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Original Research

The Ecological Status of Lakes in National and Landscape Parks: Does the Location of a Lake and Its Catchment within a Protected Area Matter?

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Abstract

This study identifies the ecological status of lakes which are significant water bodies located within Polish national and landscape parks. The assessment carried out on the basis of data from the National Environmental Monitoring System coming from 2010-12 took into account the requirements of the Water Framework Directive (WFD). Half of the lakes analyzed were characterized by at least good status, while the others were in moderate or even poor or bad status, although they were situated in protected areas. The study shows multi-aspect (morphometric, hydrological, and catchment-related) factors that determine the water quality and the status of the lake ecosystem. A strong correlation was found between eutrophication indicators (chlorophyll *a* concentration, water transparency, nutrient concentrations in water) and the majority of limnological parameters of lakes. There was no direct relationship between the percentage shares of the major land uses of lake catchments and the ecological status of lakes, but the nitrogen and phosphorus load theoretically emerging in the catchment correlated with the nutrient concentrations in water, as well as with chlorophyll *a* and water transparency. On the basis of data available, it proved impossible to identify a positive impact of covering lakes with protection within a national or landscape park on their ecological status.

Keywords: lakes, lake catchments, ecological status, national and landscape parks, environmental monitoring

Introduction

The quality of lake waters is affected by a number of factors that have a natural character or ensue from human activities. Anthropogenic impacts result usually in a deterioration of the natural values of an aqueous system as a whole; however, intervention is easier in the case of human-caused changes, since they can be eliminated completely or at least reduced, or their impacts can be mitigated. Different forms of natural protection are designed to serve this purpose. Among them, large-area national and landscape parks, enabling the control of external influences, are of the greatest importance for lake ecosystems. A national park (NP) is a form of nature protection involving the highest protection requirements in Poland [1]. A landscape park (LP) is a form with a more lenient protection regime, allowing for the economic development of its area, but one which would ensure the preservation of the natural values of a park [2].

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Given the existing legal restrictions, ensuring or restoring at least good ecological status of lakes in protected areas should be less problematic than in the case of lakes situated outside of protected areas.

By 2014, 23 national parks and 121 landscape parks had been established in Poland. The oldest landscape parks were set up in the second half of the 1970s, and the youngest one in 2001. The provisions of the conservation plans of parks list objectives related to the protection of aqueous ecosystems, such as:

- Improving the resilience of surface water ecosystems to degradation
- Reducing nutrient runoffs from the fields into surface waters
- Maintaining the high quality and properties of the physicochemical composition of water
- Counteracting the growth of trophy of surface waters
- Creating buffer zones around water courses and water bodies, etc.

In Poland, intense eutrophication is the main factor which poses a risk for the water quality in Polish lakes [3]. It is understood as an effect of human activities that lead to higher nutrient concentrations in water and a number of the related adverse processes that cause a gradual degradation of an ecosystem [4]. In protected areas, where generally there are no significant point sources of pollution, the surface runoff is a major source of nutrients [5]. Therefore, knowledge of the transport of biogenic elements is particularly important for understanding the functioning of aquatic ecosystems in protected areas. The amount of nitrogen and phosphorus loads transferred from the catchment to surface waters depends on various factors such as the hydrological regime, land use, and amount of fertilization. Moreover, morphological and physical-limnological properties of a lake determine its susceptibility to external influences exerted on them; therefore, they were taken into account in water quality assessment systems [6, 7]. In the ecological status assessment, the abiotic type of lake is taken into account, according to the requirements of the Water Framework Directive (WFD) [8, 9]. A number of studies [e.g. 10-14] have presented the significance of the catchment area properties for surface runoffs of nutrients and toxic substances and, hence, for the quality of lake waters. They have confirmed that a lake, along with its catchment, constitutes a dynamic ecological system and that the risk of lake eutrophication is higher when the catchment areas are dominated by farmland and urbanized areas. There are publications discussing issues concerning the water quality of Polish lakes in protected areas against the background of land use. Studies conducted within Wielkopolski National Park by Szyper and Gołdyn [15] indicate the great importance of diffuse sources that supply varied loads of nitrogen and phosphorus to lakes, depending on the catchment use and type of lake. In Wielkopolski NP, significant loads of nutrients came from arable fields, meadows, and pastures areas, along with their inflow with the rivers, while point sources of pollution were much less significant [15]. Long-term studies on accelerated fertilization of lakes were undertaken in the Masurian LP, Suwalski LP, and Wigierski NP [5, 16, 17, 18, 19, 20]. The north-eastern part of Poland is characterized by less intensive farming than its western part. In addition, the decline of fertilizer use in the 1990s, the development of wastewater treatment plants, and a lack of strongly urbanized areas and large industrial plants contributed to the slowing down of the eutrophication processes [3, 21, 22]. Nevertheless, as underlined by Siuda et al. [22], the situation of inhibited eutrophication or even de-eutrophication of lakes is temporary and in the future increased imports of nutrients from catchments are expected as a consequence of growing tourism and a high share of monocultural agriculture. Thus, eutrophication is still the main threat for waters in Masurian LP and Wigierski NP. The role of external sources in eutrophication of water bodies located in the Drawieński NP was identified by Szyper and Kraska [23]. These authors considered that the fundamental cause of eutrophication of closed lakes were surface runoffs, while flow-through lakes were, first of all, supplied by phosphorus and nitrogen loads reaching them with the river inflow. A wide range of the nutrient loading by catchments and the contributing dispersed factors (angling and recreational activities), as well as the natural susceptibility of a lake to degradation are reflected in the differentiated trophic conditions of lakes in protected areas [5, 12, 13, 15, 18, 21-24].

An important issue that has not yet been explored to a great extent is how restrictions on the management of the areas of national and landscape parks affect the quality of waters situated within their boundaries and the degree to which this quality relates to the size of a catchment protected under these forms of natural protection. The subject matter of the study is the presentation of the ecological status of lakes situated within national and landscape parks and the examination of the relationship between the quality of their waters and the land use of the catchment area, taking into account the size of the area covered by protection. In other words, an attempt was made to answer the question whether it is a general rule that parks protect (ensure) the maintenance of good ecological status of lakes or whether covering a lake and its catchment with protection has a positive impact on the quality of their waters.

Methods

Spatial and statistical analyses were carried out using the environmental database on Polish lakes, "JEZIORA [LAKES] 2," developed at the Department of Freshwater Assessment Methods and Monitoring of the Institute of Environmental Protection – National Research Institute (IEP-NRI). The database collects data from the National Environmental Monitoring System (NEMS) concerning lake water quality, provided by the Chief Inspectorate for Environmental Protection (CIEP). Moreover, it contains information on the morphometry of lakes and their geographical locations. The two modules applied in the database – a tabular one (elaborated upon using MS Access 2007 software) and a graphic one (developed using ArcGIS 10.1 software), enable a search for a relationship between

Table 1. The values of unit loads of nutrients depend on type of land use (according to [28]).

Type of land use	Unit loads (kg/ha/year)	
	N	P
Forests	1.5	0.1
Agricultural areas and discontinuous urban fabric:		
in 11 provinces with lower pressure*	9.0	0.3
in 5 provinces with higher fertilization and soil nutrients availability**	12.0	0.4
Pastures:		
in 11 provinces with lower pressure*	3.0	0.2
in 5 provinces with higher fertilization and soil nutrient availability**	4.5	0.3
Wetlands	1.5	0.1
Land principally occupied by agriculture with significant areas of natural vegetation	3.0	0.2
Continuous urban fabric	6.0	0.9
Precipitation***	12.9	0.35

*provinces: West Pomerania, Pomerania, Warmia-Masuria, Podlasie, Mazovia, Kujawy-Pomerania, Lublin, Świętokrzyskie, Silesia, Małopolska, Podkarpacie
**provinces: Lower Silesia, Lubuskie, Łódź, Opole, Wielkopolska
***regarding a lake's area only

the abiotic parameters of the water environment and biota and relate the results obtained to their spatial distribution [25].

The study used spatial data representing the situation and boundaries of Poland's national/landscape parks, lakes, lake catchments, and land cover. The first vector layer came from the Internet service of the European Environment Agency (EEA) [26]. Made available under a liberal licence, it illustrates the situation and boundaries of all the NPs, LPs, and nature reserves in our country. The layer presenting lakes in Poland's territory is part of the Hydrographic Map of Poland (HMP). This database was acquired from the National Water Management Authority (NWMA) [27]. The layer of total lake catchments was elaborated upon by verifying topographic catchments originating from the HMP database within the framework of the project called "The formulation of restrictions on the use of the waters of lakes or reservoirs and on the use of their catchments in the conditions for the use of the waters of a water region" in 2010 [28]. The verification process mainly consisted in including/excluding fragments of catchments (they were often areas encompassing sites without outflow) and "closing" of the catchments of lakes at their outflows based on 1:50,000 topographic maps in the 1965 PUWG Coordinate System. Poland's land cover was acquired from the CORINE Land Cover 2006 project [29].

Using the layers representing lakes and national/landscape parks, it was possible to calculate the ratios of the lake area to the catchment area for the individual protected areas. It was assumed that for the areas of the parks on the seacoast (Słowiński and Woliński National Parks) the ratios of the lake area to the catchment area should be calculated in reference to the terrestrial part of the park.

The lakes selected for analyses (92 water bodies) were those that represented significant water bodies within the meaning of the provisions of the WFD, i.e. with a surface area exceeding 50 ha [8]. The majority of them (58 lakes) are medium-sized lakes (50-200 ha). Almost 30% (29 lakes) are large lakes (200.1-1,000 ha), the number of lakes with a surface area exceeding 1,000 ha is the smallest (5). In order to obtain as up-to-date information as possible on the ecological status of lakes in protected areas, use was made of NEMS data from 2010-12. The ecological status assessment contained in this study was carried out within the framework of the national lake monitoring; it was primarily based on an assessment of the ecological formations living in a lake ecosystem (mainly including phytoplankton, phytobenthos and macrophytes); the integration process took into account the decisive importance of the element in the worst status ("one out all out"), in an approach recommended by the Water Framework Directive, supported by an expert assessment [8]. Basic morphometric data were taken from the LAKES 2 database, along with the data on the quality of their waters expressing the intensity of eutrophication (the concentrations of chlorophyll *a* and total fractions of nitrogen – TN and phosphorus – TP, as well as the Secchi depth). Samples for analyses of chlorophyll *a* and chemical parameters were collected by the Voivodeship Inspectorates in the period from March/April to August/September, for most lakes three times (during spring mixing, early summer, summer stagnation) or four times a year (autumn mixing). The selected benchmark lakes were sampled 6-7 times a year at monthly intervals. Water samples were collected in the deepest part of the lake. During the summer stagnation period integrated water samples were collected from the epil-

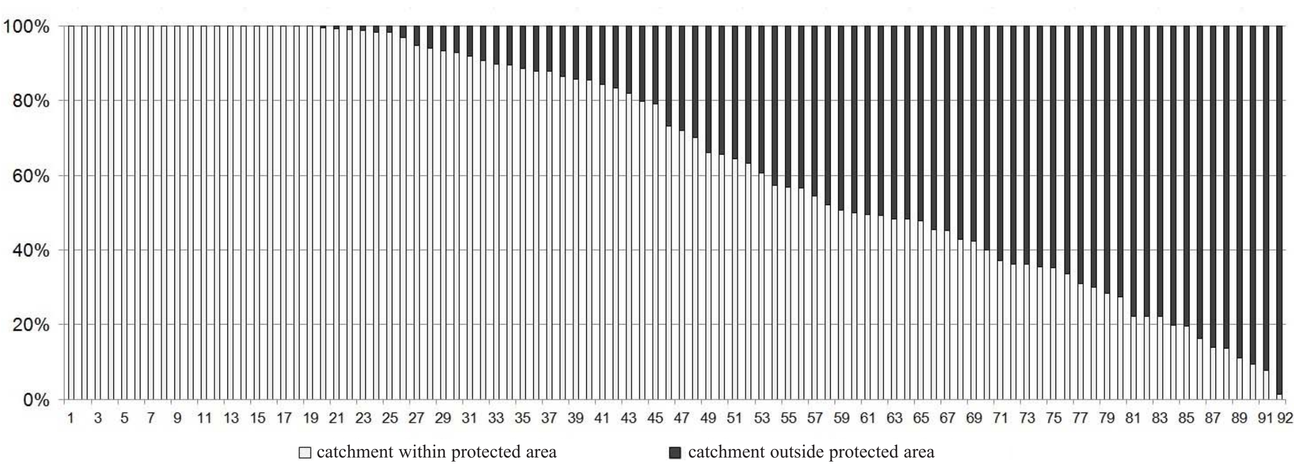

Fig. 1. The percentage share of a protected area in the surface area of the total catchment of the lakes analyzed (1-92 are the numbers of lakes).

imnion and in the spring and autumn from the euphotic layer. In polymictic lakes, integrated samples were taken from the 0-5 m layer.

The integrated assessment of the ecological status of lakes was carried out pursuant to the draft Regulation of the Minister of the Environment of 8 May 2013 [3]. Long-term trends of water quality change in the selected lakes were analyzed on the basis of archival NEMS data from 1999-2012.

Based on the unit N and P loads emerging in the catchment depending on the manner of its use, which were determined on the basis of the scientific literature used in the "The Formulation …" project implemented on commission from the Regional Water Management Board in Kraków by the consortium MGGP S.A. and the IEP-NRI, with the participation of several dozen experts – limnologists in 2010 [28], analyses of the relation between the load theoretically emerging in the catchment on the nutrient concentrations in water and the ecological status of lakes were carried out. The calculations did not cover point sources of pollution. Table 1 shows the values of unit loads applied in the above-mentioned project and used in the present study. In order to take into account in statistical analyses the nutrient loads that were theoretically generated in the catchment, along with the quantity of water in a lake – a significant morphometric factor – the nitrogen and phosphorus load was recalculated per the volume of lake waters in cubic metres.

Statistical analyses were performed with the StatSoft Statistica 8 for Windows. The non-parametric Mann-Whitney U test was used to reveal which means of abiotic and biotic parameters are significantly different between two groups of lakes, characterized by at least good and a worse than good ecological status. The Spearman rank coefficient was used to determine the relationship between the abiotic and biotic parameters of water and catchment features.

Results

The extent to which the catchments of lakes with waters located in NPs and LPs are situated within their areas varies in a wide range. In the case of 42 lakes, the whole catchment or at least 80% of it is situated in a protected area. For 27 lakes, less than 80% of their catchments, but more than 40% lies in the protected area. The catchments of the other lakes are protected to a much lower degree (less than 40% within a park), while for the catchments of seven lakes the park area represents barely several or a dozen or so percent (Fig. 1). In general, the larger the surface area of the total lake catchment, the larger share of it covered by protection; still, at the same time, the percentage share of the catchment within the park boundaries decreases. As a result, the catchments of 10 lakes which are some of the largest ones (with a surface area of about 32,000 to 248,000 ha) are situated to a small extent within a park area (from 1% to about 30%).

Out of 92 lakes analyzed, for 20 lakes there is a strong domination (i.e. more than 80% of the cover) of natural areas (forests, waters, and wetlands). In turn, more than 60% of the total catchments of two thirds of lakes were occupied by farmland (arable land, meadows, and pastures). Anthropogenic areas, i.e. mainly rural buildings, urban green areas, construction sites, and industrial areas, represent several to a dozen or so percent. An exception is Lake Krasne, where the rural buildings situated on its banks occupy more than 20% of the surface area of the total catchment. The comparison of the land use structure within landscape and national parks with the whole area of lake catchments indicates that natural areas, mostly forestland or wetlands, are more often covered by protection, whereas in the case where only part of a catchment is situated within a protected area, rural areas are located outside of it. Fig. 2 shows the structure of land use in the total lake catchments.

An ecological status assessment was carried out for 47% of all the lakes situated in landscape and national parks. Moreover, when their total surface area is considered, they represent 55% of the total surface area of these waters.

For the lakes analyzed, the indicators of eutrophication pressure reached very diversified values. The mean seasonal chlorophyll *a* concentration varied between 1.5 and 187 µg/l depending on the lake; this was reflected in the water transparency from 0.3 m to more than 7 m in terms of

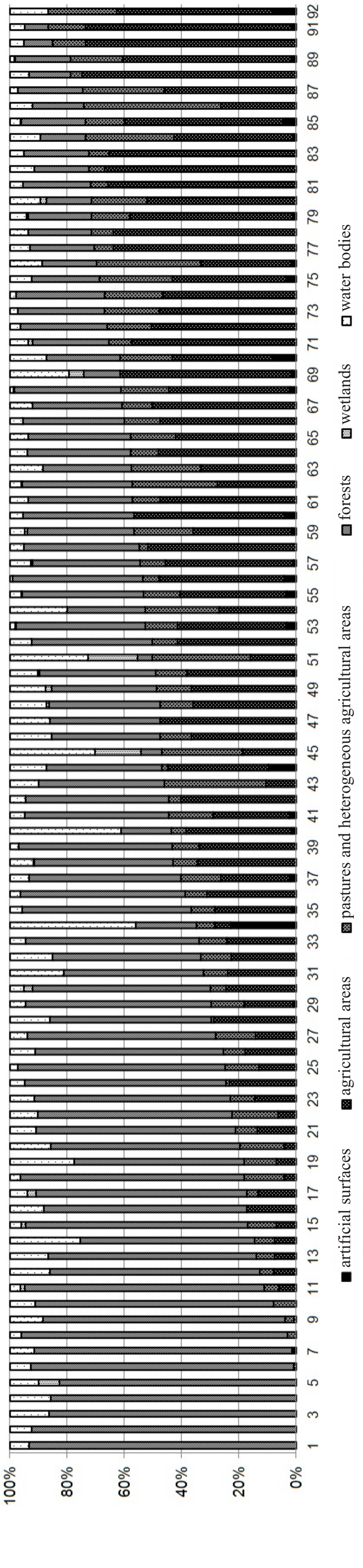

Fig. 2. The percentage shares of different uses of the total lake catchment areas (arranged in the order of a decreasing share of natural areas).

Secchi depth. The total nitrogen and phosphorus concentrations varied, respectively, from 0.55 to 5.35 mg/l and from 0.003 to 0.233 mg/l.

Based on the above-mentioned parameters, it can be said that about half of the lakes in protected areas (45%) are in at least good status and that most of them are characterized by moderate status, but 20% of them are in poor or bad status (Fig. 3). Only in three protected areas (Łagowski LP and Tucholskie Woods and Poleski National Parks) all lakes which are significant water bodies are in good or high ecological status. Also, in four parks (Wdzydzki, Drawski, and Górzniewsko-Lidzbarski LPs, and Wigierski NP), there are only lakes in at least good status, but no current data are available for some water bodies situated in them. Within all the other protected areas there are lakes in varied ecological status, also including those in a worse than good status (Table 6). No relationship was found between the form of protection, the date of its establishment, and the ecological status of the lakes situated in their areas. Lakes in a worse than good status can be found in the areas of both landscape and national parks established several dozen years ago (e.g. Lake Góreckie in Wielkopolski NP of or Lake Mikołajskie in Masurian LP) and those that have been in place for a dozen or so years (e.g. Lake Gołdap in Romincka Forest LP).

Since the areas of the total lake catchments covered by the protection varied, the relationship between the ecological status of the lakes and the size of their total catchment subject to protection was analyzed. No correlation was found between the percentage share of the catchment under protection and the eutrophication indicators (chlorophyll *a*, TN, TP, and Secchi depth), while the Spearman correlation coefficient varied between -0.06 and 0.13 and was statistically insignificant ($p>0.05$).

A strong correlation was found between the concentration of chlorophyll *a* and the nutrients in water, water transparency, and the majority of limnological parameters characterizing the lake (Table 2). A negative correlation coefficient between the chlorophyll *a* concentration and the morphometric indicators suggests that the chlorophyll *a* concentration increases as the mean lake depth, water stratification, lake volume, and the ratio of its volume to the shore line length decrease. Moreover, the lower the val-

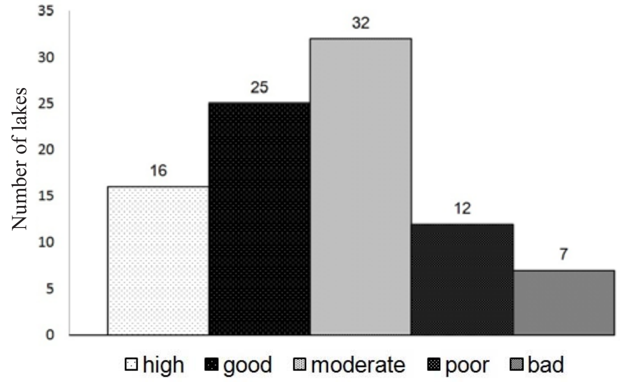

Fig. 3. The ecological status of lakes located in national and landscape parks.

Table 2. Spearman rang correlation between limnological parameters and eutrophication indicators.

Limnological parameters	Chlorophyll *a* [µg/l]	Secchi depth [m]	TN [mgN/l]	TP [mgP/l]
Mean depth [m]	**-0.41**	**0.61**	**-0.50**	**-0.20**
Lake surface [ha]	-0.11	**0.21**	-0.14	-0.06
V/L* [thous.m^3/m]	**-0.38**	**0.51**	**-0.42**	**-0.21**
Stratification [%]	**-0.42**	**0.59**	**-0.47**	**-0.24**
Lake volume [thous. m^3]	**-0.28**	**0.46**	**-0.37**	-0.12
Catchment surface [ha]	**0.23**	-0.09	0.01	**0.24**
Schindler's ratio** [m^2/m^3]	**0.55**	**-0.54**	**0.37**	**0.45**
Lake coefficient ***	**0.37**	**-0.24**	0.13	**0.35**
Water exchange [%]	**0.48**	**-0.47**	**0.32**	**0.43**

Results statistically significant are in bold (p<0.05)
* Ratio of the volume of lake to length of lake shoreline
** Ratio of the total catchment`s area to the volume of lake
*** Ratio of the total catchment area to the lake area

Table 3. The differentiation of the limnological parameters in the group of the lakes in at least good and worse than good status. The statistical significance according to the Mann-Whitney U test.

Limnological parameters	Ecological status				p
	At least good (n = 41)		Worse than good (n = 51)		
	Mean (max-min)	S.D.	Mean (max-min)	S.D.	
Lake coefficient	25.9 (2.5-112.3)	26.8	81.6 (2.2-962.7)	153.7	0.000
Mean depth [m]	8.6 (0.6-38.7)	6.7	5.7 (1.1-20.7)	3.7	0.020
V/L [thous.m^3/m]	2.3 (0.1-10.2)	2.2	1.2 (0.2-5.0)	1.1	0.007
Stratyfication [%]	19.7 (0.0-77.5)	21.0	9.2 (0.0-58.6)	12.7	0.014
Water exchange [%]	63 (0-550)	94.3	390 (3.0-7700)	1217.0	0.000
Schindler's ratio [m^2/m^3]	4.0 (0.3-17.1)	4.2	24.6 (0.2-444.5)	69.6	0.020

ues of the above-mentioned morphometric parameters, the less transparent the waters. The catchment parameters applied and the percentage rate of water exchange correlated positively with the value of chlorophyll *a*. The chlorophyll *a* concentration was the higher, the larger surface area of the total catchment of the lake was (r=0.23, p<0.05), while the impact of the size of the catchment was even more strongly expressed by the lake coefficient (r=0.37, p<0.05) and the ratio of the catchment area to the volume of lake waters (r=0.55, p<0.05). The chlorophyll *a* concentration was also enhanced by greater water exchange (r=0.48, p<0.05). Similar trends of change could also be observed between the limnological features of lakes and the mean seasonal nutrient concentrations in their waters (Table 2).

It is important to note the statistically significant differences between the mean values and the range of selected limnological parameters in lakes in high or good ecological status and those in lakes in a worse than good status (Table 3). The group of lakes in at least good status is more differentiated than the group of lakes in a worse than good status in terms of their mean depth (S.D.= 6.7 ver. 3.7), water stratification degree (S.D.=21.0 ver. 12.7), and the V/L ratio (S.D.=2.2 ver. 1.1), while the mean values of the above-mentioned parameters are higher for the former of these groups. In contrast, in the case of Schindler's ratio, lake coefficient and the rate of water exchange, their range of variation in the group of lakes in at least good status was smaller (respectively S.D.= 4.2, 26.8, 94.3) than that for lakes that had not reached good status (respectively S.D.= 69.6, 153.7, 1217.0), while their mean value was significantly lower (Table 3).

It can be noted that the total catchments of lakes the status of which was classified as high and good had on average about 10-20% more natural areas (forests, wetland, and waters) than those of lakes the status of which was classified as worse than good (Fig. 4). It is important to note the differentiation of the mean catchment areas of lakes in different status. A larger mean catchment area is characteristic of a group of lakes in poor or bad ecological status.

Table 4. Spearman rang correlation between types of land use and eutrophication indicators.

Type of land use		Chlorophyll *a* [µg/l]	Secchi depth [m]	TN [mgN/l]	TP [mgP/l]
Total catchment	Antropogenic [%]	-0.04	0.07	0.05	0.01
	Agricultural [%]	0.09	0.02	0.18	-0.05
	Natural [%]	-0.17	0.12	-0.10	0.20
Catchment within a protected area	Antropogenic [%]	-0.04	0.07	0.06	0.05
	Agricultural [%]	0.10	0.11	**0.21**	0.06
	Natural [%]	-0.14	0.00	-0.14	0.10

Results statistically significant are bold (p<0.05).

Table 5. Spearman rang correlation between the total sum of nutrients` loads theoretically generated in the catchment regarding types of land use and the eutrophication indicators.

Total nutrient load (N+P) [g/m^3/year]	Chlorophyll *a* [µg/l]	Secchi depth [m]	TN [mgN/l]	TP [mgP/l]
Total catchment	**0.53**	**-0.51**	**0.44**	**0.33**
Antropogenic	**0.22**	-0.15	0.12	0.09
Agricultural	**0.42**	**-0.33**	**0.35**	0.18
Natural	**0.57**	**-0.57**	**0.28**	**0.44**

Results statistically significant are bold (p<0.05).

The smallest catchment areas in relation to the whole set of lakes are usually those of the lakes that have been classified as high (Fig. 4). However, the differentiation of the total catchments of the lakes analyzed in terms of the percentage shares of different uses does not demonstrate a statistically significant correlation with the eutrophication parameters or with the ecological status of lakes (Table 4). A slight ($r=0.21$, $p<0.05$) but statistically significant relationship was found only between the percentage share of farmland within parks and the mean concentration of total nitrogen in water.

The amounts of nitrogen and phosphorus loads theoretically emerging in the catchments of lakes situated in protected areas were very different. The total nutrient load (N and P) varied from about 1,500 to about 800,000 kg. An exception was Lake Wielkie in Lubuskie Province within the catchment of which the theoretically emerging nutrient load reached a level of more than 1.2 million kg. The lowest total load discharged in runoffs was 0.06 g/m^3/year, whereas the highest one was 298 g/m^3/year. The estimated nutrient load emerging in the total catchment correlated positively with the nutrient concentrations in water ($r=0.44$ and $r=0.33$ with $p<0.05$, respectively for TN and TP), as well as with the chlorophyll *a* concentration ($r=0.53$, $p<0.05$) and negatively with water transparency ($r=-0.51$, $p<0.05$) (Table 5).

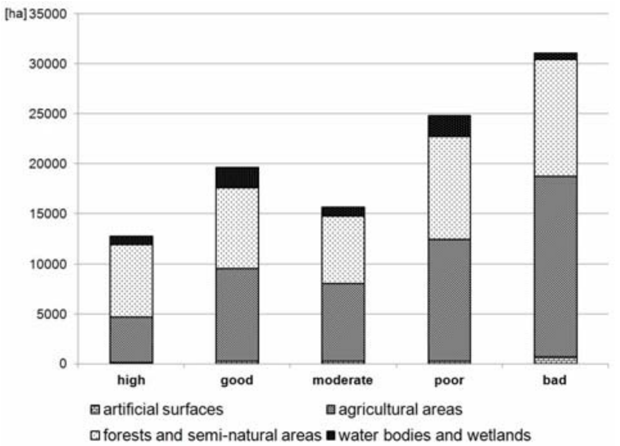

Fig. 4. The shares of different uses of the total catchment areas of the lakes analyzed, considering their ecological status.

The mean nitrogen and phosphorus load potentially emerging in farmland and in areas with natural cover in the catchments of lakes classified as ones in high or good status was significantly lower than the analogous load calculated for lakes in worse than good status. The variability of the total loads in the catchments of individual lakes, given in figures as the minimum and maximum values, was much lower in the case of lakes in at least good status than in the group of those in worse than good status (Fig. 5).

In order to identify the possible impact of the date when a lake was incorporated into the area of a national/landscape park on the ecological status of an aqueous ecosystem, long-term variations in the chlorophyll *a* concentrations were analyzed for four reference lakes where annual monitoring surveys are carried out (Fig. 6).

Two of them, North Lake Jasień and South Lake Jasień, have remained within the Słupia Valley LP since 1981.

Available data indicate that the chlorophyll *a* concentration fell in recent years. In the case of North Lake Jasień, the boundary chlorophyll value between good and moderate status was exceeded only in 2003 (when the concentration increased to about 15 μg/l), while South Lake Jasień remained in a worse than good status in 1999-2008. In Lake Śremskie, protected within Sierakowski LP since 1991, there is no clear trend of variations in the mean chlorophyll *a* concentration. In the years under analysis, its concentration varied from 3 to 11 μg/l, exceeding the good-moderate boundary in several years. Lake Długie Wigierskie within Wigierski NP is characterized by good status, but it shows a weak tendency for the chlorophyll *a* concentration to increase and once (in 2011) its value increased to about 15 μg/l, indicating moderate ecological status (Fig. 6).

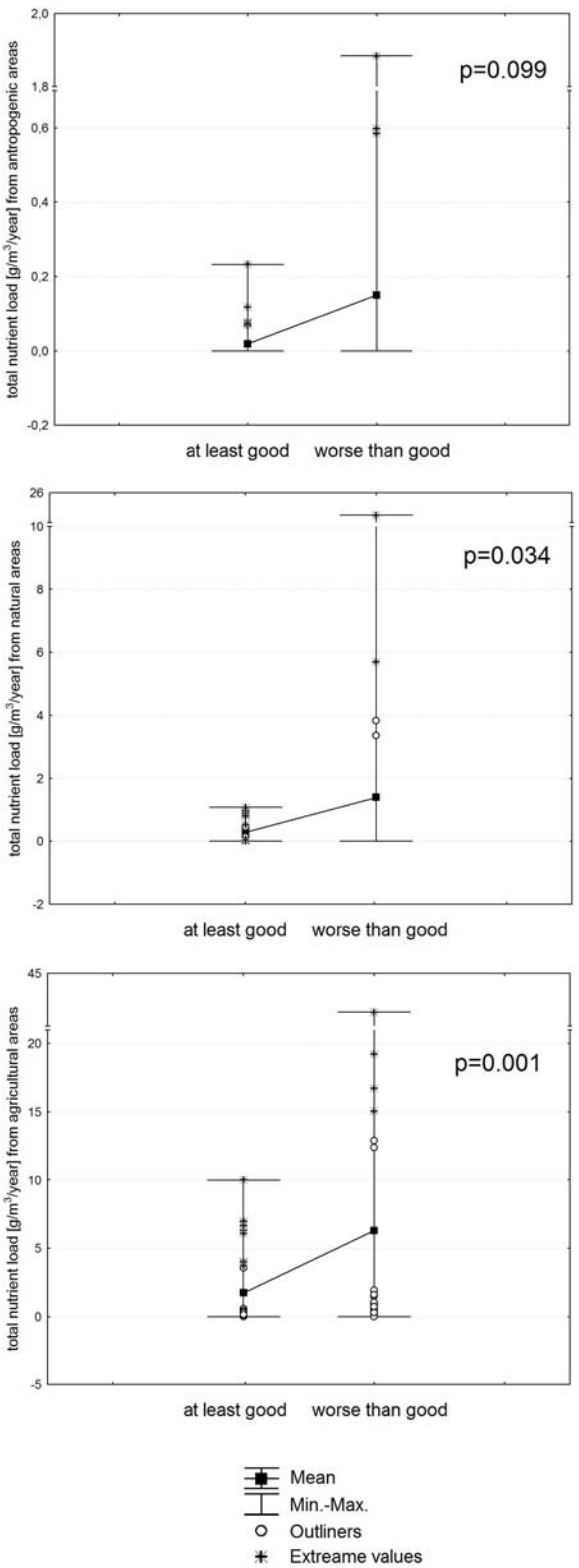

Fig. 5. The differentiation of the levels of nitrogen and phosphorous loads emerging in the areas of the major uses (mean, minimum and maximum) in the group of lakes in at least good and worse than good status. The statistical significance according to the Mann-Whitney U test.

Discussion

About 14% of Polish lakes with a surface area of more than 1 ha are situated within the landscape and national parks, including 200 lakes with a surface of more than 50 ha (2.8% of Polish lakes). The maximum ratio of the lake area to the catchment area in national parks is 44.3% (Słowiński NP), whereas for landscape parks it is 27.4% (Masurian LP).

Although the lakes analyzed are water bodies situated in areas with outstanding natural values, their ecological status is close to the distribution characteristic of the results of an assessment of the ecological status of lakes originating from an annual monitoring of lakes that covers lakes from different regions of Poland [30]. About 50% of the lakes analyzed are in at least good status. However, about 20% is even in poor and bad ecological status. On the basis of the above data, it is impossible to observe a positive impact of the integration of the lakes analyzed into parks, which would consist of the maintenance or restoration of good ecological status, as a general principle.

A significant relationship was found between ecological status and morphometric, hydrological, and catchment-related factors (mean depth, water stratification, water exchange in a year, Schindler's ratio, and the lake coefficient). They determine the natural susceptibility of lakes to degradation and they have been taken into account in the lake quality classification systems [6, 7, 11].

It was assumed that there is a relationship between catchment use and lake water quality [12, 14, 19, 31, 32]. Catchment area use can potentially enhance or reduce the strength and type of the impact of the catchment on the lake. Its use can be a sort of an anthropogenic factor that intensifies matter supply from the catchment and, thereby, a deterioration of the ecological status of a lake; as a natural factor, it can also affect the susceptibility of the lake to degradation [33, 34].

Land use in a catchment is an important factor that affects the levels of nitrogen and phosphorus loads discharged into surface waters that stimulate water eutrophication. The lost fertilizer components or the field crop production techniques applied are the basic sources of nitrogen and phosphorus loads going into waters, particularly from catchments of agricultural character [12, 15].

Modern approaches to the protection of aquatic ecosystems located in protected areas underline the need to apply preventive methods in the whole area of a catchment [35-37]. Protection activities should include not only appropriate development of water supply and wastewater systems, to limit river and water pollution, but also changes in land use, i.e. a partial or total elimination of mineral fertilization of arable lands, changes of plant cover, and the establishment of plant barriers protecting lakes and rivers [35]. It should be expected that more rigorous conditions for managing the catchments of lakes situated in protected areas (e.g. restrictions on building in the lakeside zone and those on fertilization) would be reflected in the maintenance or restoration of good ecological status of their waters, especially if all the catchment area is situated within a national or landscape park. Comparative analyses of the ecological status of lakes situated in protected areas show that a lake can be in a worse than good status, also including bad ecological status (e.g. Lakes Chłop, Kłosowskie, and Mieliwo), even if the entire or almost entire (> 80%) catchment of wooded character is also covered by a protected area. In the case of each of the abovementioned lakes, the explanation of the causes of a deterioration of the status of the ecosystem requires additional information. Catchments consisting of natural or semi-natural areas are subjected to lower human pressures and hence contribute to a lesser extent to an acceleration of the eutrophication process. It can be expected that lakes where the catchments are dominated by forests would have the reference, high or good water status. However, neglecting the assessment error, the causes of degradation of lake ecosystems can include, e.g., point sources related to the development of the lakeside zone for tourism purposes (inappropriate fishery) and unregulated wastewater management, or even large cormorant populations feeding on the lake and enriching it with organic matter [4, 15, 38]. Apart from nutrient loads, factors that intensify the eutrophication of water bodies can also be hydrological or climatic [3, 39]. Water level fluctuations caused by changes in the littoral range and the depth of the lake influence water biota assemblages and the ecological status of a lake [40, 41]. Therefore, the group of water bodies the catchments of which are for the most part covered by natural areas (more than 60% of their area) include lakes representing each of the five possible ecological statuses.

In the case of lakes with an agricultural catchment, even if the whole catchment is covered by protection in a park, this does not ensure that good ecological status of a lake is maintained. Lakes in protected areas can receive such large amounts of nutrients from an agricultural catchment that their ecological status abruptly becomes worse or at least no improvement is possible [e.g. 15, 31]. It also happens that lakes with a catchment dominated by arable land and situated within a park to a slight extent only (<20%) can be in good or high ecological status. Lakes where the catchments of which are dominated by farmland are to a large degree protected against runoff of nitrogen and phosphorus compounds from the fields by an extensive buffer zone covered

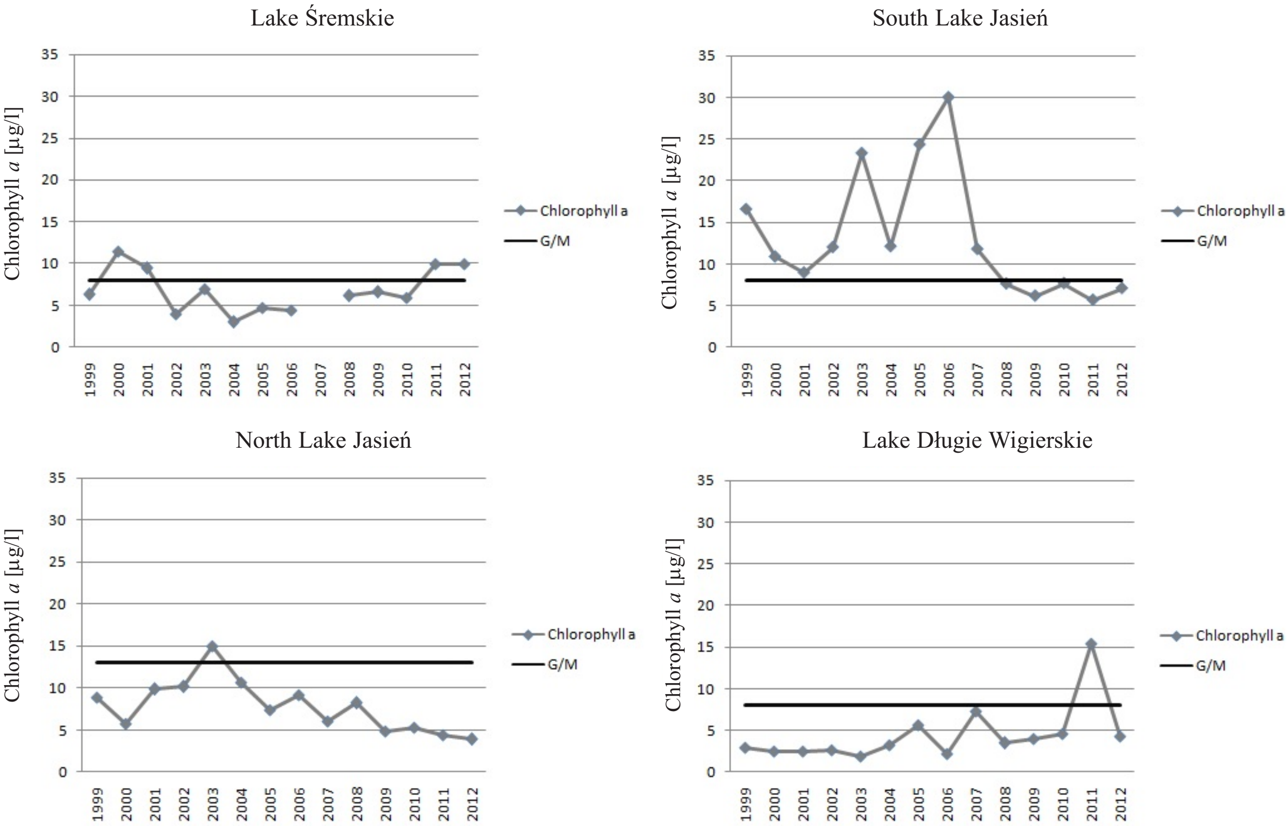

Fig. 6. Long-term variations (1999-2012) in the mean seasonal chlorophyll *a* concentrations in select reference lakes (G/M – good/moderate boundary of ecological status).

Table 6. The list of lakes in national and landscape parks – limnological characteristics and ecological status.

ID	Lake name	Form of protection	Date of establishment	Lake area [ha]	Max. depth [m]	Mean depth [m]	Ecological status
10141	Góreckie	Wielkopolska NP	1957	104.2	17.2	8.5	moderate
21045	Łebsko	Słowiński NP	1967	7140.0	6.3	1.6	moderate
30614	Hańcza	Suwalski LP	1976	311.4	108.5	38.7	high
30265	Jegocin	Masurian LP	1977	127.4	36.1	9.0	high
30224	Kołowin	Masurian LP	1977	78.2	7.2	4.0	high
30174	Kuc	Masurian LP	1977	98.8	28.0	8.0	good
30235	Łuknajno	Masurian LP	1977	680.0	3.0	0.6	high
30168	Majcz Wielki	Masurian LP	1977	163.5	16.4	6.0	good
30175	Mikołajskie	Masurian LP	1977	497.9	25.9	11.2	poor
30219	Mokre	Masurian LP	1977	841.0	51.0	12.7	moderate
30234	Śniardwy	Masurian LP	1977	11340.4	23.4	5.8	good
10708	Siecino	Drawski LP	1979	729.7	44.3	14.1	good
10682	Żerdno	Drawski LP	1979	205.0	36.0	15.2	good
20056	Goreńskie	Gostynińsko-Włocławski LP	1979	55.3	6.1	3.0	good
20007	Lucieńskie	Gostynińsko-Włocławski LP	1979	201.3	20.0	8.3	poor
21008	Jasień Płd.	LP Doliny Słupi	1981	336.7	22.6	7.5	good
21009	Jasień Płn.	LP Doliny Słupi	1981	240.5	32.2	9.1	good
21000	Skotawsko Wielkie	LP Doliny Słupi	1981	80.0	8.7	4.1	moderate
20720	Brodno Wielkie	Kaszubski LP	1983	134.1	15.7	6.6	good
20715	Raduńskie Dolne	Kaszubski LP	1983	737.2	35.4	11.2	moderate
30725	Spólne	Sobiborski LP	1983	65.3	2.3	1.4	moderate
20503	Wdzydze Południowe	Wdzydzki LP	1983	918.8	68.0	18.7	good
20189	Bachotek	Brodnicki LP	1985	211.0	24.3	7.2	moderate
20181	Dębno	Brodnicki LP	1985	59.5	15.9	5.5	moderate
20193	Mieliwo	Brodnicki LP	1985	80.9	9.4	3.4	moderate
20175	Partęczyny Wielkie	Brodnicki LP	1985	323.9	28.5	6.8	moderate
10066	Trześniowskie	Łagowski LP	1985	185.7	58.8	19.3	good
10067	Łagowskie	Łagowski LP	1985	82.4	13.5	5.3	good
20299	Ostrowite	NP Bory Tucholskie	1985	280.7	43.0	10.7	high
20381	Długie	Tucholski LP	1985	64.0	9.3	3.6	moderate
20532	Okonińskie	Tucholski LP	1985	106.5	24.5	8.8	good
20408	Szpitalne	Tucholski LP	1985	66.4	19.6	7.5	good
10329	Białe	Pszczewski LP	1986	55.6	11.5	5.7	good
10360	Chłop	Pszczewski LP	1986	227.8	23.0	9.0	moderate
10354	Konin	Pszczewski LP	1986	93.5	4.3	2.1	bad
10332	Lubikowskie	Pszczewski LP	1986	314.7	35.5	10.9	high
10333	Rokitno	Pszczewski LP	1986	61.5	10.2	5.1	high
10327	Szarcz	Pszczewski LP	1986	169.8	14.5	7.9	high
10362	Wędromierz	Pszczewski LP	1986	73.8	11.8	4.9	moderate
10353	Wielkie	Pszczewski LP	1986	188.7	3.7	2.1	bad

Table 6. Continued.

ID	Lake name	Form of protection	Date of establishment	Lake area [ha]	Max. depth [m]	Mean depth [m]	Ecological status
30619	Długie Wigierskie	Wigierski NP	1989	80.0	14.8	7.4	good
30626	Pierty	Wigierski NP	1989	228.2	38.0	10.4	good
30616	Wigry	Wigierski NP	1989	2118.3	73.0	15.9	good
10787	Ostrowiec	Drawieński NP	1990	387.6	28.5	9.4	good
20171	Leźno Wielkie	Górznieńsko-Lidzbarski LP	1990	86.2	14.5	5.5	good
30703	Bikcze	LP Pojezierze Łęczyńskie	1990	85.0	3.3	1.5	high
30700	Kleszczów	LP Pojezierze Łęczyńskie	1990	53.9	2.3	1.3	high
30691	Krasne	LP Pojezierze Łęczyńskie	1990	75.9	33.0	10.7	poor
30690	Łukcze	LP Pojezierze Łęczyńskie	1990	57.0	8.9	3.6	moderate
30692	Piaseczno	LP Pojezierze Łęczyńskie	1990	84.7	38.8	10.8	high
30689	Rogóżno	LP Pojezierze Łęczyńskie	1990	56.8	25.4	7.2	moderate
30694	Uścimowskie	LP Pojezierze Łęczyńskie	1990	66.3	4.4	2.7	moderate
30704	Uściwierz	LP Pojezierze Łęczyńskie	1990	284.1	6.6	3.2	high
30706	Łukie	Poleski NP	1990	150.1	6.5	1.8	high
20290	Charzykowskie	Zaborski LP	1990	1363.8	30.5	9.8	moderate
20329	Kruszyńskie	Zaborski LP	1990	461.3	7.0	3.1	moderate
20342	Laska	Zaborski LP	1990	70.4	3.6	1.4	poor
11025	Barlineckie	Barlinecko-Gorzowski LP	1991	259.1	18.0	7.1	high
10896	Chłop	Barlinecko-Gorzowski LP	1991	64.3	16.0	6.4	moderate
10892	Lubie	Barlinecko-Gorzowski LP	1991	79.4	8.9	4.5	moderate
10029	Białe-Miałkie	Przemęcki LP	1991	104.4	10.2	1.9	bad
10017	Dominickie	Przemęcki LP	1991	343.9	17.1	6.5	good
10025	Lgińsko	Przemęcki LP	1991	68.6	16.9	7.0	moderate
10022	Przemęckie Północne	Przemęcki LP	1991	243.4	5.0	1.6	poor
10031	Przemęckie Zachodnie	Przemęcki LP	1991	220.2	5.6	3.2	poor
10295	Barlin	Sierakowski LP	1991	103.2	3.2	1.5	bad
10274	Białkowskie	Sierakowski LP	1991	145.9	31.4	9.6	bad
10273	Chrzypskie	Sierakowski LP	1991	304.3	15.0	6.1	moderate
10287	Jaroszewskie	Sierakowski LP	1991	92.2	35.7	14.2	good
10294	Kłosowskie	Sierakowski LP	1991	137.8	14.3	3.9	poor
10286	Kubek	Sierakowski LP	1991	69.0	3.8	2.0	poor
10285	Lutomskie	Sierakowski LP	1991	172.7	15.0	6.7	poor
10301	Ławickie	Sierakowski LP	1991	90.1	17.2	7.3	moderate
10292	Śremskie	Sierakowski LP	1991	117.6	45.0	20.2	moderate
10276	Wielkie	Sierakowski LP	1991	260.8	30.1	9.6	poor
10129	Zbęchy	LP im. gen. Dezyderego Chłapowskiego	1992	108.9	8.5	4.3	bad
20566	Gardzień	LP Pojezierza Iławskiego	1993	85.5	2.1	1.2	high
20754	Januszewskie	LP Pojezierza Iławskiego	1993	104.0	2.0	1.2	poor
20120	Płaskie	LP Pojezierza Iławskiego	1993	620.4	5.7	2.4	poor
20150	Kiełpińskie	Welski LP	1995	60.8	11.0	6.1	good

Table 6. Continued.

ID	Lake name	Form of protection	Date of establishment	Lake area [ha]	Max. depth [m]	Mean depth [m]	Ecological status
20415	Lutowskie	Krajeński LP	1998	143.2	12.1	3.8	moderate
10492	Stryjewskie	Krajeński LP	1998	151.2	16.7	7.5	moderate
10501	Więcborskie	Krajeński LP	1998	194.0	18.5	8.3	moderate
10486	Zakrzewskie	Krajeński LP	1998	66.6	7.5	3.9	moderate
10059	Borak	Krzesiński LP	1998	62.0	8.4	4.0	bad
30576	Gołdap	LP Puszczy Rominckiej	1998	149.0	10.9	5.6	poor
10398	Budzisławskie	Powidzki LP	1998	140.8	35.2	10.8	high
10416	Kamienieckie	Powidzki LP	1998	232.5	18.5	8.8	good
10409	Niedzięgiel	Powidzki LP	1998	550.9	21.5	5.5	moderate
10102	Powidzkie	Powidzki LP	1998	1035.9	45.4	12.7	good
10101	Powidzkie Małe	Powidzki LP	1998	52.0	7.5	3.5	moderate
10401	Wilczyńskie	Powidzki LP	1998	173.8	23.2	7.3	moderate

by natural vegetation (lakes Pierty and Szpitalne). The importance of buffer zones as barriers for water protection was emphasized by Hillbricht-Ilkowska [3]. In an agricultural landscape, the high efficiency of buffer zones in reducing nutrient runoffs was described Skwierawski et al. [42]. Morphometric conditions, such as substantial depth in the case of Lake Hańcza, are another factor that enhances the resilience of a lake to degradation. Nevertheless, large organic loads may cause a deterioration of the oxygen conditions in the meta – and hympolimnion and eventually contribute to intensified internal loading with nutrients, increasing the vulnerability of Lake Hańcza to eutrophication [24].

This study did not find a relationship between the percentage shares of the major uses of lake catchments and the ecological status of lakes. There are different land uses in the catchments of lakes that are in at least good status and those below good status. At the same time, good or high status of a water body can be met more often in the case of lakes with a smaller total catchment. It seems justified to explore the causes of extreme cases, i.e. such in which, despite their high resilience to degradation and their location, along with their catchment, within a protected area, lakes do not achieve good ecological status while, conversely, good status is characteristic of lakes affected by adverse catchment-related factors and vulnerable to nutrient runoffs.

Some lakes in the analyzed set lie within parks with a long tradition (those established 40-50 years ago), while others are located in areas covered by protection for a shorter period, but not less than 15 years. The analysis of long-term measurement series does not show a relationship between the date when an NP or LP was established and the improvement in the quality status of lakes situated within parks. This observation is probably not limited only to Polish protected areas and concerns, for example English Lake [43]. As pointed out by many authors, freshwater ecosystems are commonly protected only incidentally as a result of their inclusion within terrestrial protected areas and this does not guarantee their effective protection [36, 37, 44]. Negative activities such as alteration of hydrology, land-use disturbances, high fertilization, and more can occur within NPs and LPs. Even if they take place outside of the park boundaries they can still have negative consequences for water habitats within the protected area.

In conclusion, it seems that in order to enable the implementation of the conservation tasks of parks relating to aqueous ecosystems, watersheds would have to be considered in designating their boundaries, as pointed out by Choiński [44]. The park boundaries must not be delineated only by the natural ground cover (the park boundary often ends at the forest line), but their range should include areas used by humans; therefore, related agricultural and economic restrictions should be imposed. It is also well-advised to enforce the provisions of protection programs providing for establishing buffer zones around lakes.

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