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Diversity of Aquatic and Coastal Vegetation in the Lublin Coal Basin Complex - Long-Term Changes

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Abstract: Natural resources are fundamental to the survival and development of human populations, and their exploitation is associated with problems such as resource depletion and environmental degradation. Within the borders of the Lublin Coal Basin (LZW) there is the Łęczna-Włodawa Lake District, which includes over 60 lakes. It is one of the most valuable natural areas in the Lublin Voivodeship and the entire region. Due to the undoubted impact of LZW, as well as the lack of detailed botanical studies in the existing literature, research has been undertaken since the 1980s to analyse the floristic and ecological vegetation of aquatic and coastal plants of 6 lakes in the mine's impact zone. Macrophytes are recognized by the WFD as one of the key groups suitable for freshwater biomonitoring and for ecological classification purposes. The conducted research confirmed the progressive degradation of the analyzed lakes. Since the 1990s, there have been significant changes in the use of the area covered by the analyses. The share of built-up areas has significantly increased, but also the share of surface waters. The share of built-up areas has significantly increased, but also the share of surface waters. The qualitative and quantitative structure of macrophytes has undergone very significant changes towards a reduction in the number of species and phytodiversity. The share of species in fertile habitats has increased. Despite the introduction of various forms of legal protection in this area, changes in the depletion of biodiversity are continuing.

Keywords: Macrophytes, Coal mine, Lakes, Land development, Biodiversity index

Introduction

Human development is possible thanks to the use of Earth's resources. Currently, they are used on an unprecedented scale. Natural resources are fundamental to the survival and development of the human population, and their exploitation is associated with resource depletion and environmental degradation. An industry that contributes greatly to environmental degradation is mining (Carvalho, 2017; Goudie, 2018; Sengupta, 2021). Mining can have significant impacts on water resources, including pollution and depletion (Santana et al., 2020; George et al., 2010). In the Lublin Coal Basin, this is done by pumping groundwater from exploited Carboniferous deposits and then discharging them into surface waters, and (after partial exploitation of the deposit), closed tunnels are closed. Mining is carried out using the collapse mining method (Kraśnicki, 2019). Therefore, it is important to monitor and manage these impacts to minimize negative effects on the environment (Dmitruk, 2021).

Despite its rich deposits, the Lublin Coal Basin is one of the most recently developed mining regions in our country. Coal has been mined here since the 1970s. According to data from the Polish Geological Institute, there

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are 11 documented hard coal deposits in the LCB; moreover, coal reserves account for approximately 21.5% of Poland's hard coal resources (610 km²) (Malon & Tymiński 2011).

Within the Lublin Coal Basin are the Łęczna-Włodawa Lake District, which includes many lakes, peat bogs, forests and wetlands. It is one of the most valuable natural areas in the Lublin region and is also a recreational area. In addition to the environmental transformations caused by the mine's activities, since the late 1950s, engineering and water investments have led to significant changes in the hydrological regime of this region. It is one of the longest drainage systems in Europe (139.9 km) - Wieprz - Krzna Canal (Janiec, 1993; Poleszuk, 2002). Its aim was to regulate water relations in order to revitalize the region's economy (Solis, 2012; Sender & Maślanko, 2017).

Due to such a strong impact, as well as the lack of detailed hydrobotanical studies in the literature since the 1980s (Popiołek, 1988), research was undertaken to analyze the aquatic and coastal vegetation of 6 lakes in the LCB impact zone. Macrophytes are recognized by the WFD as one of the key groups suitable for freshwater biomonitoring and for ecological classification purposes (Szoszkiewicz et al., 2007). Macrophytes of a variety of aquatic ecosystems have been extensively studied for decades, and their ecological properties have been a common topic of study for a long time (Westlake, 1975; Haslam, 1982; Maberly & Haslam, 1988; O'Hare et al., 2006; Wiegleb et al., 2015). The undertaken research will allow for the assessment of the degree of transformation in the qualitative and quantitative structure of plant ecosystems in the mine's impact zone. The assessment was based on research conducted in the 1970s and 1980s, before the period of the mine's impact, and current research from 2022 and 2023. The degree of changes in the structure of lake macrophytes and their surroundings as well as habitat changes based on the plant requirements were assessed. It was assumed that the mine activity in this area indirectly affects the structure of plants in lakes, which will manifest itself in a decrease in phytodiversity and an increase in habitat fertility. It is expected that in the vicinity of lakes (shoreside) there may be an expansion of plants with lower moisture requirements. In some lakes there may be an increase in species diversity due to the increase in their fertility. The question was asked whether the forms of protection introduced in this area and the mine activities undertaken affect the direction of vegetation changes?

Material and Methods

Study Area

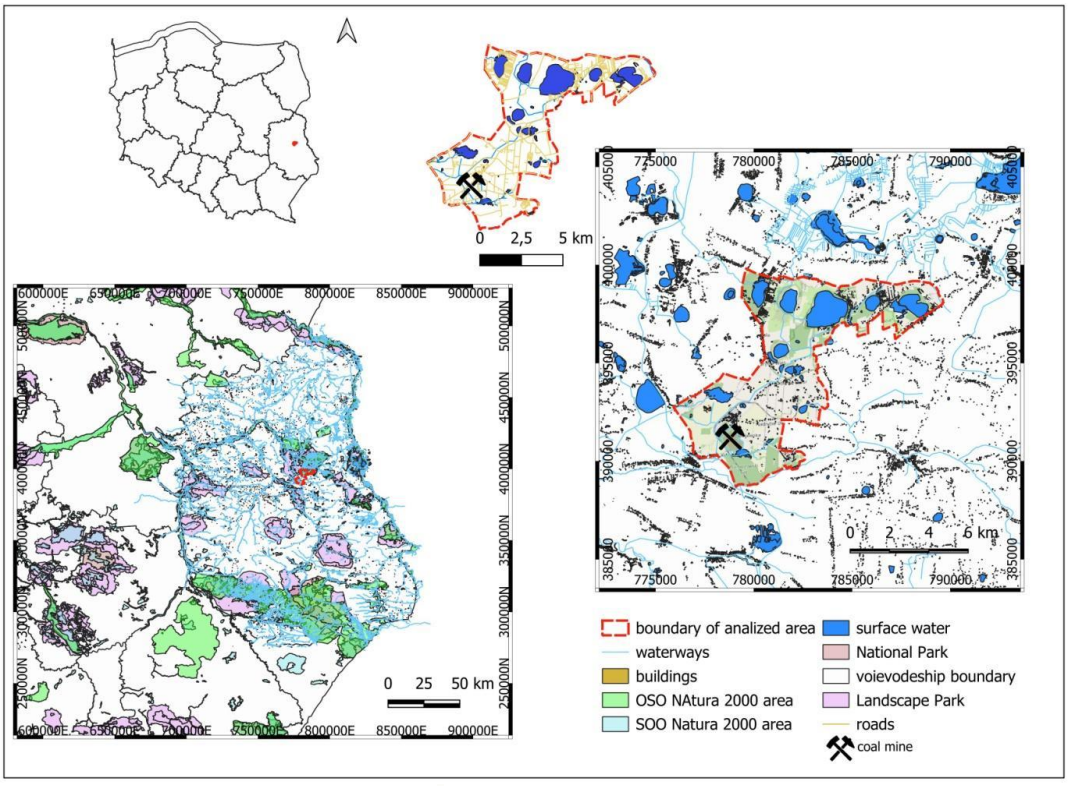

Figure 1. Localization of study area.

Lublin Coal Basin (LCB) is located in eastern Poland, in the Lublin Voivodeship. It is located on the Lublin Upland and is an extension of the Lviv-Volyn Coal Basin, which belongs to Ukraine. In total, the LCB covers an area of over four thousand square kilometers (180 km long, 20 km wide). Currently, there are two large mines operating here - the Bogdanka Hard Coal Mine and the Stefanów Mine. The study analyzed six natural lakes that are located the nearest location and have been subject to mine pressure over the years (Figure 1).

Until the end of the 1980s, there were two forms of protection in the analysis area (Poleski Landscape Park and Polesie Protected Landscape Area). Since 1990, three further forms have been established in this area, including the Łęczyńskie Lakeland Landscape Park, the Uściwierz and Ciesacin ecological areas. Since 2004, areas of international importance have been introduced here - Natura 2000 Uściwierskie Lakes and Polesie. The Polesie National Park, established in 1991, is located nearby (Figure 1).

Field Study

Vegetation structure research was carried out in 6 lakes in the area of the most intensive mine impact and subject to various forms of impact of the area's drainage system. In the study, we analyzed data concerning plant communities and rare plant species from two periods: 1) 1979- 1984 (referred to in the manuscript as 1988) and 2) 2022-2023 (referred to as 2022). Date from the first period come from the literature (Popiołek 1988). Therefore, the data for both study periods were obtained using the same transects and methods. In both periods and for each lake, a total of 200 phytosociological relevés performed according to Braun-Blanquet (1964) method were used. The adopted nomenclature of species followed Mirek et al. (2002) while the taxonomy and nomenclature of communities followed Matuszkiewicz (2012). The investigation of macrophytes were recorded during the summer of 2022 and 2023 at 4 or 5 transects of each lakes along the 50 - 100m long transects.

The study analysed the frequency of plant species in both periods. For the evaluation of plant species, the following scale was used: 0 – absent; 0.1 – extremely rare (few individuals, 1-5%); 1 – very rare (cover 5-25%), 2 – rare (cover 25-50%); 3 – frequent (cover 50-75%); 4 – very frequent (cover 75-100%) (Pawłowski 1977). We tried to select phytosociological relevés in an objective and representative way for the analysed sites to repeat the research in the second period, showing changes in the frequency of occurrence of plant species. Based on the recorded percentages of the plant species occurring, Ellenberg ecological indicator values (Ellenberg et al., 1992) were calculated to assess the climatic and edaphic conditions of the studied lakes. The following ecological indices were considered: L – light, T – temperature, F – moisture, R – soil reaction (pH), N – nitrogen content and S - salinity. Data from two periods were used to the assess changes in habitat conditions over time.

Cartographic Analyzes of Changes

Land use analyzes were carried out in the entire area including the mine and 6 lakes. For cartographic analyses, land cover maps from 1990 and 2022 downloaded from the Corine Land Cover 1990 and 2022 website (by Copernicus) were used. On this basis, changes in the development of the entire research area were determined. For this purpose, QGIS software was used, in which, after generating the area up to the study limits, the share of areas such as: mixed forests, complex crop and plot systems, areas occupied mainly by agriculture with a large share of natural vegetation, arable land beyond the reach of irrigation devices, meadows, pastures was determined, inland swamps, reservoirs, deciduous forests, urban and recreational development, industrial or commercial areas.

Moreover, after determining a 300m buffer zone, comparative analyzes of development were performed for each lake, paying particular attention to water conditions. For this purpose, the length of watercourses, including canals, embankments and roads, was determined. The share of surface forms of land development was analyzed, including waters, forests, fields, meadows, fallow lands, buildings, wetlands and beaches. The basis for the analyzes were orthophotomaps (year 2022) and archived topographic maps (year 1975), downloaded from the geoportal website. gov.pl.

Botanical and Statistical Analyses

Species diversity indices were used for the analysis (number of species, Shannon index H' and Pielou species evenness index J') (Moffatt, McLachlan 2004). During the calculation of the Shannon index, the Braun-Blanquet

quantitative degrees were transformed to the van der Maarel scale (1979), and the EXCEL program was used for calculations. The diversity analysis was extended to compare changes in the quantitative share of distinguished ecological groups of species (the sum of Braun-Blanquet quantitative degrees transformed to the van der Maarel scale). Differences between the two research periods were tested using the Wilcoxon test. STATISTICA 13.3 (StatSoft, Inc.) was used for calculations.

Results

Changes in the Use of the Impact Area

The entire analyzed area was subject to very dynamic changes in terms of land use (Figure 2). In the study area, since 1988, the share of marshes (-24.9%), meadows and pastures (-45.7%), agricultural areas with a large share of natural vegetation (-42.8%), and complex cultivation systems (-38.7%) has significantly decreased. However, there was a very significant increase in the number of industrial areas (32.3%), the share of areas with urban and recreational development increased 5 times (+479.73%), and the area of water reservoirs in this area increased by 18.67% and it was not the area of lakes but the appearance numerous flood waters (Figure 2).

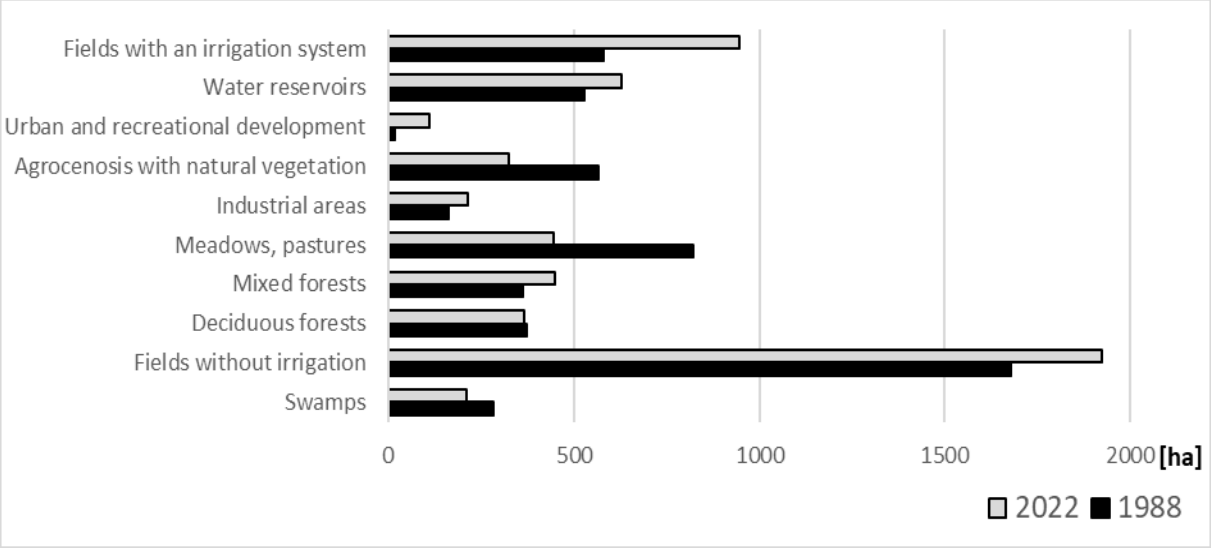

Figure 2. Changes in land use in the area affected by the mine

Changes in the Use of the Lake Buffer Zone

The development of the buffer zone of the 6 analyzed lakes was subject to very significant changes. Among the surface forms of cover, forests (trees and shrubs) had a significant increase in all buffer zones. The largest increases in forest cover were recorded in the vicinity of the lakes Nadrybie - 40%, Bikcze - 34% and Sumin - 33%. The share of meadows decreased significantly in all buffers, the largest in lakes Nadrybie (41%), Rotcze (36.5%) and Uściwierz (30.1%). The increase in land occupied for development was observed in the 4 analyzed buffer zones on lakes Piaseczno 25%, Sumin 12%, Rotcze 26% and Uściwierz 12%. Additionally, only in Lake Piaseczno the share of beaches increased, in the remaining lakes their share either decreased or did not exist at all (Figure 3). In the vicinity of most lakes, despite the construction of numerous ponds, the degree of irrigation of this zone decreased, which was reflected in the decrease in the share of permanently wet areas, the largest in the vicinity of Sumin lake - 19.7%, Rotcze - 20% and Bikcze - 12.7%.

The length of roads increased in the vicinity of all lakes. The largest increase was recorded at lakes Piaseczno 36.4% (from 1.2 km in 1988 to 5.6 km in 2022), Sumin 35.2% (from 1.06 km to 3.94 km) and Uściwierz 36, 9% (1.09 km to 5.35 km). The network of canals, rivers and embankments remained at a very similar level in the analyzed periods. Some of the drainage is currently not operational, e.g. at Lake Piaseczno, Uściwierz and Bikcze. This network was and is the most developed in the vicinity of the lakes Nadrybie 9.5 km and Sumin 9.3 km in 1979 (Figure 4).

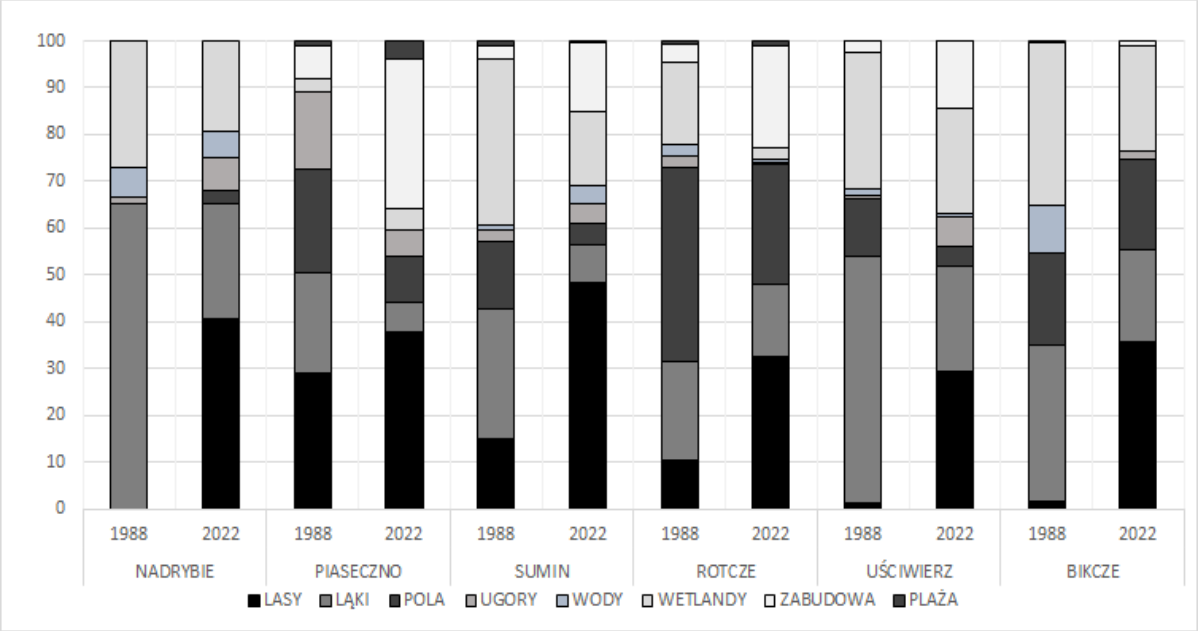

Figure 3. Changes in the use of the lake buffer zone - surface forms

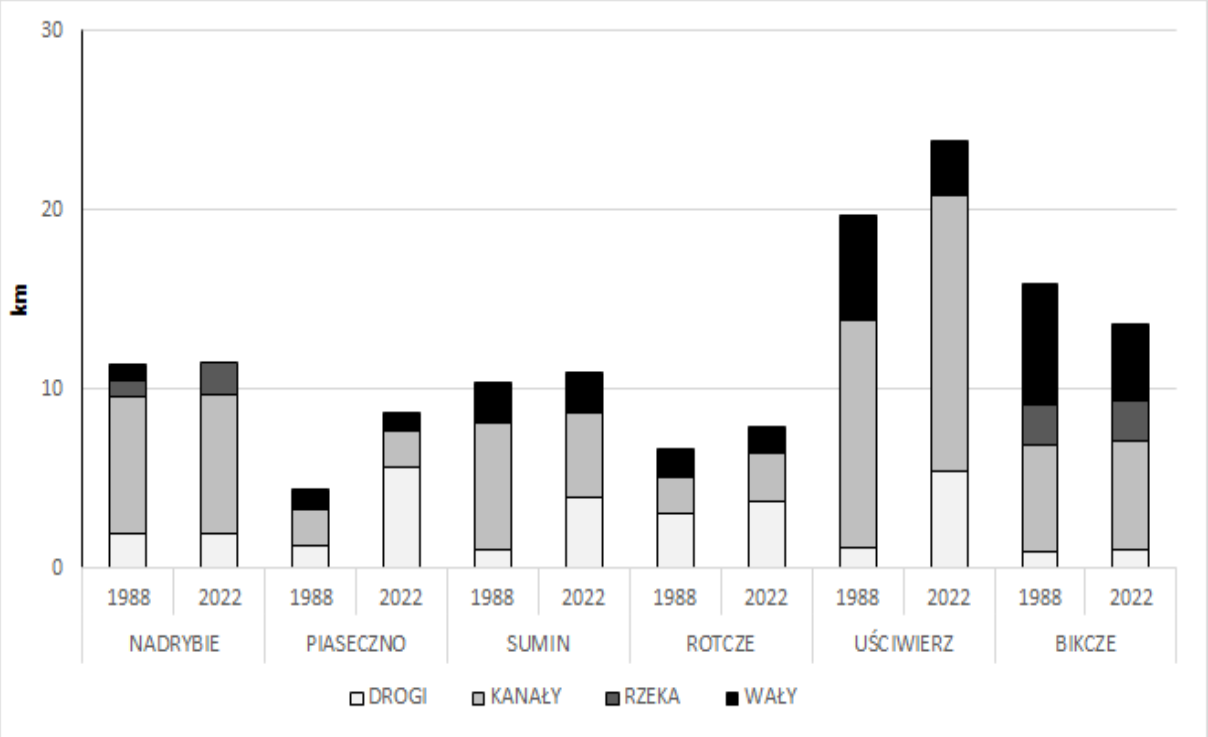

Figure 4. Changes in the use of the lake buffer zone - linear forms

Long-term Analysis of Changes in the Structure of Macrophytes

Changes in Floristic Structure and Quantity

The largest number of species occurred in the water and coastal zone of Lake Bikcze in 1988 - 63, and in 2022 - 59. The fewest species were in Lake Nadrybie - 39 species in 1988 and 32 in 2022 (Table 1). In most lakes, changes in the total number of species were observed, towards their depletion. Compared to 1988, 7 species disappeared in the Sumin and Nadrybie lakes, in the remaining lakes there were 8 species less. The exception was Lake Rotcze, where the trend was completely opposite, the number of species is now higher by 7 (mainly shore plants) (Table 1).

Table 1. Number of species occurring in the shoreline and littoral zones of the analyzed lakes

	Littoral zone		Shoreline zone	
Lake	1988	2022	1988	2022
Bikcze	31	30	32	29
Nadrybie	18	17	21	15
Piaseczno	26	31	30	17
Rotcze	22	21	23	31
Sumin	29	25	25	22
Uściwierz	36	35	19	12

In most of the analyzed lakes, there was a clear increase in the area covered by individual species in the analyzed transects among the littoral and shoreline vegetation. The greatest increase in vegetation cover was recorded in Piaseczno lakes by 20.5% for littoral plants. In two lakes, Rotcze - 20.7% and Nadrybie - 5.04%, the cover among littoral plants was reduced. The most stable lake in terms of the number of plants covering it was Lake Sumin, with an increase in aquatic vegetation by 0.3% and a decrease in shoreline vegetation by 0.51% (Table 2). Among the shoreline vegetation, the cover was reduced on lakes Piaseczno - 40.6%, Uściwierz - 44.6% and Bikcze - 8.4%. In other lakes, there was sometimes a significant increase in the cover of shore plants, in Lake Rotcze by 44.2%, and in Nadrybie by 7.44% (Table 2).

Table 2. Macrophyte coverage of the shoreline and littoral zones in the analyzed transects (%)

	Littoral zone		Shoreline zone	
Lake	1988	2022	1988	2022
Nadrybie	60.26	57.22 -5,04%	39.74	42.78 7,44%
Uściwierz	76.34	86.90 13,8	23.66	13.10 -44,6%
Rotcze	68.11	54.00 -20,7%	31.89	46.00 44.2%
Bikcze -	64.28	67.27 4,65%	35.72	32.73 -8,4%
Piaseczno	66.49	80.1 20,5%	33.51	19,9 -40,6%
Sumin	65.14	65.32 0,27%	34.86	34.68 -0,51%

Changes in Diversity Indicators

The Shannon-Wiener and Pielou indices of floristic diversity usually reached lower values in the last period. mong the littoral plants, the highest values of the Shannon-Wiener index, both in 1988 and 2022, occurred in Lake Bikcze and Uściwierz - H = 1.20, and the lowest in Lake Nadrybie. The highest values of the Shannon-Wiener index for plants in the coastal zone in the 1980s were recorded for lakes Sumin - H=1.20 and Bikcze - H=1.20, while the lowest for lake Uściwierz H=1.00. Nowadays, the values of this indicator have increased for plants on lakes Bikcze to H=1.26 and Rotcze, where it reached the highest value of H=1.34.

The values of the Pielou index determine the share of individual species, values close to 1 mean high uniformity, and values close to 0 mean low uniformity. The greatest uniformity of the share of littoral plant species was observed in 1988 for Lake Sumin, and in 2022 for Lake Rotcze (Table 3). The lowest index values in both analysis periods for this group of plants were in Lake Nadrybie, reaching J = 0.74 and J = 0.65, respectively. For shore plants, the highest value of the Pielou index was recorded at Lake Sumin in 1988, J = 0.81, but in 2022 it was already J = 0.78. The value of this indicator for this group of plants also decreased in the lakes Piaseczno, Uściwierz and Nadrybie. In the remaining two cases, the value of the indicator increased (Table 3).

Table 3. Indicators of floristic diversity in the studied lakes

	H' Shannon-Wiener index				J' Pielou index			
	Littoral zone		Shoreline zone		Littoral zone		Shoreline zone	
Lake	1988	2022	1988	2022	1988	2022	1988	2022
Bikcze	1.2	1.17	1.2	1.26	0.81	0.71	0.81	0.78
Nadrybie	0.98	0.86	1.08	0.97	0.74	0.65	0.8	0.72
Piaseczno	1.13	1.11	1.07	1	0.75	0.74	0.7	0.65
Rotcze	1.05	1.16	1.18	1.34	0.75	0.83	0.75	0.85
Sumin	1.18	1.04	1.2	1.15	0.81	0.71	0.81	0.78
Uściwierz	1.2	1.19	1	0.84	0.77	0.77	0.78	0.66

Changes in Habitat Conditions based on Species Composition

In most lakes, among the species of the littoral zone, there was a tendency towards a greater share of species with greater light (L) and temperature (T) requirements (Table 4). The values of the acidity index (R) for individual macrophyte species indicated the dominance of neutral species and those tolerant to a wide pH range (from 5.79 in Piaseczno to 6.73 in Sumin). The indicator values for nitrogen (N) indicated eutrophic habitats, rich in nitrogen, from 5.24 units in Rotcze to 6.17 units in Nadrybie. This lake also saw its largest increase since the 1980s (Table 4).

Among the plants of the littorl zone in Lake Piaseczno, a statistically significant decrease in the T value was shown in 2022 (p-value < 0.05); Lake Bikcze showed a statistically significant increase in the value of L in 2022 (p-value < 0.05), while lake Nadrybie showed a statistically significant decrease in the value of the F index (p-value < 0.05) (Table 5).

Table 4. Values of Ellenberg number indices for littoral and shoreline plants (Li - littoral, S - shoreline) (L – light, T – temperature, F – moisture, R – reaction, N – nitrogen, S – salinity)

			L	T	F	R	N
SUMIN	1988	Li	7,55	5,26	9,97	6,40	5,32
		S	7,80	5,23	8,85	4,46	3,44
	2022	Li	7,22	5,30	9,66	6,73	5,81
		S	7,55	5,06	8,88	4,74	3,70
PIASECZNO	1988	Li	6,99	5,60	9,80	6,09	5,64
		S	7,81	4,95	7,48	7,48	3,29
	2022	Li	7,18	5,22	9,82	5,79	5,44
		S	7,90	4,47	6,40	6,40	4,31
BIKCZE	1988	Li	7,02	5,68	10,74	6,55	5,93
		S	7,66	5,04	7,28	4,51	3,86
	2022	Li	7,25	5,44	10,45	6,35	5,83
		S	7,37	4,60	7,61	4,33	3,85
ROTCZE	1988	Li	7,09	5,67	10,60	6,31	5,46
		S	7,59	5,37	8,44	5,37	4,44
	2022	Li	7,23	5,41	10,06	5,97	5,33
		S	7,78	5,16	8,51	4,89	3,69
UŚCIWIERZ	1988	Li	7,24	5,23	10,26	5,93	5,24
		S	7,84	4,62	6,76	5,62	3,90
	2022	Li	7,12	5,31	10,47	6,40	5,78
		S	6,91	4,29	6,32	4,63	3,41
NADRYBIE	1988	Li	7,44	5,81	10,60	6,02	5,73
		S	7,56	4,15	7,11	4,17	4,02
	2022	Li	7,50	5,76	10,20	6,06	6,17
		S	7,09	4,74	6,28	4,57	3,71

Among the plants inhabiting the lake shore zone, species with a wide range of light tolerance have definitely dominated and still dominate (L from 6.91 Uściwierz lake to 7.9 Piaseczno lake). These plants prefer very large amounts of light. The greatest decrease in the L index (requirements for the amount of light) was recorded among the shore plants of Lake Uściwierz; in the 1980s it was 7.84, and currently it is 6.91 (Table 4).

Both in the 1980s and now, there are species tolerant to low temperatures in the lake shore zone, and these are moderately thermophilic plants. In all lakes, the value of the indicator (T) in the subsequent years of study decreased slightly (on average by 0.5), only in Lake Nadrybie it increased (from 4.15 to 4.74).
The vegetation of the shore zone of the analyzed lakes is mostly mesophilic and tolerates a wide range of humidity. In the vicinity of three lakes: Piaseczno, Uściwierz and Nadrybie, the values of the index (F) decreased in the subsequent decades of research, which indicates the direction of habitat drying, particularly visible at Lake Piaseczno (from 7.48 to 6.4). In the remaining lakes there was a slight increase in the value of this indicator (Table 4).

The surroundings of most lakes are inhabited by plants of slightly acidic habitats, from 4.17 at Lake Nadrybie to 5.62 at Lake Uściwierz. In two of them, Sumin and Nadrybie, the value of the acidity index (R) increased by approximately 0.5 in the following decades. Only in the vicinity of Lake Piaseczno, the acidity index values indicate a slightly alkaline character (7.48), with a slight downward trend (6.40). The nitrogen content of the

habitat increased in two lakes, Sumin and Piaseczno, in Lake Bikcze it did not change, while in the remaining lakes it decreased slightly, on average 0.6. Plant species inhabiting the shores of these lakes prefer habitats with moderately high nitrogen content. The shores of the studied lakes were inhabited primarily by plant species preferring habitats with moderate salinity (S 1.65 Uściwierz to 4.91 Rotcze). In most lakes, the value of this indicator decreased in the following decades. The exception was Lake Piaseczno, where both its values were the highest and the current value means a significant increase in salt concentration in the soil from moderate (4.00) to high (5.50) (Table 4).

Table 5. Significance of changes in Ellenberg indicators over time, p-value for the Wilcoxon test; * - statistical significance at the 0.05 level, gray field - insufficient data

	Shoreline zone					
Lake	L	T	F	R	N	S
Sumin	0.6121	0.7353	0.7532	0.173	0.2367	
Piaseczno			0.0500*			
Bikcze	0.3452	4652	0.5006	0.0796	0.3452	
Rotcze						
Uściwierz	0.0679	0.4652	0.0144*	0.1088	0.1441	1797
Nadrybie	0.398	0.0464*	0.3454	0.398	0.6121	0.1797
	Littoral zone					
Sumin	0.1097	0.5754	0.7671	0.7353	0.8589	
Piaseczno	0.3269	0.0251*	0.2076	0.1235	0.1614	
Bikcze	0.0281*	0.0712	0.1361	0.1823	0.5829	
Rotcze	0.4413	0.6112	0.4838	0.9528	0.2135	
Uściwierz	0.5701	0.8203	0.9588	0.1208	0.0979	
Nadrybie	0.9989	0.4445	0.0342*	0.7221	0.2721	

For shore plants in Lake Nadrybie, a statistically significant increase in the value of the T index was demonstrated in 2022 (p-value < 0.05) and a statistically significant decrease in the value of the F index for these plants in lakes Piaseczno and Usciwierz (p-value < 0.05) (Table 5).

Discussion

In the area of analysis, over 40 years have been a period of intensive changes in the way of development. Especially swampy and meadow areas gave way. The changes in water conditions in the area of analysis undoubtedly resulted in flood waters, which may have both a positive and negative impact on the environment. On the one hand, they are a refuge for various species of plants and animals and promote water retention. On the other hand, floodwaters may also cause flooding of agricultural areas and local buildings. It is important to sustainably manage floodplains, including by regularly monitoring their condition (water level, water quality and biodiversity) (Opperman et al., 2010). According to Michalczyk et al. (2011), the appearance of new floodplains in the analyzed area, created in the depressions around the mine, from the point of view of protecting these areas, is indicated as necessary to prevent the spread of excessively eutrophic and mineralized waters.

One of the most important factors influencing the structure of lake vegetation is the management method in its immediate surroundings (Young et al., 2005, Twesigye et al., 2011). The immediate surroundings of the analyzed lakes were subject to very high dynamics, despite the naturally valuable areas and various forms of protection successively introduced there. The greatest changes in the way the surroundings were developed among surface forms concerned meadows, which were replaced by forests and a significant increase in areas intended for development. Increasing the forest cover in this area is one of the priority activities carried out by the Central Coal District. This entire area is treated as a zone of increased protection of natural values. Due to the shortage of forests in the region and the expected deterioration of climatic conditions due to industrial activities, it was proposed to plant new forests in suitable areas, which also had no or little value for agricultural development, and insulating plantings around industrial zones (Dmitruk, 2021).

On lakes attractive to tourists, there was also a significant increase in beach areas, which resulted in the destruction of the coastal zone (Delgado-Fernandez et al., 2019). The share of dug reservoirs - ponds whose main function is to store water and drain areas originally occupied by wetlands - has increased. Most of them were created in the vicinity of the Uściwierz and Nadrybie lakes, where, apart from the above-mentioned

functions, the ponds were used mainly for breeding purposes. Hydrological changes were also reflected in a greater share of species with lower moisture requirements.

The hydrological conditions of the Lublin coal basin are exceptional and unique in this type of investments in the country. The operation of the mine means constant pumping out of groundwater, which results in a decrease in the local groundwater level and the formation of subsidence basins. Mining waste is deposited in a dumping ground and recultivated, which is intended to reduce dust generation. Mine water is discharged to the sedimentation tank and then to the Świnka River, some of it is also used for coal enrichment, sprinkling and fire protection (Suita & Łyszczarz 1997). These changes are indirectly visible in the structure of macrophytes in lakes and the surroundings. The response to these changes is the decreasing species diversity and, therefore, lower values of the analyzed diversity indices compared to the 1980s. The index value decreased in the Piaseczno, Uściwierz and Nadrybie lakes. In the two remaining lakes Bikcze and Rotcze there was an increase, while for Lake Sumin it remained unchanged, however, reaching small values in both periods. The increase in the index values may be generated by an increase in the fertility of lake waters, which is confirmed in the analyzes carried out by changes in the Ellenberg indexes, manifested by a greater share of species preferring higher nitrogen contents or alkaline habitats. At the same time, changes in the lake surroundings, in addition to the increase in habitat fertility, resulted in lower species diversity. In addition to species diversity, the area occupied by plants in the lake is also an indicator of changes. As a rule, an increasing plant area means an increase in the fertility of the habitat, but this only happens to a certain extent. Overfertilization often causes plants to decline and their area to be reduced (Budzyńska et al., 2019, Trajanovska et al., 2014). The greatest decline in vegetation cover (by 20%) occurred in Lake Piaseczno, which was also associated with a decline in biodiversity. Similarly, in Lake Rotcze, the cover was reduced by over 20.7%. However, in this lake the species diversity indicators were high, which does not confirm the direction of changes in depletion. There was also an increase in the share of species belonging to rushes, such as: *Phragmites australis, Typha latifolia* and *Carex rostrata*. The share of submerged species such as *Chara fragilis, Elodea canadensis, Nymphaea candida*, and *Potamogeton lucens* decreased. This situation may be explained by changing conditions of light availability, which is lower in more fertile waters (Søndergaard et al., 2013).

Certainly, one of the most important factors influencing changes in the structure of lake vegetation are changes in water conditions, which are undoubtedly influenced by mine activities, e.g. by lowering the water table in lakes and the level of shallow groundwater. The flow directions of shallow groundwater are changing, the mineralization of groundwater and surface water is increasing and their outflow is accelerating. Due to the complexity of various impacts related to global climate and anthropogenic changes in the analyzed area, it is difficult to clearly determine the impact of the Mine on the natural values of the region, especially the studied lakes. Water conditions were significantly transformed with the introduction of very extensive drainage works carried out before the mine was opened, the impact of which was often described as negative (Poleszuk, 2002, Radwan, 1994, Sender & Maślanko, 2017). The response of lake vegetation is ambiguous. There is a depletion of the qualitative and quantitative structure of vegetation and an increase in the fertility of habitats, but it is also a natural process (Scheffer, 2020), the pace of which, however, may be accelerated by human activity.

Sustainable use of environmental resources is a priority in this area. That is why various forms of protection have been introduced here in large numbers, because they limit human activity, and the existing infrastructure, including the mine, is obliged to act to protect the resources of this region (Łyszczarz, 2005). It is therefore difficult to assess the impact of creating protected areas, because we do not know how nature would behave without their creation.

Conclusions

In the analyzed lakes and their surroundings, there are changes in the area inhabited by lake plants, a reduction in the number of species, a greater share of species indicating an increase in habitat fertility and the disappearance of species with greater moisture requirements. However, it is not possible to clearly indicate the Lublin Coal Basin Mine as directly influencing these changes. The impacts are multidirectional, and the most important medium in this area is water, which has been and is subject to significant transformations. In the analyzed area there are very significant changes in the way of land development, on the one hand they are related to the operation of the mine (increase in forest cover, larger water surface), and on the other hand, with the tourist attractiveness of the area (recreational development, access roads). The forms of protection introduced in this area and the mine activities undertaken influence the direction of changes in vegetation and prevent changes leading to a rapid depletion of species and habitats.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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