



Article Phytosociological Data in Assessment of Anthropogenic Changes in Vegetation of Rzeszów Reservoir

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Abstract: Phytosociological research on aquatic and marsh vegetation was conducted in Rzeszów Reservoir (SE Poland): 134 relevés according to the Braun-Blanquet method were collected there in 2016 and compared to 91 relevés published in 1994 (225 relevés in total). Changes in vegetation type, diversity measures, species composition, and Ellenberg Indicator Values (EIVs) for light, moisture, reaction, and nitrogen were analysed. Over the 22 years (1994–2016), the greatest changes were noted in communities of the classes *Lemnetea* and *Potametea* and the alliance *Salicion albae*. The long-term observations demonstrated the disappearance of 14 phytocoenoses and the occurrence of 12 new ones. An expansion of marsh communities (*Typhetum latifoliae, Typhetum angustifoliae, Glycerietum maximae, Leersietum oryzoidis*) was noted, causing a decline of several species and vegetation types. According to canonical correspondence analysis (CCA), four environmental variables (light, moisture, nitrogen, and pH) were related to plant distribution. The strong disturbances reflected in intensive eutrophication were due to human activity, which is the main factor shaping the ecological succession and overgrowing of the reservoir.

Keywords: aquatic ecosystems; biodiversity; central Europe; ecological succession; eutrophication; plant associations; transformation of vegetation

1. Introduction

Reservoirs, as artificial water bodies, play an important role in the human economy and at the same time they are extremely valuable components of the natural environment, they have mostly been built by the damming of rivers [1,2]. They have changed the original river habitat considerably, not corresponding to flowing waters but more resembling natural lakes. These altered habitat conditions are reflected by the vegetation communities. Reservoirs may be of particular interest as they provide various ecosystem services, such as a supply of drinking water, industrial water supplies, power generation, flood control, water retention, and recreation, while contributing to the improvement of landscape aesthetics and increasing habitat diversity [3–5]. Water and marsh ecosystems are of particular importance in the urban landscape. They are a habitat for many plant species, including protected and rare ones, and maintaining a diverse landscape is important for improving local biodiversity [6]. Changes that occur as a result of human activity in aquatic ecosystems contribute to the degradation of these areas, and as a result, the withdrawal of species with narrow ecological requirements and the impoverishment of the flora.

In recent years, the importance of the aquatic ecosystem has been emphasized in the context of the relationship between plant-associated and communities of microbes (the phytomicrobiome). The plant microbiome plays multiple roles, can stimulate plants growth by helping them with the necessary nutrients, enhance the resistance of the plant



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). to stress, as well as be used for bioremediation, help to clean water reservoirs from nutrient contamination. Using microorganisms from the environment supports sustainable development [7,8].

Like all water ecosystems, reservoirs are polluted with municipal wastewater, discharged directly or indirectly (from the catchment area). Besides, reservoirs are affected by the non-point source of pollution resulting from agriculture [9,10]. Rzeszów Reservoirs come under intensive human impacts, which degrade their water quality [11–13]. Eutrophication of water by nitrogen and phosphorus compounds is known to cause changes in the plant community composition, where macrophytes may eventually be replaced by green macroalgae or phytoplankton as a consequence of light deficiency [14,15].

Urbanization is one of the most important causes of degradation of natural habitats and it simplifies species composition of aquatic plants and disrupts hydrological systems [16,17]. The intensity and types of human impact, as well as accumulation of alluvial deposits carried by the current, affect the rate and range of transformation of aquatic and marsh vegetation. This is closely linked with the decline and appearance of new communities [18], and also with changes in the diversity of plant communities [14,19–21]. Vegetation dynamics in aquatic ecosystems could be fast and intense, especially in river ecosystems, because they are naturally disturbed ecosystems, and available sites are continuously created and destroyed by flow alterations, invasive species, and recreational use. Transformations usually concern the littoral zone-areas with great contrasts and heterogeneous environment (e.g., temperature, physical forces, disturbance regimes) [22,23]. Reservoirs have asymmetrical basins: they are the deeper at the dam, and shallow at the inflow. Their hydrological regime is intermediate between rivers and lakes, which causes instability and the disturbance of ecosystems occurring there [24]. The small depth and large area make the reservoirs particular habitats, where abiotic factors determine the functioning of the ecosystem, and in which homeostatic processes are poorly developed, given their artificiality [25,26].

The relationships between different environmental factors and the distribution of aquatic vegetation have been discussed in numerous publications [27–29]. Thus, aquatic macrophytes and communities have frequently been used in vegetation ecology as reliable indicators of habitat conditions in waters, as they seem to be directly correlated with specific environmental conditions and can reflect changes in trophic status [30–32]. Aquatic macrophytes are one of the biological quality elements for monitoring the ecological status of surface waters in view of the provisions of the EU Water Framework Directive 2000/60/CE. Therefore, they are widely used for environmental monitoring and water quality assessment throughout Europe [33,34]. Moreover, multitemporal analyses of aquatic vegetation could be an instrument to assess the direction of environmental changes, both over a short period [35] or over a long period [21].

Phytosociological studies are extremely useful as they make it possible to determine the current state and diversity of the vegetation cover and recognise the degree of naturalness and dynamism of communities in a given ecosystem. On their basis it is possible to draw conclusions about changes taking place in entire ecosystems, to follow the pace and directions of changes in flora and vegetation, which makes it possible to identify potential threats to the ecosystem and take protective measures.

The aim of this study was to analyse the transformation of the vegetation in Rzeszów Reservoir during the last 22 years (1994–2016) in case of changes, to explain the possible drivers of change.

2. Materials and Methods

2.1. Study Area

Rzeszów Reservoir is located in south-eastern Poland (50°02′ N, 21°59′ E) at the boundary of two large geographical regions, the Carpathian Mountains and their foothills [36] with a temperate continental bioclimate [37]. In 1994 and 2016, the annual mean air temperature was 9.1/9.5 °C and precipitation reached 693/720 mm, respectively, the long-term mean annual air temperature in 1994–2016 was 8.8 °C (min. 6.9 °C, max. 10.2 °C). The observation of temperature changes over a more than 150-years period (1851–2010) indicates an increase in mean annual air temperature reaching 1.5 °C. Average annual precipitation is 680 mm (min. 471 mm–max. 981 mm) [36,38].

It is part of the protected Natura 2000 area with code PLH 180030 (Figure 1). The reservoir was established in 1973 by building a dam on the 64th km of the Wisłok River. It was set up to protect the functioning of industry and to serve as a municipal drinking water intake and a reservoir for recreation and sport purposes. Originally, it covered an area of 68 ha and had a volume of 1.8 mln m³. Over the last 20 years, however, the reservoir was greatly transformed. As a result of intensive sedimentation of the materials carried by the Wisłok River and its tributary, the Strug River, the surface area of the reservoir was reduced, its volume decreased to ca. 0.5 mln m³, and the average depth declined from 1.5 to 0.5 m, so that large parts of the water body are much shallower now [39].



Figure 1. Location of the study area (source: Google Earth 2018).

2.2. Data Collection

The phytosociological relevés used for the study come from two periods: (i) 1994—the first description of 91 relevés by Kwiatkowska [40]; and (ii) 2016-134 relevés collected by our research team. The geographic position of our relevés was recorded with a differential GPS. Historical and recent relevés were made in aquatic and bank vegetation as well as plant communities directly adjacent to the reservoir, using the standard Braun-Blanquet method [41], during the period of maximum vegetation development (June–August). The names of vascular species follow Mirek et al. [42], and the names of liverworts follow Szweykowski [43]. Taxa were classified into vegetation units according to Matuszkiewicz [44].

2.3. Data Analysis

To identify the general pattern of variation in species composition within the entire data set an indirect ordination method (detrended correspondence analysis, DCA) was used. The species data show a clear unimodal response (length gradient > 3), enabling us to use canonical correspondence analysis (CCA). The significance of the environmental variables was calculated using a Monte Carlo test (499 permutations) and only predictors with p < 0.05 were included in the CCA model. CANOCO for Windows 5.0 software was used for the ordination [45].

The ecological indicator values (EIVs) were calculated for all the species recognized in each relevés, using Ellenberg et al. system [46] adopted for Polish conditions by Zarzycki et al. [47]. We took into account 4 environmental variables related to ecological indicator values describing the most typical habitat conditions–light (L), moisture (F), reaction pH (R), and nitrogen (N). The share of species with a specific indicator value in each relevés was determined using a modified formula for the weighted average (1):

$$W_{A} = \frac{\sum_{i=1}^{n} (A_{i}^{2} \times I_{i})}{\sum_{i=1}^{n} A_{i}^{2}}$$
(1)

where: W_A —weighted average, A_i —abundance of cover of the *i*-th species in relevé, I_i —ecological indicator value for the *i*-th species, *n*—number of species in relevé.

The non-parametric Mann-Whitney test was applied to analyse the differences between the old and new relevés in EIV, the number of species, and the coverage of vegetation layers. The synoptic table was made for both periods, with the number of species and cover index, calculated as a total of the mean percentages of coverage of species in all relevés, divided by the total number of relevés and multiplied by 100. The value of the cover index gives a good estimation of the role of species in the communities.

The flora of the relevés was also compared based on a few other indices, focusing on (i) species richness (S = number of species); (ii) species diversity measured as the Shannon index (2):

$$\mathbf{H}' = -\Sigma p_i \log_n p_i,\tag{2}$$

where p_i = frequency of species *i*; (iii) species evenness measured as the Pielou index: $J' = H'/\ln S$, defined as a ratio of the observed diversity to the maximum diversity, where S = number of species and H_{max} = lnS [48,49]. The multivariate statistical package (MVSP 3.1) was used for these analyses [50]. The mean values of indices and SD (standard deviation) were computed, and the values obtained were compared. The original Braun-Blanquet [41] scale for species occurrence in phytosociological relevés was transformed as follows: r = 0.1%; + = 0.5%; 1 = 5%; 2 = 17.5%; 3 = 37.5%; 4 = 62.5%; and 5 = 87.5% [51]. The level of statistical significance of differences between the means for all the analyses was p = 0.05. Statistical tests were performed with STATISTICA 10.0 software [52].

In order to investigate the differences in macrophyte species composition, an Indicator Species Analysis (ISA) [53] was performed on the species per species matrix, after removing rare species, that is, low-frequency species that appeared in only one relevé. For each species *i* in each site group *j*, the relative abundance RA_{ij} and the relative frequency RF_{ij} , are computer as follows (3):

$$RA_{ij} = A_{ij} / A_i, \tag{3}$$

where A_{ij} = the mean abundance of species *i* across sites of the group *j*, A_i = the sum of the mean abundance of species *i* over all groups. $RF_{ij} = S_{ij}/S_j$, where S_{ij} = the number of sites in group *j* where species *i* is present, S_j = the total number of sites in that group. Then the Indicator Value (IV) of species *i* in the group *j* are: $IV_{ij} = RA_{ij} \times RF_{ij} \times 100$. Indicator Values range from 0 (no indication) to 100 (perfect indication). The ISA values were tested for significance using a Monte Carlo test (4999 permutations, $\alpha = 0.05$). The ISA was performed using the PC-ORD software [54].

3. Results

The vegetation units represented four major ecological groups: aquatic vegetation (*Lemnetea* and *Potametea* classes), marsh plants (*Phragmitetea* class), meadow plants (*Molinio-Arrhenatheretea* class), and shrubs (*Salicetea purpurea, Alnetea glutinosae* classes). Results of the vegetation composition analysis show that the studied communities have changed. The DCA diagram clearly distinguishes two major specifically concentrated sets of data (Figure 2).



Figure 2. Indirect ordination analyses (DCA) of all relevés. A—indicates relevés made in 1994, B—indicates relevés made in 2016.

In 1994, 23 types of plant communities comprising 125 species were distinguished [40], while now there are 21 phytocoenoses with 107 species. Overall, there were eight common plant communities in both study periods (Table 1). However, no differences in mean species diversity were noted (H' = 1.4–3.28, mean 2.01 in 1994, and H' = 0.68–2.21, mean 2.03 in 2016). Only the value of species evenness increased slightly, from 0.954 to 0.972 (Table 2).

Table 1. Syntaxonomic composition of communities in the Rzeszów Reservoir of each period studied.

Syntaxonomic Composition	1994 No. of Relevés	2016 No. of Relevés
Cl. Lemnetea minoris R.Tx. 1955		
O. Lemnetalia minoris R.Tx. 1955		
All. Lemnion gibbae R.Tx. et A. Schwabe 1974 in R.Tx. 1974		
Lemnetum gibbae Miy. et J. Tx. 1960	2	
community with Lemna gibba and Lemna minor	1	
community with Lemna minor and Spirodela polyrhiza	7	
Spirodeletum polyrhizae (Kelhofer 1915) W.Koch 1954 em.		r
R.Tx. et A.Schwabe 1974 in R.Tx. 1974		2
community with Lemna minor and Lemna trisulca		3
Cl. Potametea R.Tx. et Prsg		
O. Potametalia Koch 1926		
All. Potamion Koch 1926 em. Oberd. 1957		
community with Potamogeton crispus	1	
Potametum pectinati Carstensen 1955	5	
Ranunculetum circinati (Bennema et West. 1943) Segal 1965	2	
Elodeetum canadensis (Pign. 1953) Pass. 1964	3	
community with Elodea canadensis and Potamogeton natans	2	
community with Utricularia vulgaris		2
Ceratophylletum demersi Hild. 1956		6
All. Nymphaeion Oberd. 1953		
Hydrocharitetum morsus-ranae Langendonck 1935		3
Potametum natantis Soó 1923		3
community with Potamogeton natans and	1	
Myriophyllum verticillatum	1	
Myriophylletum verticillati Soó 1927	2	
Trapetum natantis Müll. et Görs 1969		8
Scirpetum lacustris (Allorge 1922) Chouard 1924		3

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Tabl	le	1.	Cont.

Syntaxonomic Composition	1994 No. of Relevés	2016 No. of Relevés
Cl. Phraomitetea R Tx. et Prsg 1942		
O. Phragmitetalia Koch 1926		
All Phragmition Koch 1926		
Tunhetum angustifoliae (Allorge 1922) Soó 1927	6	10
Sparsanietum erecti Roll 1938	3	8
Eleocharitetum nalustris Šennikov 1919	2	1
Eauisetetum fluviatilis Steffen 1931	-	7
Phraomitetum australis (Gams 1927) Schmale 1939	2	7
Tunhetum latifoliae Soó 1927	18	19
Oenantho-Rorinnetum Lohm, 1950	10	17
Glycerietum maximae Hueck 1931	5	8
Scirpetum maritimi (BrBl. 1931) R.Tx. 1937	2	Ũ
All. Magnocaricion Koch 1926		
Caricetum rinariae Soó 1928	1	4
Caricetum gracilis (Graebn, et Hueck 1931) R.Tx. 1937	-	2
Phalaridetum arundinaceae (Koch 1926 n.n.) Libb. 1931	11	7
All. Sparganio-Glycerion fluitantis BrBl. et Siss. in Boer 1942		
Leersietum oruzoidis (Krause in R.Tx. 1955) Pass. 1957		8
Cl. Scheuchzerio-Caricetea nigrae (Nordh. 1937) R.Tx. 1937		
O. Caricetalia nigrae Koch 1926 em. Nordh. 1937		
All. Caricion nigrae Koch 1926 em. Klika 1934		
community with <i>Juncus articulatus</i>	2	
Cl. Bidentetea tripartiti R.Tx., Lohm. et Prsg 1950		
O. Bidentetalia tripartiti BrBl. et R.Tx. 1943		
All. Bidention tripartiti Nordh. 1940		
community with Polygonum nodosum	1	
Cl. Molinio-Arrhenatheretea R.Tx. 1937		
O. Molinietalia careuleae W.Koch 1926		
All. Calthion palustris R.Tx. 1936 em. Oberd. 1957		
Scirpetum sylvatici Ralski 1931	2	5
Cl. Salicetea purpurea Moor 1958		
O. Salicetalia purpurea Moor 1958		
All. Salicion albae R.Tx. 1955		
Salicetum triandro-viminalis Lohm. 1952		18

Table 2. Mean values of particular indexes during period 1994–2016; ns—statistically not significant; U—statistic value, *p*—probability (Mann-Whitney test).

	Period					
-	1994		2016		U	р
-	Mean	$\pm SD$	Mean	$\pm SD$	-	
Species richness (S)	8.89	4.01	9.03	4.26	7111	ns
Diversity (H')	2.01	0.39	2.03	0.51	6606	ns
Evenness (J')	0.954	0.014	0.972	0.018	2440	< 0.05
Ellenberg indicator valu	les					
Light (L)	4.06	0.19	4.01	0.06	5342	< 0.05
Moisture (F)	5.33	0.57	5.29	0.51	7111	ns
Nitrogen (N)	3.82	0.25	3.74	0.21	5952	< 0.05
Reaction (R)	4.04	0.31	4.32	0.58	4578	< 0.05

High variability was noted in communities of the classes *Lemnetea* and *Potametea* and of the alliance *Salicion albae*. Among permanent components of vegetation, there was a growing tendency in the vegetation surface area in the class *Phragmitetea* (Figure 3). The observations demonstrated disappearance of 14 phytocoenoses, e.g., *Lemnetum gibbae*, community with *Potamogeton crispus*, *Potametum pectinati*, *Ranunculetum circinati*, *Elodeetum*

canadensis, Myriophylletum verticilati, and *Oenantho-Rorippetum,* and appearance of 12 new to this study area and yet undescribed communities, with special emphasis on the association *Trapetum natantis* (the largest local population of this species in south-eastern Poland), which occupies a significant area of the reservoir (Table 1).



Figure 3. Vegetation succession in the Rzeszów Reservoir ((a,b) A—1994, (c,d) B—2016).

In 1994, only 11 species exceeded 20% of frequency in the relevés. The most abundant were: *Phalaris arundinacea* L. (75 records), *Lemna minor* L. (73), *Rorippa amphibia* (L.) Besser (62), *Typha latifolia* L. (58), *Alisma plantago-aquatica* L. (51), *Bidens tripartita* L. (31), *Salix viminalis* L. (24), *S. purpurea* L. (24), *Lycopus europaeus* L. (24), *Spirodela polyrhiza* (L.) Schleid. (23), and *Lythrum salicaria* L. (23). After 22 years, 15 species reached a high frequency (>20%): *Typha latifolia* (77 records), *Glyceria maxima* (Hartm.) Holmb. (74), *Lemna minor* (61), *Berula erecta* (Huds.) Coville (55), *Spirodela polyrhiza* (54), *Phalaris arundinacea* (52), *Hydrocharis morsus-ranae* L. (47), *Mentha aquatica* L. (42), *Lycopus europaeus* (41), *Lythrum salicaria* (38), *Lemna trisulca* L. (38), *Trapa natans* L. s. 1. (37), *Rumex hydrolapathum* Huds. (35), *Ceratophyllum demersum* L. s. str. (34), and *Poa palustris* L. (32).

In spite of significant changes in the composition of aquatic communities (*Lemnetea* and *Potametea* classes), the number of species in plant communities remains similar, but the cover index decreased 74% and 68%, respectively. We observed an increase in the number of species from marsh communities (*Phragmitetea* class), and the cover index increased by 8%. In the *Molinio-Arrhenatheretea* class, the number of species and cover index decreased by 23%. Marsh communities in 2016 were the major components of vegetation in the study area, and the largest surfaces were covered by *Typhetum latifoliae*, *Typhetum angustifoliae*, *Glycerietum maximae*, and *Leersietum oryzoidis*. At the edges of the reservoir, contributions of species of the classes *Artemisietea*, *Salicetea purpurea*, and *Alnetea glutinosa* substantially increased, while the cover index of aquatic plants was lower than in 1994 (Table 3, Figure 4).

The CCA analysis, based on 225 relevés that were sampled in two periods (in the 1994s and 2016s), revealed two main axes (eigenvalues 0.643 and 0.333) with the first axis sharing a close positive correlation with EIVs for moisture (F) and second axis correlated positively with EIVs for reaction (pH) (Figure 5).



Figure 4. Number of species on different ecological groups in the Rzeszów Reservoir (A—1994, B— 2016). Explanation: aquatic vegetation (*Lemnetea* and *Potametea* classes), marsh plants (*Phragmitetea* class), meadow plants (*Molinio-Arrhenatheretea* class), and shrubs (*Salicetea purpurea* and *Alnetea glutinosae* classes).



Figure 5. Ordination biplot diagram of the canonical correspondence analysis (CCA) for the 1994 (black points) and 2016 (white points) years based on species matrix. The diagram explains 14.7% of total variance: EIV-F—5.8%, p = 0.002; EIV-N—3.7%, p = 0.002; EIV-R—3.1%, p = 0.032; EIV-L—2.1, p = 0.008. Abbreviation for vegetation ecological groups: circle—aquatic plants (*Lemnetea* and *Potametea* classes), triangle—marsh plants (*Phragmitetea* class), diamond—meadow plants (*Molinio-Arrhenatheretea* class), star—shrubs (*Salicetea purpurea* and *Alnetea glutinosae* classes); EIVs abbreviations: L—light, R—reaction pH, N—nitrogen, F—moisture.

Diagnostic Species Croups	199	4	2016	
Diagnostic Species Gloups	No. of Species	Cover Index	No. of Species	Cover Index
ChCl. Lemnetea minoris	5	2912.94	4	773.37
ChCl. Potametea	9	1772.57	10	579.19
ChCl. Phragmitetea	26	5022.60	32	5492.37
ChCl. Bidentetea tripartiti	5	5.49	4	26.71
ChCl. Molinio-Arrhenatheretea	33	291.17	16	222.75
ChCl. Artemisietea	12	35.70	15	205.89
ChCl. Salicetea purpurea	6	57.54	7	844.92
ChCl. Alnetea glutinosae	4	3.36	9	193.93
Others	25	6697.91	10	238.63

Table 3. Comparison of changes of diagnostics species and cover index from 1994 to 2016.

The ISA results (Table 4) showed that from the 45 macrophyte species in 1994, only four were found to be diagnostics (*Rorippa amphibia*, *Phalaris arundinaceae*, *Lemna minor*, *Alisma plantago-aquatica*). In 2016, they were represented by 13 species (28.8% of the macrophyte) (*Glyceria maxima*, *Berula erecta*, *Mentha aquatica*, *Typha latifolia*, *Rumex hydrolapathum*, *Galium palustre*, *Hydrocharis morsus-ranae*, *Leersia oryzoides*, *Carex pseudocyperus*, *Phragmites australis*, *Spirodela polyrhiza*, *Trapa natans*, *Sparganium erectum*).

Table 4. ISA results: show here are the indicator value and *p*-value for macrophyte species in both study periods (A—1994, B—2016).

Species	Period	IndVal	<i>p</i> -Value
Rorippa amphibia (L.) Besser	А	61.8	0.015
Phalaris arundinaceae L.	А	59.9	0.019
Lemna minor L.	А	55.6	0.017
Alisma plantago-aquatica L.	А	39.3	0.121
Glyceria maxima (Hartm.) Holmb.	В	58.6	0.009
Berula erecta (Huds.) Coville	В	53.2	0.006
<i>Mentha aquatica</i> L.	В	42.9	0.071
Typha latifoliae L.	В	40.7	0.006
Rumex hydrolapathum Huds.	В	32.5	0.053
Galium palustre L.	В	27.9	0.046
Hydrocharis morsus-ranae L.	В	26.4	0.043
Leersia oryzoides (L.) Sw.	В	25.3	0.042
Carex pseudocyperus L.	В	18.7	0.003
Phragmites australis (Cav.) Trin. ex Steud	В	18.6	0.025
Spirodela polyrhiza (L.) Shleid.	В	18.1	0.031
<i>Trapa natans</i> L. s. l.	В	15.4	0.025
Sparganium erectum L. Emden. Rchb. s. str.	В	15.3	0.025

The A period is represented by four indicator species, while the B period is related to 13 indicator species, belonging to macrophyte species. Only species with a significant *p*-value are shown.

4. Discussion

Freshwater resources, including reservoirs, provide a wide range of ecosystem services, such as flood control, climate change mitigation, river flow regulation, energy provision, as well as water storage. As, such they play crucial roles in human societies (drinking water provision, recreation), and economic development. Therefore all freshwater ecosystems exploited by human activities demand management. This may involve regular monitoring and include efforts to protect the system as well as restoration of damaged natural habitats. In the case of lakes and reservoirs, due to their economic benefits, there is an increasing requirement for policy for the sustainable exploitation of lakes and reservoirs, to sustain their beneficial uses over the long term [55,56].

A vast majority of European aquatic ecosystems are under the strong influence of long-term human activity. Reservoirs as artificial ecosystems are relatively less stable and exposed to the processes of more rapid ageing. Water bodies located within urban agglomeration undergo strong anthropogenic pressure, which influences the floristic and community structure of aquatic vegetation. The most important anthropogenic factors are the intensity of agriculture and wastewater discharges within the catchment that affect the eutrophication process [14,15,57,58].

Human activity has a significant impact on the species richness of aquatic ecosystems, directly and indirectly causing the loss of aquatic vegetation and/or limiting their diversity [59]. Reduction of heterogeneous habitats eliminates sensitive plant communities and species of the varied littoral zone, resulting in the appearance of anthropogenic communities with numerous synanthropic and invasive species [24,60,61]. On the other hand, reservoirs built on rivers may provide new artificial habitats for macrophytes [18]. A study by Hrivnác et al. [62] showed that species richness may be higher in artificial than natural aquatic habitats in different regions typical for the Central Europe landscape. Man-made habitats such as water reservoirs also provide suitable environmental conditions for the potential establishment and growth of macrophytes. Species richness did not change significantly in the studied area (H' = 2.01, H' = 2.03, respectively), and a similar indicator of diversity follow from the replacement of one phytocoenosis with another, visible within Lemnetea and Potametea classes. Similar results were observed by Sand-Jensen et al. [63] in the lakes of North-West Europe. The richness and species composition of aquatic plant communities are decisive by environmental variables, substrate, and chemical characteristics, nutrients availability and light conditions, etc. [25,26]. In our research, the depth of water determined the regression of submergent and floating-leaved macrophytes (Lemnetea, Potametea classes) and increase tall emergent macrophytes (Phragmitetea class) [64]. These results confirm the findings reported by Bakker et al. [65] and Lukács et al. [18], who indicated a relationship between species composition and various environmental variables, thus showing that depth and nutrient levels are the two most important factors. In addition, shallow water reservoirs are exposed to rapid heating and an increase in water temperature. As reported by Baláži et al. [24], the strongest factors influencing the composition of macrophyte communities are associated with water temperature.

The major factor modifying the aquatic and marsh vegetation of the study reservoir seems to be eutrophication. Increased discharge of domestic wastewaters and non-point pollution agricultural practices and urban development have recently led to excessive nutrient loading, which is considered to be one of the major causes of reservoir eutrophication. The reservoir characterised by stagnation of water has limited possibilities of neutralization of contaminants flowing from the catchment. This process leads to significant changes in species composition and cover of aquatic vegetation. Eutrophication enhances the density and height of tall emergent plants (Phragmitetea class) and floating-leaved species (e.g., Trapa natans), thereby increasing their ability to competitively exclude submerged communities (e.g., with Potamogeton crispus, Potametum pectinati, Myriophylletum verticillati). A similar trend in changes has been reported by many authors [10,15,66,67]. The inflow of nitrogen and phosphorus compounds from the catchment area was shown to result in the accelerated growth of algae and higher plants. This, in turn, leads to a disturbed balance of the rate of processes of production and decomposition of organic matter [68]. Eutrophication progress is linked with a decline of submerged vegetation, probably because increased water turbidity (low transparency) leads to light limitation in turn, and these features enable emerged vegetation to be dominant [18,69]. As argued by Sand-Jensen et al. [63], the development of aquatic vegetation depends on the extent of nutrient enrichment. The relationship is explained by increased competition at higher nitrate availability resulting in a shift towards floating-leaved macrophytes and thus light limitation [65]. The field observation in European lakes has confirmed that submerged aquatic macrophytes recover and increase in abundance in response to nutrient loading reduction, especially in small and shallow lakes [65,70].

Many studies confirm that the occurrence of some macrophytes is an indicator of eutrophication [33,71]. Significant quantitative bioindicators, suggesting that Rzeszów Reservoir is eutrophic, are the presence of *Ceratophyllum demersum* and the high frequency and abundance of *Trapa natans*, which are fast-growing, nutrient demanding species capable

of forming a dense canopy on the water surface. Similarly, the development of hydrophilic vegetation (e.g., *Ceratophyllum demersum* L. s. str., *Polygonum amphibium* L., *Mentha longifolia* (L.) L., *Bidens cernua* L., *Phragmites australis* (Cav.) Trin. ex Steud.) indicates that the water is rich in nutrients and the reservoir is, to a certain extent, eutrophic [72].

Particularly noteworthy in recent years is the appearance of water chestnut *Trapa natans* (threat status VU in Poland) [61,62,73,74]. The community *Trapetum natantis* covers a large area and spreads to new areas, mostly colonising the places where a lot of muddy sediments have accumulated. Its occurrence is probably related to human activity (transfer of seeds), as its presence is not mentioned in earlier reports [75].

The depth of reservoirs and the intensifying eutrophication process increase the sedimentation rate, thereby causing overgrowth [22,29,58]. Excessive eutrophication for many years has contributed to ecological succession and overgrowing of Rzeszów Reservoir. Currently, in terms of space, the dominant role is played by species from the *Phragmitetea* class (e.g., Glyceria maxima, Berula erecta, Typha latifoliae, Leersia oryzoides, Phragmites australis) characterised by high viability and resistance, which is confirmed by the ISA results of macrophytes. The accumulation of biomass for 22 years and eutrophic sediments of Wisłok River support stands of Typha spp. and P. australis, which clearly benefit from these processes. Their density and widespread nature could cause the loss of rare species, which show a significant decrease in abundance and species richness after 22 years [61]. As with the present results, the research observed by Svitok et al. [32] show to dominant Typha latifolia, i.e., the most widespread species that appear soon after disturbance in wet habitats and occurs early in the succession of open water. The abundance of Typha spp. and *P. australis* is probably related to the increased availability of nitrogen and phosphates in the substrate [22,76]. Our research confirms the relationship between the decreasing water depth and progressing ecological succession, and the decrease in water level has uncovered a part of the littoral zone. Similar directions of changes were observed in another reservoir [77]. All authors emphasize the importance of decomposition of submerged vegetation, as it contributes to shallowing, which can stimulate succession. Arthaud et al. [78] explain the consecutive stages of succession with progressive enrichment of ruderal phytocenosis that generally have high fecundity and good dispersal ability. In eutrophic lakes, the competitive exclusion of aquatic plants is particularly rapid. A further succession process facilitates the colonisation of woody vegetation on the edges (Salicetea and Alnetea classes).

5. Conclusions

The artificial water bodies are sensitive and unstable ecosystems with constantly changing abiotic conditions. They play an important role in maintaining biodiversity, especially in areas affected by strong anthropopressure in urban areas (land-use changes, pollution, landscape fragmentation). The ongoing changes are reflected in the vegetation of the reservoir. Within two decades, intensive development of marsh communities (class *Phragmitetea*) took place, with the simultaneous disappearance of submerged and floating communities (classes *Lemnetea* and *Potametea*). The intensive development of rushes (*Phragmition*) indicates progressive eutrophication of the reservoir and leads to further ecological succession towards shrub communities. The study made it possible to determine the directions of changes and the degree of plant cover degradation. Knowledge of processes and factors affecting species diversity in such water reservoirs may prevent their further depletion and contribute to the effective protection of aquatic ecosystems.

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