among the measured parameters were

Table 2

Results of two-way ANOVA testing the differences in water physicochemical parameters measured in 2012 among the studied lakes and sampling layers (surface and bottom)

Parameters	Type of transformation	Lake		Sampling layer		Lake*Sampling layer	
		dF = 14		dF = 1		dF = 14	
Phosphates (mg PO_4^{3-}-P dm^{-3})	square root	5.67	***	16.73	***	2.91	*
Total phosphorus (mg PO_4^{3-}-P dm^{-3})	square root	3.75	**	16.23	***	1.86	ns
Nitrites (mg NO_2^--N dm^{-3})	square root	0.29	ns	0.58	ns	0.22	ns
Nitrates (mg NO_3^--N dm^{-3})	square root	1.27	ns	0.13	ns	1.14	ns
Ammonium (mg NH_4^+-N dm^{-3})	square root	2.90	*	33.23	***	2.67	*
Kjeldahl nitrogen (mg N dm^{-3})	square root	1.33	ns	0.55	ns	0.70	ns
Total nitrogen (mg N dm^{-3})	square root	1.28	ns	4.42	*	1.14	ns
Sulfates (mg SO_4^{2-} dm^{-3})	-	4.35	*	0.54	ns	0.56	ns
Magnesium (mg Mg^{2+} dm^{-3})	ln	3.80	**	0.26	ns	0.58	ns
COD (mg O_2 dm^{-3})	-	9.38	***	41.07	***	6.28	***
Chlorides (mg Cl^- dm^{-3})	-	25.89	***	16.18	***	3.35	**
Calcium (mg Ca^{2+} dm^{-3})	-	17.91	***	0.00	ns	0.76	ns
Oxygen (mg O_2 dm^{-3})	-	0.93	ns	48.86	***	0.90	ns

Data are F ratios and significance levels given as ***p<0.001; **p<0.01; *p<0.05 and ns p>0.05.

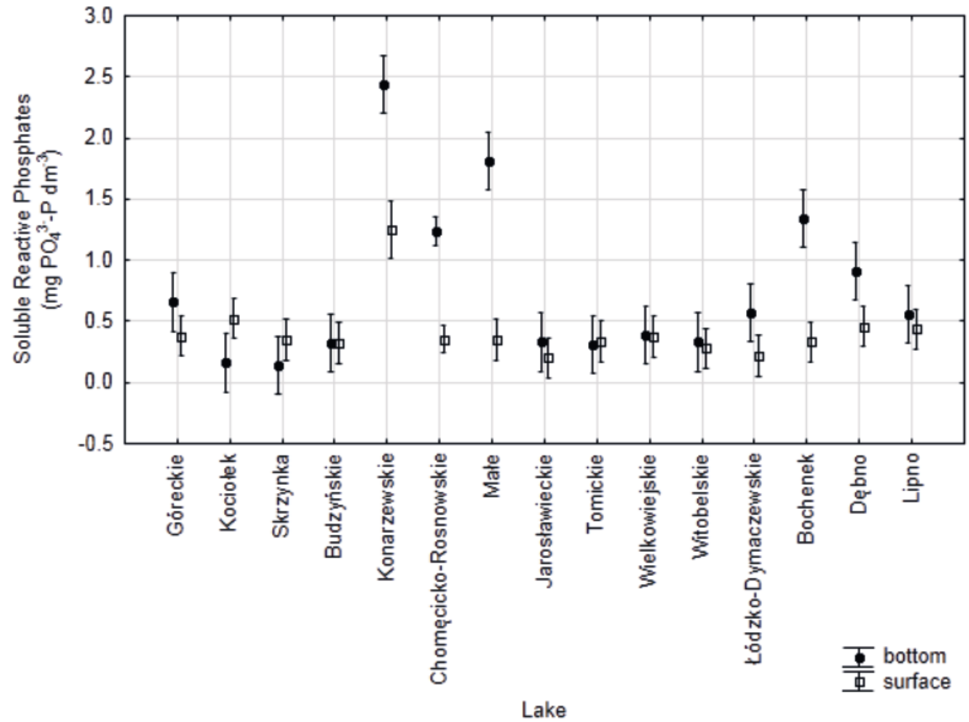

Figure 4

Variations of the soluble reactive phosphates in the studied lakes in 2012

Explanations: midpoint – mean; whiskers – standard error

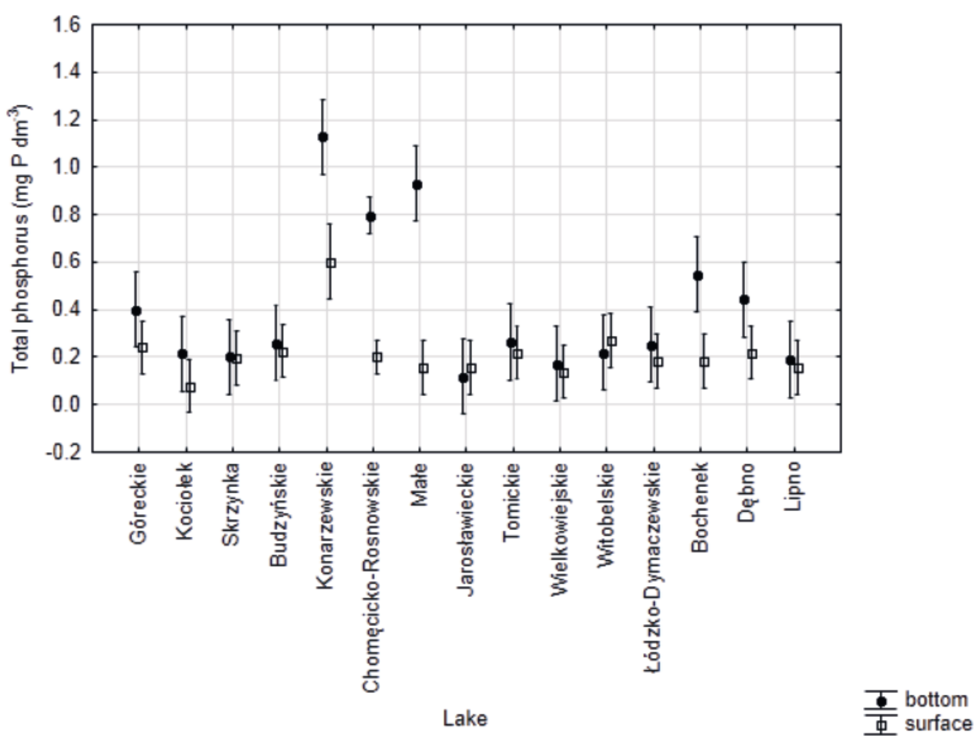

Figure 5

Variations of the total phosphorus in the studied lakes in 2012

Explanations: midpoint – mean; whiskers – standard error

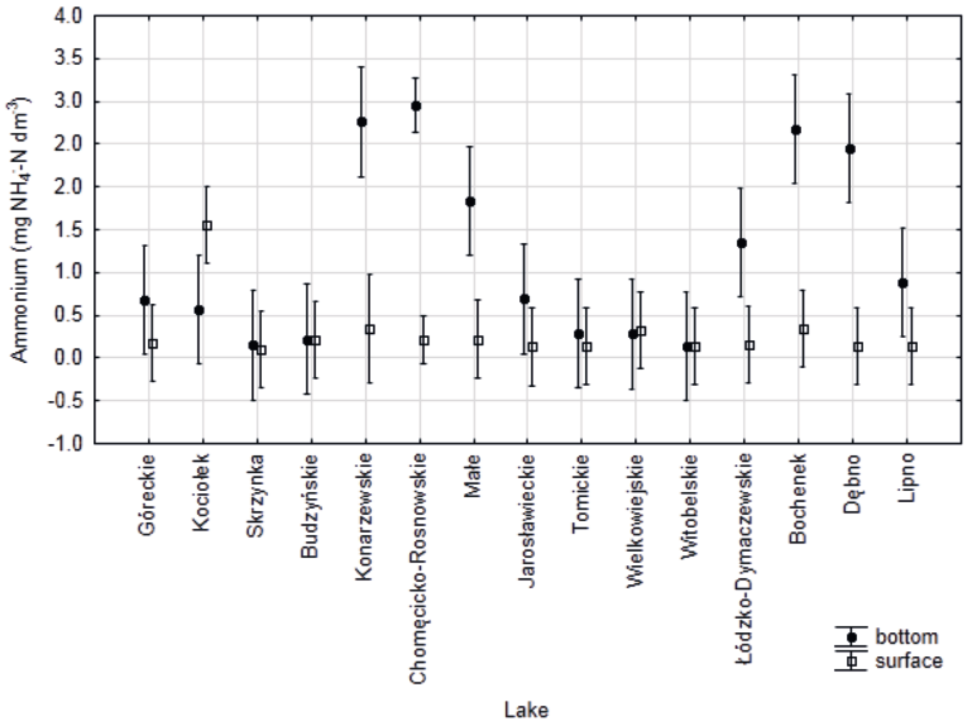

Figure 6

Variations of the ammonium in the studied lakes in 2012

Explanations: midpoint – mean; whiskers – standard error

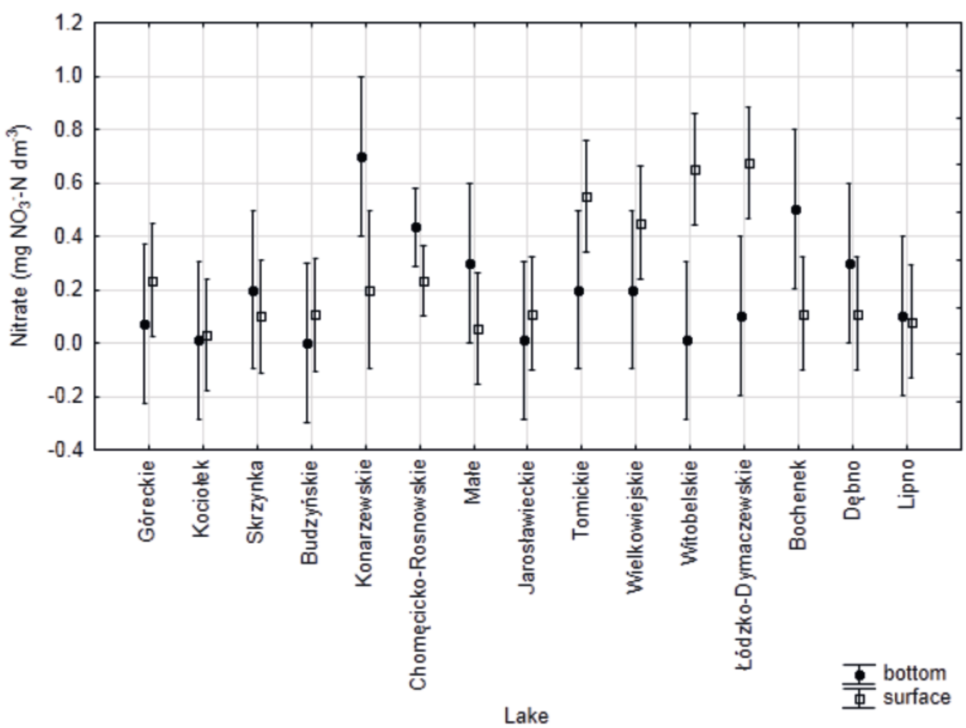

Figure 7

Variations of the nitrate in the studied lakes in 2012

Explanations: midpoint – mean; whiskers – standard error observed for the content of organic compounds in water expressed as chemical oxygen demand (COD). The highest value was determined in the sub-bottom of lakes Bochenek and Dębno.

Macrophytes and phytoplankton analyses showed high diversity of the studied lakes (Table 3). Only lakes Budzyńskie and Wielkowiejskie have a very good ecological status based on macrophytes. Lakes Kociołek, Małe, Jarosławieckie and Dębno were classified as having a good ecological status taking into account the development of macrophytes. Also low phytoplankton biomass was noted in these water bodies, except for Lake Dębno (Table 3). Intensive algal blooms in lakes Lipno, Witobelskie and Konarzewskie caused disappearance of submerged macrophytes, which indicated their bad ecological status. The ecological status of Lake Skrzynka did not decline despite the absence of submerged macrophytes.

Lakes located in the park, where the border of the park is defined along the shoreline of the lakes, as well as in the buffer zone were exposed to human impact (LHMS>10). The remaining lakes are highly natural. Based on nitrogen and phosphorus concentrations in the water column, the ecological status of all the lakes was below good (Table 3). Taking into account the physicochemical and hydromorphological parameters, the ecological status of the lakes ranged from moderate to bad. Unfortunately, the ecological status of two lakes in the Wielkopolska National Park and two lakes in the buffer zone was bad. The remaining lakes in the buffer zone had a poor status. The status of the other lakes was moderate.

Water quality expressed by the TSI index showed significant differences between the studied lakes ($F=7.03$; $p<0.01$). These differences were not significant among the analyzed years. Moreover, two-way analysis of variance revealed significant differences between the lakes during these years ($F=6.33$; $p<0.01$). No statistically significant differences were determined between the lakes situated in the Wielkopolska National Park and its buffer zone. Changes in the TSI index are shown in Figure 8.

The best water quality was observed for Lake Skrzynka in 1974, indicating oligotrophy. During about 20 years, the water quality in Lake Skrzynka significantly declined. The TSI synthetic index increased from 26.2 to 63.8. The increase in phosphorus concentrations caused algae growth and deterioration of water transparency (Fig. 6). In 1935, the water transparency was 1.2 m, and after almost 50 years it increased to 1.7 m (Brzęk 1948, Dąmbska 1978, Siepak 2001), and systematically decreased to 0.9 m in 2012. The HDI reached 12.78, clearly indicating a lack of the dystrophication process.

The lowest water quality was determined for lakes Witobelskie and Łódzko-Dymaczewskie, where hypereutrophic water quality has been reported since 1998. An improvement in water quality was observed for Lake Góreckie, which in 1974 was characterized by hypertrophic water quality. Currently, the TSI classified this lake as eutrophic. The remaining lakes are classified as eutrophic and their water quality assessed based on the TSI index did not change significantly during the studied years.

Table 3

Ecological status of the lakes located in the Wielkopolska National Park and its buffer zone

Lake	Chlorophyll *a* (μg dm^{-3})	ESMI	SE	Ecological status based on			Ecological status of the lake
				biological parameter	hydro-morphological parameters	physico-chemical parameters[1]	
Góreckie	9.62	0.298	III	moderate	I	<II	moderate
Kociołek	5.2	0.573	II	good	I	≥II	good
Skrzynka	8.81	0.347	III	moderate	I	<II	moderate
Budzyńskie	2.06	0.845	I	very good	I	<II	good
Konarzewskie	13.26	0.242**	V	bad	<I	<II	bad
Chomęcicko-Rosnowskie	15.00	0.462	III	moderate	<I	<II	moderate
Małe	3.85	0.503****	III	moderate	<I	<II	moderate
Jarosławieckie	2.41	0.554	II	good	<I	<II	moderate
Tomickie	21.23	0.092	IV	poor	<I	<II	poor
Wielkowiejskie	8.37	0.489***	I	very good	I	<II	good
Witobelskie	28.07	0.268*	V	bad	<I	<II	bad
Łódzko-Dymaczewskie	35.70	0.464*	V	bad	I	<II	bad
Dębno	5.37	0.731**	II	good	<I	<II	moderate
Bochenek	25.43	0.284	III	moderate	I	<II	poor
Lipno	26.90	0.52*	V	bad	<I	<II	bad

Explanations: SE – ecological status: I – very good, II – good, III – moderate, IV – poor, V – bad; * – absence of submerge macrophytes ;** – expert evaluation; [1] – based on the total P value as a determining factor; *** – more than 25% of the littoral zone covered by charophytes; **** – dominance of *C. demersum*

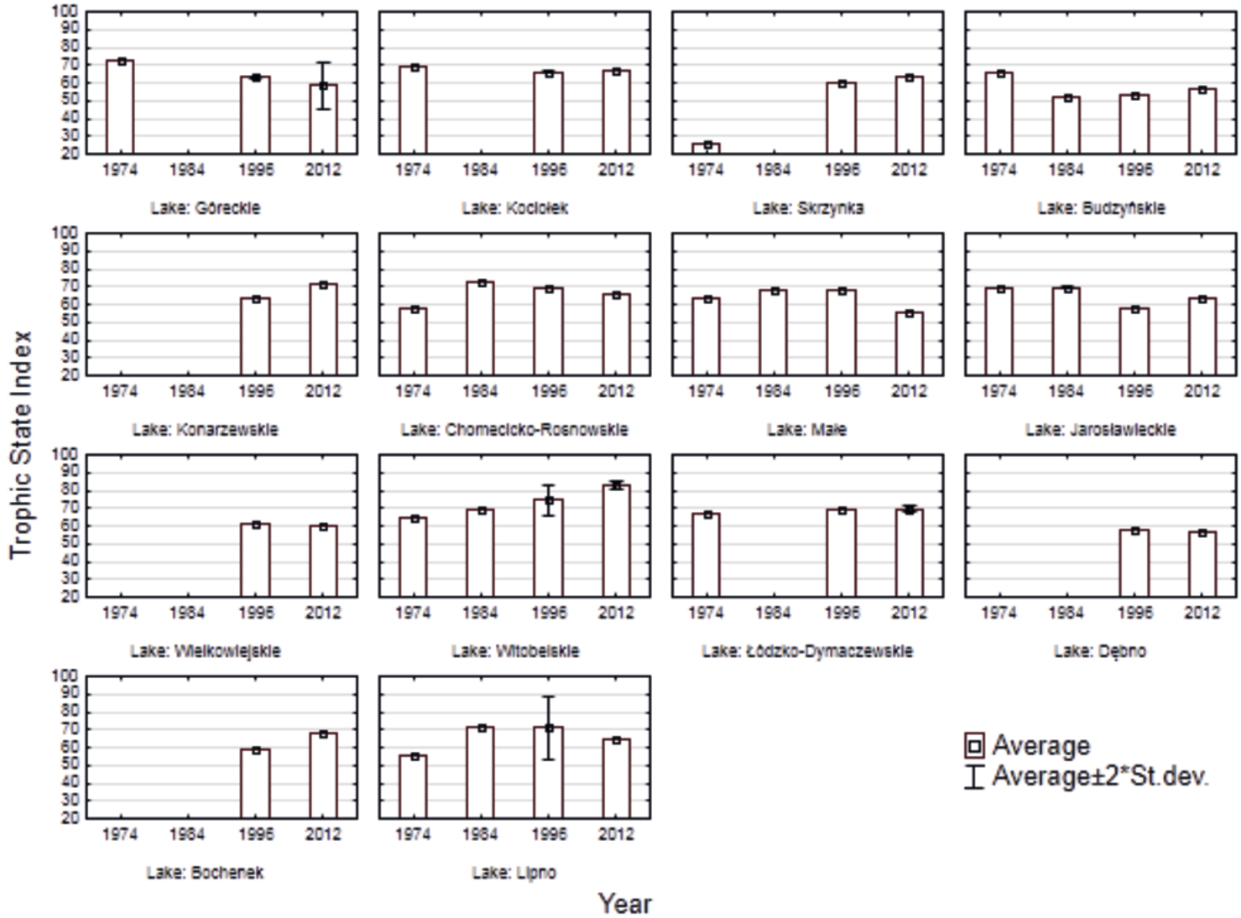

Figure 8

Changes in water quality presented as Carlson TSI index in four periods

Discussion

The performed analyses showed low water quality in the studied lakes located in the Wielkopolska National Park and its buffer zone. All water bodies were characterized by an advanced process of eutrophication. However, the best water fertility was observed in the lakes located in the park. Over the past 30-40 years, degradation of water quality based on the Carlson index was determined for two lakes: Witobelskie and Łódzko-Dymaczewskie. A slight improvement in water quality was noted in lakes Jarosławieckie and Małe. The water quality improved only in Lake Góreckie – from hypereutrophic to eutrophic. However, further analyses will be necessary to confirm that this is a continuous trend rather than periodic variation, which strongly depends inter alia on meteorological conditions (Jeppesen et al. 2009; 2011).

Greater variability between the lakes was observed with respect to the ecological status evaluated based on macrophytes. The ESMI indicated a very good status of lakes Budzyńskie and Wielkowiejskie, and good conditions in lakes Kociołek, Małe, Jarosławieckie, and Dębno. Lakes Budzyńskie and Wielkowiejskie are characterized by a high percentage of charophytes, which covered more than 25% of the littoral zone. Although the value of ESMI classified Lake Wielkowiejskie into the second class, the high cover of charophytes modifies the lake's ecological status from good to very good according to the Regulation of the Minister of the Environment (2014). Submerged macrophytes, particularly charophytes, have a positive effect on water transparency due to secretion of allelopathic substances reducing the productivity of phytoplankton (Fonseca, De Mattos Bicudo 2010) and competitive interactions for nutrients and light. Macrophytes also create a refuge for zooplankton, which may avoid fish predation (Nurminen et al. 2010).

An elongated shoreline, small average depth, large area of shallow parts, and a gentle slope of the bottom of lakes increase the area suitable for plant development. At the same time, lakes Budzyńskie and

Wiekowiejskie are characterized by a considerable thickness of nutrient-rich sediments (Lawniczak et al. 2013). These features provide perfect conditions for the development of macrophytes (Bornette, Puijalon 2011). On the other hand, an increased area covered by highly productive macrophytes may contribute to the gradual overgrowing of lakes, which causes their disappearance as well as reduced water resources (Lawniczak et al. 2011; Ptak, Ławniczak 2012). However, this particularly applies to species from highly eutrophic habitats such as submerged *Ceratophyllum demersum* or emerged *Phragmites australis* or *Typha angustifolia*.

A high percentage of rootless species such as *Ceratophyllum demersum* in the littoral zone indicates a high level of nutrient availability in the lake. According to Ciecierska (2008), high abundance of this species shows an advanced stage of eutrophication; thus the status of the lakes cannot be very good. For this reason, the ecological status of Lake Dębno was changed based on macrophytes, i.e. from very good to good. Also in Lake Jarosławieckie, *Ceratophyllum demersum* was the only submerged macrophyte that created well-developed assemblages. Although the present study showed good ecological status of Lake Jarosławieckie based on macrophytes and slight improvement in water quality evaluated by the Carlson index, the long-term analyses of plant species composition have shown a negative transformation of water quality. In the 1970s, eight macrophyte communities were identified (Dąmbska 1988) and the number gradually increased to 18 in 2001/2002, which was linked with an increase in the Secchi disc visibility (Pełechaty, Krupska 2009). After 2002, a sharp decline in the number of plant communities was observed. It was mostly related to disappearance of charophytes (Pełechaty, Krupska 2009). In 2012, *Ceratophyllum demersum* was the only submerged macrophyte that created well-developed assemblages. These changes indicate degradation of water quality. The macrophytes' delayed response to environmental changes are a good indicator of these changes (Szoszkiewicz et al. 2010; Schneider et al. 2012). On the other hand, Schneider et al. (2012) suggested that the ecosystem subject to increasing pressure of macrophytes will have a tendency to indicate an overestimated status ("too good" or "too bad"). However, this hypothesis has yet to be tested in lentic waters.

The problem of assessing the ecological status of lakes occurs in the case of dystrophic lakes that naturally have a low presence or absence of submerged macrophytes. Then, the lack of submerged macrophytes is not a determinant of the ecological status of such a lake. Methods for assessing the ecological status of lakes based on macrophytes developed in the European Union do not include dystrophic lakes, and all methods are suitable only for lakes with trophic status ranging from mesotrophic to eutrophic (i.e. Schneider 2007, Ciecierska 2008; Penning et al. 2008). Also in the Polish method, reference conditions apply exclusively to mesotrophic lakes with the dominance of charophytes. Therefore, this method cannot be used to assess coastal, oligotrophic or dystrophic lakes.

Moreover, biological parameters are the most important in the evaluation of the ecological status of a lake, but taking into consideration the physico-chemical parameters of water quality of the studied lakes, their ecological status has been modified. High concentrations of total phosphorus indicate richness of nutrients in the lake, which can be released in unfavorable conditions (Scheffer et al. 2001). Of the studied lakes, two lakes located in the park and two lakes in its buffer zone were classified in the last category due to a lack of submerged macrophytes. Very good status of lakes Wielkowiejskie and Budzyńskie assessed based on charophytes has been reduced mostly due to high nitrogen or phosphorus concentrations in the water, respectively. Taking into consideration all analyzed parameters, the ecological status of most of the analyzed water bodies was below good. Only two lakes were characterized by a good ecological status. However, Carlson's methods applied to evaluate the lake conditions show an advanced stage of eutrophication in all the studied lakes. The results are comparable to other lakes in the Wielkopolska region, located in the agricultural catchment area and exposed to strong human impact (Pietruczuk, Szoszkiewicz 2009). On the other hand, water quality of the lakes located in Suwałki Landscape Park in the north-eastern part of Poland ranged from mesotrophic to eutrophic. The TSI indicated moderately eutrophic waters (Jekatierynczuk-Rudczyk et al. 2014).

Among the analyzed lakes, water quality improved in Lake Góreckie from hypereutrophic to eutrophic. In the 1930s, however, the lake water quality was mesotrophic (Brzęk 1948) with the Secchi disc visibility of 4.5 m. Oxygen concentration was very good; it varied from 4.3 to 5.0 mg O_2 dm^{-3} in the sub-bottom zone. In the 1950s, the water transparency was similar compared to that observed 20 year earlier and varied from 3.5 to 4.5 m. Oxygen concentrations as well as water trophic conditions did not change. The study of Dąmbska (1988) from the 1970s showed deterioration of the water quality. Total phosphorus in the surface and bottom was high during the summer water stagnation, i.e. 0.44 and 0.36 mg P dm^{-3}, respectively. Water visibility decreased to 1.9 and 2.5 m, and oxygen deficiency and hydrogen sulfide were noted in the bottom. In 1998, oxygen depletion was already exacerbated at a depth of 8 m (Siepak 2001). The content of total phosphorus did not decrease and was still high in the water column. In 2005, the highest concentrations (0.48 mg P dm^{-3}) in the analyzed years were determined in the bottom. In 2010, lake recultivation was undertaken, consisting in coagulation of phosphates by application of a ferric coagulant, hypolimnion aeration and biomanipulation by removing 3 tons of planktivorous fish. Application of the ferric coagulant was not high and the effect of hypolimnion aeration was located only in one spot, i.e. in the deepest part of the lake. However, as indicated by Sobczyński et al. (2012, 2013), the effect of the remedial action was not strong and water conditions in 2010-2011 were not improved. Moreover, measurements carried out in 2012 showed a slight improvement in water quality. Also, analyses of phytoplankton carried out from 2007 to 2011 showed reduction in the biomass productivity and positive rebuilding of the community structure from the dominance of cyanobacteria to the dominance of chrysophytes and green algae (Pełechata et al. 2015). According to Scheffer & Jeppesen (1998), this stage of the lake recovery can be referred to as hysteresis. This phenomenon refers to changes in the states following different pathways in the forward and reverse directions.

Only Lake Skrzynka, among lakes of the Wielkopolska National Park, was classified as dystrophic. The absence of submerged macrophytes, low pH, high concentrations of humic matter and organic acids, and nutrient poor status were observed (Siepak 2001). Currently, the absence of submerged macrophytes is still observed along with the eutrophication of the water body. The HDI calculated as a geometric mean of pH, conductivity, and the ratio of dissolved organic carbon to dissociated inorganic carbon concentrations showed the advanced process of lake eutrophication and the essential process of lake dystrophication (the boundary value between eutrophy and dystrophy is 50, and the value in Skrzynka was 13). Already in the 1970s, however, Dąmbska (1988) observed succession of reeds and bushy and woody vegetation in the littoral zone, which also indicated an increase in nutrient availability in the lake. Presently, species from nutrient rich sites and succession of reeds and floating-leaved macrophytes are observed in the lake.

In lakes Małe, Budzyńskie and Wielkowiejskie, characterized by high nutrient concentrations, low biomass of phytoplankton and very dense vegetation occur. Lakes Budzyńskie and Wielkowiejskie are characterized by typical zonal distribution of macrophytes and intensive processes of vegetation overgrowth. According to alternative stable states of shallow lakes (Scheffer, Jeppesen 1998), these lakes represent a clear state. Macrophytes play a major role in the maintenance of clear water through an increase in sedimentation, reduced sediment resuspension and nutrient uptake resulting in the reduction of algae growth, as well as providing a good refuge for zooplankton (Fonseca, Bicudo 2010; Holmroos et al. 2015). However, Scheffer & Jeppesen (1998) stressed that this state can be temporary and easily turned into turbid water due to nutrient loading or collapse of macrophytes caused by grazing snails or herbivorous fish. Furthermore, bottom sediments in these water bodies are rich in nutrients that can be released in unfavorable conditions (Zhu et al. 2015). Furthermore, reckless actions of a leaseholder of Lake Małe, taken without the consent of Wielkopolska National Park, such as grass carp stocking and removal of macrophytes, can cause lake degradation.

On the other hand, lakes Witobelskie and Łódzko-Dymaczewskie represent a turbid stage dominated by phytoplankton. Dense blooms of cyanobacteria effectively reduce the development of submerged macrophytes. Based on TSI values, progressive degradation of Lake Witobelskie is observed. Hypereutrophic water quality has persisted since 1996. The dominant species (in terms of phytoplankton abundance) are represented by three species of cyanobacteria: *Pseudanabaena limnetica*, *Planktothrix agardhii*, *Aphanizomenon flos-aquae* (Pełechata after Lawniczak et al. 2013); the latter two have the ability to produce toxins. Filamentous cyanobacteria such as *Planktothrix* indicate high trophic status and intensive mixing of water in the lake. High tolerance of *Planktothrix* to large deficiencies of light contributes to high competitiveness in relation to other phytoplankton taxa (Scheffer et al. 1997).

The major problems concern nutrient loading from the catchment into the lakes. Active protection has been implemented in the park and partly in the buffer zone. However, most of the lakes' catchment area is located outside the park. Another unfavorable factor is that lakes Witobelskie and Łódzko-Dymaczewskie are the last water bodies along the course of the Samica Stęszewska river. The upper part of this river catchment has been defined as a nitrate vulnerable zone (NVZ), characterized by high nitrate concentrations in the ground and surface water. However, nutrient concentrations in the surface water of NVZ significantly decreased due to undertaken actions (Kupiec et al.

2008), but high nutrient loads have been accumulated in the lakes. A similar situation is observed in Lake Chomęcicko-Rosnowskie, which is supplied with polluted water via a ditch from Lake Konarzewskie (Lawniczak et al. 2013).

Lack of significant differences in physicochemical water qualities between the park and its buffer zone indicated that actions aimed at protecting the water, particularly in the park, are ineffective. However, the ecological status of the lakes in the buffer zone, specifically lakes Konarzewskie, Bochenek, Lipno and Tomickie, is worse compared to the lakes in the park. Low presence of submerged macrophytes, or lack of them, and high nutrient concentrations indicate severe trophic conditions of the water. Unfortunately, most of the park's lakes are fed by the waters discharged from these lakes. Some of the lakes' catchment areas are located in the Wielkopolska National Park (Kociołek, Góreckie, Skrzynka, Jarosławieckie), but most of the studied lakes collect water from areas outside the park. The situation is even worse in lakes Łódzko-Dymaczewskie, Witobelskie, and Chomęcicko-Rosnowskie because the effective protection is hindered due to the fact that the boundary line of WPN overlaps with the shoreline of these lakes. Our studies confirm the observations made by Pasztaleniec & Kutyła (2013), which showed a lack of correlation between the location of the lakes in the national or landscape parks with their long tradition of protection, and improvement in their quality status.

In many cases, lack of knowledge about the sources of water pollution and carelessness regarding the water quality caused significant degradation of the waters in the 1970s and 1980s, particularly by agriculture and sewage. Failure over many years has contributed to a reduction in water quality and ecological degradation of the lakes. Effective water quality improvement will be possible after cutting off the sources of pollution. Recent studies have shown that in order to effectively protect and improve the ecological status of the lakes, more radical conservation measures are necessary not only in WPN and its buffer zone, but also in the whole catchment area.

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