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CHANGES IN LAND USE IN THE DIRECT CATCHMENT OF LAKE GĄSAWSKIE IN THE PERIOD OF 1945–2011 IN VIEW OF ITS ECOLOGICAL STATUS*

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Key words: ecological status, changes in lake area, land use, macrophytes.

Abstract

The aim of this study was to evaluate land use in the sub-catchment (i.e. direct catchment) of Lake Gąsawskie in the period of 1945–2011, focusing on its effect on the current ecological status of the lake.

The rate of lake overgrowing and changes in its area were assessed over the period of 66 years. The extent of sewerage cover in the Gąsawa commune located in the direct catchment of the lake was taken into consideration. The lake catchment is characterised by the predominance of arable land. Analysis of cartographic materials from 1945, 1991 and 2011 showed an increase in building development in the catchment of the lake at the expense of the percentage of arable land. At the same time the area of this lake was found to decrease from 105.85 ha to 94.98 ha, i.e. by 10.3%. The rate of its depletion is 0.15 ha annually.

Studies of the ecological status conducted using macrophytes index ESMI and physico-chemical parameters of water showed a poor condition of the lake. This is also evidenced by a limited number of plant communities, a slight share of immersed macrophytes, particularly hornwort (*Ceratophyllum demersum*). High concentrations of nutrients promote an intensive development of phytoplankton, as indicated by low water transparency.

Results of this study showed that undertaking effective actions in the lake catchment is necessary to limit further degradation of Lake Gąsawskie waters.

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ZMIANY SPOSOBU UŻYTKOWANIA GRUNTÓW W ZLEWNI BEZPOŚREDNIEJ JEZIORA GĄSAWSKIEGO W LATACH 1945–2011 W KONTEKŚCIE JEGO STANU EKOLOGICZNEGO

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Słowa kluczowe: stan ekologiczny, zmiana powierzchni jeziora, użytkowanie terenu, makrofity.

Abstrakt

Celem badań była ocena sposobu użytkowania gruntów w zlewni bezpośredniej Jeziora Gąsawskiego w latach 1945–2011 ze szczególnym uwzględnieniem jego wpływu na aktualny stan ekologiczny jeziora.

Oceniono tempo zarastania jeziora oraz zmiany jego powierzchni w ciągu 66 lat. Zlewnia jeziora charakteryzuje się dominacją gruntów ornych. W analizie materiałów kartograficznych z lat 1945, 1991 i 2011 wykazano wzrost zabudowy w zlewni jeziora kosztem udziału gruntów ornych. Jednocześnie stwierdzono zmniejszenie się powierzchni jeziora z 105,85 ha do 94,98 ha, czyli o 10,3%. Tempo jego zaniku wynosi 0,15 ha rocznie.

W badaniach stanu ekologicznego wykonanych metodą ESMI i parametrów fizyczno-chemicznych wody wykazano słaby stan jeziora. Świadczy o tym również niewielka liczba zbiorowisk roślinnych oraz nieznaczny udział makrofitów zanurzonych, w szczególności rogatka sztywnego (*Ceratophyllum demersum*). Wysokie stężenie biogenów sprzyja intensywnemu rozwojowi fitoplanktonu, o czym świadczy niska przezroczystość wody.

Wykazano, że podjęcie skutecznych działań w zlewni jeziora jest niezbędne, aby ograniczyć dalszą degradację wód Jeziora Gąsawskiego.

Introduction

Lakes are a significant component of landscape, as well as an important element of the ecosystem, on which their existence is dependent. Water bodies are responsible for the modification of microclimate, hydrogeological conditions, while also being a reservoir of water for all living organisms. In relation with the increasing demand for water and climate change, the accelerating incidence of droughts and torrential rains, water resources are becoming increasingly depleted. The present-day society faces a very difficult challenge connected with the extension of water discharge from the catchment and ensuring its best possible quality.

In order to maintain good water quality it is necessary to undertake effective actions aiming at the limitation of its further degradation and finally improvement of its condition. This was the objective for the Water Framework Directive (European Commission Directive 2000), on the

power of which the approach to evaluation of water and its resources was changed, treating water as the environment for living organisms and not as it was the case previously – in view of its economic use. Biological evaluation of the ecological status of waters was introduced, comprising the quantitative and qualitative status of phytoplankton, macrophytes, phytobentos, bentic macroinvertebrates and ichthyofauna. Hydromorphology and physico-chemical parameters of waters supplement analyses of the biological condition of waters.

Major source of water pollution are area sources (GARDNER et al. 2002, JASIEWICZ and BARAN 2006, DURAND et al. 2011, PYTKA et al. 2013), primarily of agricultural origin. They result e.g. from the application of excessive doses and inappropriate dates of mineral and artificial fertilisation, crop monoculture and failure to apply crop rotation (GROCHOWSKA et al. 2014, LAWNICZAK et al. 2016). Agricultural land use has also influenced water retention in soil, caused decreased soil infiltration capacity and faster water drainage from the catchment (KĘDZIORA 2007).

Land use in the catchment is crucial for the maintenance its good quality. Frequently the share of point pollution is considerable in water pollution. Nevertheless, in recent years we have been observing an increased effect of area pollutants in water pollution, which is connected with improved sewage disposal in catchments and elimination of point pollution sources (BOROMISZA 2013).

Point sources connected with agricultural land use include illegal dumps, inappropriate disposal of animal waste, artificial fertilizers or pesticides. Although the development of sewerage systems has been intensive in recent years, it is necessary to ensure adequate sewage treatment and maintain adequate leak tightness of sewerage systems. All these pollutants may penetrate to surface waters through underground flow, subsurface flow and surface runoff.

A significant threat may also result from the recreation management of land directly adjacent to the water body. Recreation infrastructure facilities often have no regulated water supply and sewage disposal systems, or municipal waste disposal, which leads to problems with an increased nutrients inflow (ŁAWNICZAK et al. 2015).

Inflowing pollutants accelerate the natural, slow eutrophication process. These changes lead to disappearance of lakes, which is manifested in two simultaneous processes. One of them is connected with the decreasing lake depth due to the deposition of plant residue and animal waste on the bottom. The other process is related with overgrowing, which as a result of the decreasing depth of the water body increases the potential area for colonization by aquatic vegetation. Thus it is absolutely crucial to ensure

proper catchment management so as to minimize the risk of deterioration of the condition of its waters.

The aim of this study was: 1) to evaluate land use in the direct catchment of Lake Gąsawskie in the period of 1945–2011, focusing on the effect on the current ecological status of the lake; and 2) to assess the rate of overgrowing and disappearance of the lake during the analyzed period.

Methods

Catchment use was evaluated using the vector Georeference Database of Topographic Objects (GBDOT 2011). That map presents the status of 2011 at a 1:10000 scale. This study takes into consideration all elements from the class of land cover objects and the class of rushes and marshes. For the purpose of this study these data were divided into the following categories: built-up areas, meadows and pastures, forests, wetlands, arable lands, surface waters, the littoral zone within the analyzed lake including emergent vegetation and vegetation with floating leaves. Cartographic analyses were conducted in the ArcGIS environment. The lake catchment was based on the Map of Hydrographic Division of Poland at a 1:10000 scale (MPHP 2010). The littoral zone of the lakes was analyzed using additionally an orthophotomap with a 0.25 m resolution (ISOK 2010).

The historical cartographic material used in this study comprises topographic maps from the 1990's in the Polish Coordinate System of 1965, as well as German topographic maps at a 1:25000 scale (Mestichiblatte 2nd edition) of 1945. The rate of the water body overgrowing was also assessed using black-and-white aerial photographs taken in 1966. Preparation of archival materials consisted in the provision of georeferences in their original system of geographic coordinates, followed by their transformation to the current national geodetic coordinate system (PUWG 1992) system. The next process comprised digitalization and classification of land use in accordance with the adopted categories.

The rate of lake overgrowing was assessed based on maps referring the area of the pelagic zone free from emergent vegetation in the analyzed years to the shoreline of the lake in the 1940's.

The degree of sewerage system cover in the direct catchment of the lake was evaluated based on data from the Local Data Bank (GUS 2016) in relation to the Gąsawa commune.

The ecological status of Lake Gąsawskie was evaluated based on the Ecological Status Macrophyte Index (ESMI) (Ciecierska 2008) as well as physico-chemical parameters of water.

In-situ studies comprised analyses of the lake vegetation condition (CIECIERSKA 2008), consisting in:

– determination of transects of 30 m in width and length determined by the depth of plants, located perpendicular to the shoreline;

– identification of cover for plant communities found in a given transect;

– estimation of total bottom cover with vegetation in a given profile;

– estimation of cover for individual communities in the Braun-Blanquet scale;

– determination of the depth range of macrophytes (for each community).

Analyses were conducted from a dinghy and from the lake shore. An anchor was used to identify submerged vegetation.

Based on the collected data the ESMI values were calculated:

$$\mathrm{ESMI} = 1 \quad \exp\left(\frac{H}{H_{\max}} \cdot Z \cdot \exp\left(\frac{N}{P}\right)\right)$$

where:
ESMI – Ecological Status Macrophyte Index
H – phytocenotic diversity index
$H_{\max}$ – maximum phytocenotic diversity
Z – colonization index
N – total littoral area (100%)
P – lake area [km^2].

Percentage of plant cover was evaluated base on Braun-Blanquet scale (Table 1) (WIKUM and SHANHOLTZER 1978)as required by United States government regulatory agencies, vegetation studies are conducted using a variety of methods. Density measurement (stem counts. A total of 20 transects, uniformly distributed in the water body, were prepared. Analyses were conducted in July 2014.

Table 1

Braun-Blanquet cover-abundance scale (WIKUM and SHANHOLTZER 1978)

Braun-Braunquet scale	Range of cover [%]
5	> 75
4	50–75
3	25–50
2	5–25
1	< 5; few individuals
+	< 10, few individuals
r	< 5, few individuals

Water samples for quality testing were collected in deepest part of the lake from the subsurface layer of the lake and comprised the determination of the following indexes:

– total phosphorus – by mineralization using persulfate in an acid environment (HACH DR/2800);

– ammonia nitrogen – by colorimetry using the salicylate method (HACH DR/2800);

– nitrite nitrogen – by spectrophotometry using the diazotization method (HACH DR/2800);

– nitrate nitrogen – by spectrophotometry using the cadmium reduction method (HACH DR/2800) (HACH 1992).

The ecological status of the lake was evaluated in relation to the Regulation of 21 July 2016 (Rozporządzenie Rady Ministrów z 21 lipca 2016… Dz.U. 2016 poz. 1187).

Study area

Lake Gąsawskie is located in the Kujawsko-Pomorskie province, the Żnin county, the Gąsawa commune (Figure 1). Its direct catchment occupies the area of 1148.78 ha. The central part of the catchment is covered by legal protection as the Protected Landscape Area of Żnińskie Lakes, which aims at the protection of the landscape of the lacustrine-riverine channel as well as the cultural and historical value of the area. The lake is elongated in shape from the south-east to north-west with an enlarged part in its southern part. The shoreline is poorly developed (k = 1.51) with a length of 5.3 km. Lake Gąsawskie constitutes a Uniform Surface Water Body, code PLLW 10455. Its abiotic type is 3a, which means that it is a lake with a high calcium content, with a considerable effect of the catchment, stratified. Lake area is 99 ha, while its maximum depth is 10.5 m and mean depth is 5.8 m (*Bathymetric map*… 1958). The Gąsawka River, a left tributary of the Noteć, flows through the lake. This watercourse flows through several lakes, of which Lake Gąsawskie is the second in the river course, fed with waters of the Gąsawka from Lake Oświęcickie. The Gąsawka next flows through Lakes Godawskie, Biskupińskie, Skrzynka, Weneckie, Skarbińskie, Żnińskie: Małe and Duże, Dobrylewskie and Sobiejuskie, to flow into the Noteć near Rynarzewo. Boulder clay predominates in the lake catchment (Kozłowska and Kozłowski 1992).

In the assessment of lake susceptibility degradation according to the Lake Quality Assessment System (Kudelska et al. 1994) Lake Gąsawskie was classified to category II with the total score of 2.43, i.e. a lake

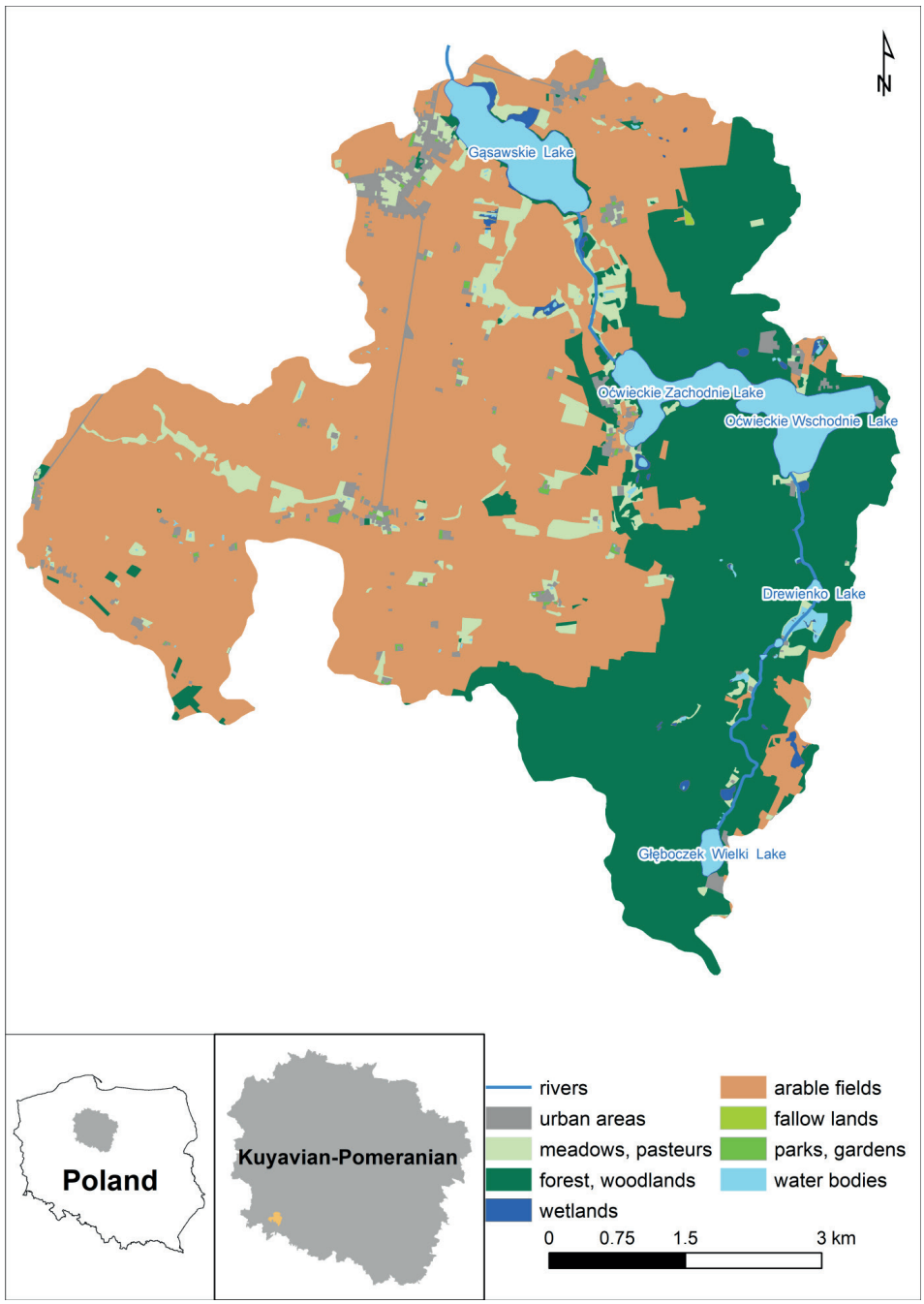

Fig. 1. Location and land use in total catchment of the Gąsawskie Lake

moderately resistant to degradation. A low ratio of lake volume to the length of its shoreline (1.07 thousand m^3 m^{-1}) and the agricultural character of the catchment to the greatest extent determine the reduced lake resistance to degradation. The most advantageous parameter is the ratio of active bottom area and the volume of the epilimnion (of 0.10 m^2 m^{-3}), which shows internal enrichment of the lake with nutrients. The Schindler index, i.e. the ratio of total catchment area with the area of the lake to lake volume, indicates the considerable role of the catchment in the modification of quality parameters in waters of Lake Gąsawskie (H = 8.3) (MARKIEWICZ 2005).

Results and Discussion

Land use structure in the catchment

In the catchment of Lake Gąsawskie arable land predominates, covering the area of 780.2 ha, i.e. 67.9% (Table 2, Figure 2). In comparison to the 1940's the area of arable land decreased slightly by 2.6% (i.e. by 21 ha).

Table 2
Area of analysed land use forms in the direct catchment of Lake Gąsawskie in 1945, 1990 and 2011 years

Land use forms	Area [ha]		
	1945	1990	2011
Urban areas	40.0	62.3	67.4
Meadows, pasteurs	84.4	77.8	73.7
Forest, woodlands	110.6	112.7	112.5
Wetlands	4.1	16.2	11.6
Arable fields	801.1	776.8	780.2
Fallow lands	0.0	0.2	0.2
Parks, gardens	0.6	5.7	5.7
Water bodies	2.1	2.8	2.6

It is a similar result to the changes taking place in the Wielkopolska region (2.0%) within the last 100 years, where a relatively limited area of utilized agricultural area is replaced by forests and anthropogenic areas (MATYKA 2012). In terms of land use area forests rank second in the lake catchment (112.54 ha, i.e. 9.8%; Table 2), located mainly at the eastern boundary of the catchment and overgrowing a narrow belt along the southern lake shore (Figure 2). Their area in the analyzed period did not change markedly, as

it decreased by as little as 1.9 ha. Such a low share of tree stands in the lake catchment is not an advantageous phenomenon, particularly as forested areas exhibit positive properties in the pollutant filtration and purification, thus being highly desirable elements in catchments (HEFTING et al. 2005, RANALLI and MACALADY 2010). Along the 2/3 length of the shoreline a narrow belt of trees is found, with a mean width of 25 m. As it was shown by studies of HEFTING et al. (2005) and AGUIAR et al. (2015), in order to ensure high effectiveness in pollution reduction its width should be min. 60 m, particularly since the large share of farmland is connected with an inflow of pollutants with surface runoff, subsurface flow and underground runoff (CARPENTER 1998, LAWNICZAK et al. 2016). This pertains particularly to fields cropped to maize (LAWNICZAK et al. 2016), found in the direct vicinity of the lake.

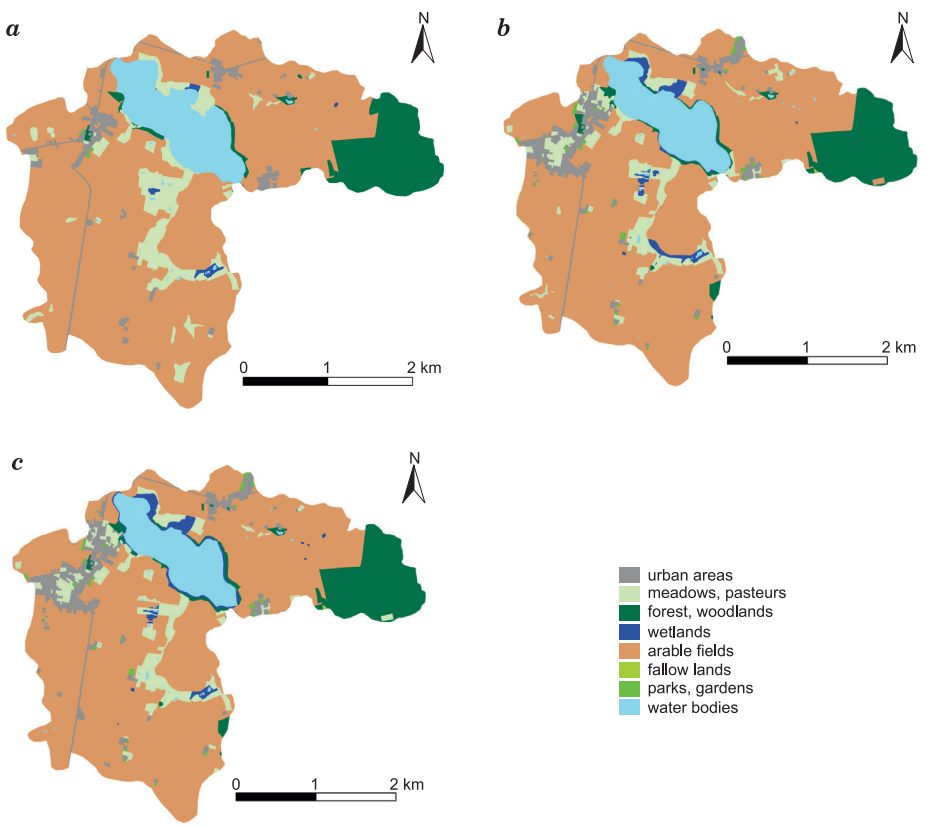

Fig. 2. Land use in the direct catchment of Lake Gąsawskie in: a) 1940 b) 1990 c) 2011 years

Building development is concentrated mainly in the northern part of the catchment and it comprises first of all the villages of Gąsawa and Łysin, which joint area is 67.4 ha, i.e. 5.9% of the catchment (Table 2, Figure 2). Within the 66 years their area increased by 27.4 ha, i.e. by 2.4% area of the entire catchment. The increase in built-up areas leads to a faster runoff of surface waters to lakes (ŁAWNICZAK et al. 2015). Rainwater from built-u areas is drained to surface waters, causing their contamination with municipal pollution, heavy metals, sparsely soluble motor oils (SŁOWIK et al. 2008, PIEKUTIN 2016). The tendency towards an increase in urbanized areas may be observed worldwide (PAUL and MEYER 2001), which has an adverse effect on water quality and a reduction of natural and seminatural areas.

In the catchment of Lake Gąsawskiego surface waters occupy approx. 7.81% (i.e. 97.6 ha) and they are located mainly in its central part (Figure 2). The greatest complex of small water bodies is found surrounded by meadows, which take an area of 2.6 ha. In the course of 66 years their area decreased by as little as 0.5 ha. Meadows and pastures decreased in area by 10.7 ha and currently they cover 73.3 ha, which largest share is found in the southern part of the catchment.

Water supply and sewage disposal

In the Gąsawa commune the water supply and sewage disposal system is poorly developed. The degree of sewerage system cover in the last decade increased by as little as 13%. Moreover, only 43% population use the sewerage system, at an almost complete cover of the commune area by the water supply system (Table 3). Most farms use drainless tanks with an unknown degree of leak tightness.

Table 3

The percentage of population using the water supply and sewerage system in the Gąsawa commune in the years 2003–2014 (GUS 2016)

System	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Water supply [%]	92.6	92.1	92.3	92.1	91.9	92.6	93.0	93.6	93.7	93.4	93.5	99.9
Sewerage [%]	29.9	30.1	33.7	33.9	34.4	34.7	35.2	35.5	36.7	38.5	40.1	43.0
Ratio sewerage/water supply	0.32	0.33	0.37	0.37	0.37	0.37	0.38	0.38	0.39	0.41	0.43	0.43

Overgrowing rate and changes in lake area. The analysis of changes in lake area in the period of 1945–2011 showed a decrease in its area by 10.3% (i.e. 10.9 ha) in relation to the reference year of 1945 (Table 4), which is equivalent to the decrease rate of 0.15 ha annually. Slight fluctu-

ations of 0.5 ha between 1990 and 2011 may result from changes in water levels, at which analyses were conducted, or from the difference in the scale of examined maps. The results in relation to studies by other authors are very similar. For the Wielkopolska region the process of lake disappearance is 15.21% from 1920 to 1975 (CHOIŃSKI and PTAK 2008), which is one of the most significant in Poland. For example, for the Pomerania Lake District this rate is 12% in the class of water body size of 50–100 ha (PTAK 2013).

Table 4

Changes in area of Lake Gąsawskie in the period of 1945–2011

Year	Area [ha]	Changes in area of lake [%] in comparison to the year 1940
1945	105.85	–
1966	97.58	7.8
1990	94.47	10.8
2011	94.98	10.3

The overgrowing rate for Lake Gąsawskie in the 1940's was 14%. In 1990 the area covered by emergent macrophytes decreased to 12.03%. At present the share of the emergent littoral in the lake in comparison to the 1940's increased by 18.7%. The rate of lake overgrowing in the period of 1940–1990 was 0.04 ha/year in the period of 1940–2011 was 0.05 ha/year.

Evaluation of the ecological status of the lake. Phytosociological studies carried out in 2014 showed in Lake Gąsawskie the existence of only five well-developed macrophyte communities. Vegetation did not cover only a short section of the shoreline, on which a bathing beach was located. The greatest percentage in the littoral zone of the lake was recorded for the community with common reed (*Phragmites australis*), occupying 88.3% (i.e. 5.21 ha) of the littoral, characterised by greatest frequency, since it was the only one found in all examined transects. The reed rush was found over the entire length of the shoreline except for the short section of the beach. The other taxa accounted for a much lesser percentage in the lake. Macrophytes with floating leaves showed lesser frequency. They were recorded in 5 transects (i.e. 25% analysed transects), but only in one they were abundant. They covered an area of 0.56 ha, i.e. 9.48% littoral zone (Figure 2). Submerged plants were represented by only one taxon – hornwort (*Ceratophyllum demersum*), which covered an area of 0.12 ha (i.e. 2% total littoral and they were found along the rush belt.

Macrophytes were found to a mean depth of 0.9 m. The most distant locality was colonized by nymphoid-water forms and it was found at a depth of 1.6 m. Only in three analysed transects the depth reached by vegetation exceeded 1 m. The Shannon diversity index, reflecting the actual taxonomic composition, was low amounting to 0.48, similarly as the maximum phytocenotic diversity at 1.61. The colonization index, which describes the ratio of the actual littoral area to the potential area which may be colonised by plants, i.e. a depth of 2.5 m, was found to be 0.36 m. These results indicate adverse conditions determining the development of litoral in Lake Gąsawskie.

Ecological groups of plants and their quantitative ratios are presented in Figure 3. A vast majority of littoral vegetation (89% littoral) and a very small number of elodeid-form species (2%) is characteristic to lakes of poor ecological status (CIECIERSKA et al. 2013, PEŁECHATY and PRONIN 2015). This is particularly evident, since this group was represented only by hornwort, which is a species characteristic to waters with high trophic levels (MURPHY 2002).

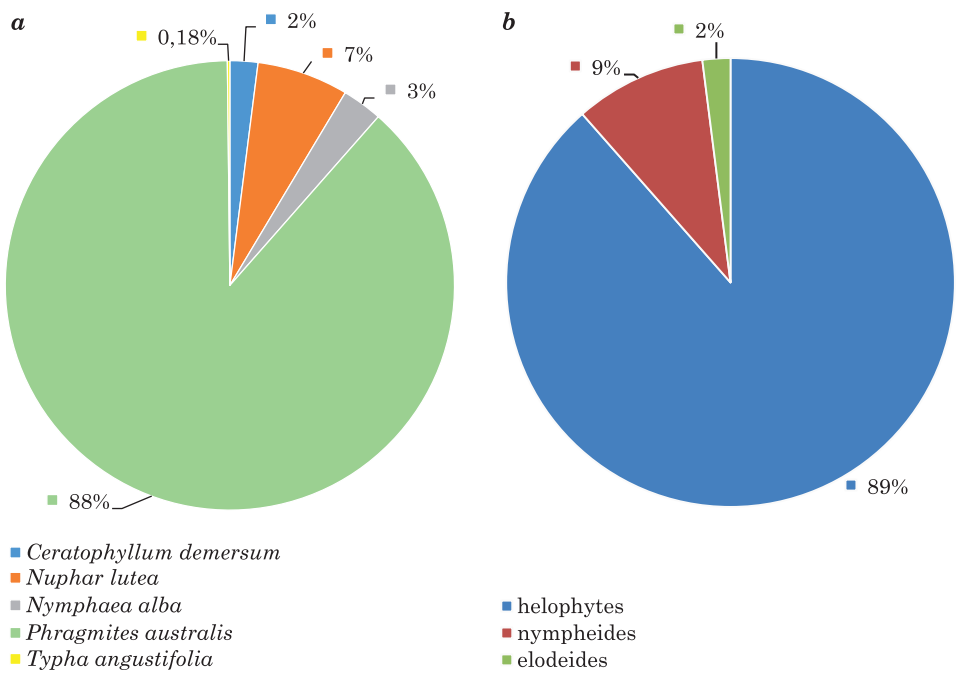

Fig. 3. Percentage of *a*) dominant macrophytes *b*) plant growth forms in the littoral zone of Lake Gąsawskie

The Ecological Status Macrophyte Index was 0.107, which indicates a poor ecological status of this lake. Results of water quality analyses showed high concentrations of nitrogen and total phosphorus as well as poor water transparency indicated by low visibility in the Secchci disc test (Table 5). In view of biological and physico-chemical parameters the condition of the lake was evaluated to be poor.

Table 5

Evaluation of ecological status of Lake Gąsawskie in 2014 according Polish Regulation (Rozporządzenie Rady Ministrów z 21 lipca 2016… Dz.U. 2016 poz.1187)

Indicator	Unit	Value	CWQ*
Biological elements			
ESMI	–	0.107	IV
Physico-chemical parameters			
Transparency of water – Secchi depth	m	0.45	<II
Total nitrogen	mg N dm^{-3}	7.078	<II
Conductivity	μS cm^{-1}	647	I/II
Total phosphorus	mg P dm^{-3}	0.075	<II
The ecological status based on biological parameters		poor	
The ecological status		poor	

*CWQ – class water quality; I/II – very good and good, < II – ecological status under good

In comparison to the 1980's the condition of the lake deteriorated (MAKAREWICZ 2005). In 1987 it was classified to water quality class III, i.e. such that may be used as a source of water supply for industrial plants except for those requiring classes I and II, as well as for watering agricultural and horticultural areas (Rozporządzenie Rady Ministrów z 9 czerwca 1970… DZ.U. 1970 no. 17 poz.144).

A bad lake condition was also found in Lake Oświęcickie, located above Lake Gąsawskie (MAKAREWICZ 2005). Despite the considerable share of forests in the direct catchment of the lake the quality of its water is not satisfactory. As it was indicated by (MAKAREWICZ 2005, STACHNOWICZ and NAGENGAST 2010), the primary cause is the inappropriate sewage disposal in the catchment of this lake.

Conclusions

The analyses of the condition of Lake Gąsawskie showed an unsatisfactory water quality and poor ecological status based on the macrophyte index and physico-chemical parameters of water. In the course of 66 years

the area of this lake decreased from 105.85 ha to 94.98 ha, i.e. by 10.87 ha. The rate of its disappearance is high, but comparable to other lakes located in agricultural areas of the Wielkopolska region. The most significant changes which have taken place in the land use structure in the catchment of Lake Gąsawskie in the years 1945–2011 include an increase in anthropogenic areas, particularly building development, at the expense of arable land. This is particularly important, since the sewerage system cover in the Gąsawa commune, where Lake Gąsawskie is located, is only 43%. The effect of agricultural land use in the catchment and the lack of regulated sewage disposal in the catchment is manifested in the poor condition of the lake. This is evidenced by the very low number of plant communities, the slight share of submerged macrophytes, including the species characteristic of fertile habitats, i.e. hornwort. High nutrient concentrations promote intensive development of phytoplankton resulting in limited water transparency, effectively limiting development of submerged vegetation. At the same time we may observe an intensive development of emergent vegetation, influencing the gradual overgrowing of the lake. Results of this study showed that undertaking effective actions in the lake catchment is crucial for any improvement of water quality in Lake Gąsawskie.

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