

Wetland Vegetation of Novel Ecosystems as the Biodiversity Hotspots of the Urban-Industrial Landscape

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ABSTRACT

Wetlands represent a small proportion of all habitats. Still, they are very important features within the landscape, particularly in the ecosystem mosaic. They are composed of many specifically adapted organisms. Wetlands spontaneously establish and provide a significant source of heterogeneity and diversity in an urban-industrial landscape. Most of Earth's wetlands are at risk or have disappeared due to human activity. Apart from natural wetlands, unique anthropogenic wetlands are observed in southern Poland. The aim of study was to assess and analyze the water quality and the spontaneous wetland vegetation which has developed on anthropogenic wetland habitats. The study was conducted on the spontaneous wetland vegetation developed in habitats that emerged due to mineral excavation activities of quarries in the Silesia Upland and Krakow-Częstochowa Upland. The research subjects were wetlands that provide special water chemistry conditions for developing the peat bog vegetation. Water sampling and analyses, vegetation recording, and vegetation numerical analyses were conducted on studied wetlands. The results of a study conducted on flooded post-excitation sites revealed that diverse wetland spontaneous vegetation colonized such habitats. This research showed that anthropogenic wetlands can provide habitats for the development of outstanding biodiversity and form a refuge for calcareous plant species and the subsequently assembled rare peat bog vegetation. The high moisture and the increased presence of magnesium and calcium ions are developing in some sites of the post-mineral excavations. Such habitat conditions in anthropogenic wetlands enhance the occurrence of rare calciphilous species. Maintaining the relevant water conditions is crucial for the protection of these sites. The study presented that, quite frequently, the human-induced transformation results in establishing habitats that provide conditions for refuge organisms, mostly plants crucial for conservation perspective, particularly in the urban-industrial landscape. The additional importance of this study is related to the fact that the area of wetlands decreased. Therefore such anthropogenic wetlands should be integrated into urban planning and industrial site management to enhance biodiversity conservation.

Keywords: wetlands; anthropogenic habitat; rare plant species; hydrology.

INTRODUCTION

Wetland ecosystems are dependent on flooded water conditions or being saturated by water. The flooding conditions can be seasonal (weeks, months). Sometimes the conditions are permanent (years or decades). These conditions can be changeable in time and space, caused by natural or anthropogenic factors [Keddy, 2010]. The main characteristics that distinguish wetlands from terrestrial ecosystems are the different types of aquatic and wetland vegetation which are composed of plants adapted to the specific anoxic conditions in hydric wetlands soils (Fraser and Keddy, 2005). Wetlands ecosystems are amongst those of the highest biologically diverse and provide conditions for many plant and animal species. The average regular flooding results in the prevailing of soils' oxygen-free (anoxic) processes [Keddy, 2010]. Wetlands are mainly classified based on the sources of water including tidal wetlands and floodplains with excess water from overflowed rivers or lakes [Fraser and Keddy, 2005; Keddy, 2010] and depending on their dominant vegetation type, marshes dominated by reeds, and sedges and swamps dominated by trees and shrubs. Some wetlands have various vegetation types supplied by different water sources, making them difficult to classify.

Urban wetlands are considered important “green-blue” bodies offering a wide range of ecosystem services which enhance the social life of local population and environmental sustainability of the region. They can be either natural, or artificial, and have no more than 6 m water depth located within the urban area and its suburbs [<https://aquadocs.org/handle/1834/330>]. The development of methods for assessing wetland functions, and ecological health [Davidson, 2014; Dorney et al., 2018] is vitally important, and these can be used for research purposes and to contribute to the conservation of wetland diversity by increasing the general cognition of functions of wetlands within the ecosystem [Dorney et al., 2018].

In the Silesian Upland, the occurrence of wetland vegetation, together with the species assembled in vegetation patches, represents the *Scheuchzerio-Caricetea nigrae* phytosociological class. The assembled plant species combinations in the flooded post-mineral excavation areas studied are similar to bog and wetland vegetation types. Most studied sites were gravel pits, sandpits, railway areas, and the transition zones of anthropogenic post-excavation water bodies [Stebel and Błońska, 2010; Stebel

and Błońska, 2016]. Anthropogenic wetlands fulfill the requirements of novel ecosystems. Such man made habitats differ from natural and semi natural ecosystems, and the newly established ecosystem develops after the human agent is no longer active [Hobbs, Higgs and Hall, 2013].

Plants spontaneously colonize the mineral material habitats of sandpits [Rahmonov and Szymczyk, 2010; Prach et al., 2013; Prach et al., 2014; Prach et al., 2015; Prach et al., 2017]. Moisture, light, granulometric composition (texture) of the soil, pH, and soil fertility are the most important driving factors regulating the composition and abundance of plants [Rzętała and Jaguś, 2012; Horáčková et al., 2016]. Abandoned open-cast sandpit sites are spontaneously colonized by xerophytic and oligotrophic species, mainly from ruderal and psammophilous grasslands habitats [Prach et al., 2013; Prach et al., 2014; Prach et al., 2017]. The plant species assemble from pioneer species-poor phytocoenoses.

The establishment of different wetland vegetation on the mineral habitats, occurs mainly at the lowest levels of the excavation areas in places where the groundwater outflow occurs, is less frequent [Rahmonov and Szymczyk, 2010; Prach et al., 2014; Prach et al., 2015]. Such habitat types occur within a few non-managed sand or gravel pit sites. These water-rich sites at the proper hydrogeological conditions of the post-mineral excavation of sand or gravel pits are flooded with groundwater. These oligotrophic habitat conditions are appropriate for the occurrence of rare plant species, especially those species frequently present in low-carbonate bogs. In environmental studies and published reports, specialists emphasize the importance of such wetlands for conserving biological diversity, thus indicating the habitat conditions for rare oligotrophic plant species. Particular attention is drawn to plant species typical of low carbonate bogs in relation to the phytosociological syntaxa of the *Caricetalia davallianae* order [Czyłok, Rahmonov and Szymczyk, 2008; Bzdon, 2009; Czyłok and Szymczyk, 2009; Rahmonov and Szymczyk, 2010; Stebel and Błońska, 2010; Wiland-Szymańska et al., 2016; König, 2017]. However, the specifics of the hydrogeochemical parameters of this type of man-made wetlands with wetland and bog vegetation are crucial for nature protection and conservation management. The *Caricetalia davallianae* order of neutro-base and nutrient-poor fens is characterized by *Carex davalliana*, *Primula farinosa*, and *Tofieldia calyculata*,

often together with species of fresh, calcareous primaeval meadows. Patches of this vegetation type occur in flat and transitional bogs, wet meadows, and disturbed areas of high altitudes such as torrent floodplains, their terraces, and hillside swamps. The vegetation patches representing the *Caricetalia davallianae* order appear on peat soil (histosol), and mineral soil (redoxisol, reductosol, fluvisol) with a constantly high or slightly fluctuating water level [Matuszkiewicz, 2018]. However, anthropogenic wetlands are unique to southern Poland, which is related to the specific geological conditions and disturbance of water relations due to surface exploitation of sands.

This study aimed to assess and analyze the water quality and spontaneous wetland vegetation which has developed on anthropogenic wetland habitats. The geo-hydrological conditions are the basis of wetland habitats, arising mainly in old, unexploited open-cast sand pits and the surrounding sandstones or sandstone quarries. The hydrochemical quality of such habitats determines the floristic species composition and vegetation diversity. It is also essential to emphasize the role of anthropogenic wetlands as a refuge for rare and protected plant species.

MATERIALS AND METHODS

Study area

The study was conducted in wetland habitats that have emerged due to mineral excavation

activities located in the Silesia Upland and Kraków-Częstochowa Upland [Kondracki, 2011; Solon et al., 2018], (Figure 1). The research was conducted on nine wetlands of anthropogenic origin. The surveyed vegetation patches had mostly developed at the bottom of old sand pits, and well-developed vegetation were of different ages. The mineral material excavation activity caused the destruction of the original plant cover, which had mostly been coniferous pine forests. Open-cast pit exploitation changed the water quality. The changes are manifested, among others, by the transformation of the surface hydrographic network. In the initial period of exploitation, the post-excavation mineral materials are supported only by rainwater and surface runoff flowed into the excavation area. As soon as the bottom of the excavation lowered below the groundwater table, outflow of water took place and saturated the sands lying in the bottom of the excavation area [Dulias, 2013]. The dewatering of the mineral, e.g., sand excavation pit, takes place mostly by gravity and in some sites by a network of ditches or by the application of a series of pumps.

Temporal submerging or drying of such post-excavation ponds depends on the dewatering process. There are many open-cast excavation sites where cavities within the large pit are challenging to dewater through gravity. Such parts of the pits, which are the bottom of hollows, are continually flooded [Błońska et al., 2020]. The feedwater initially has a composition similar to that of

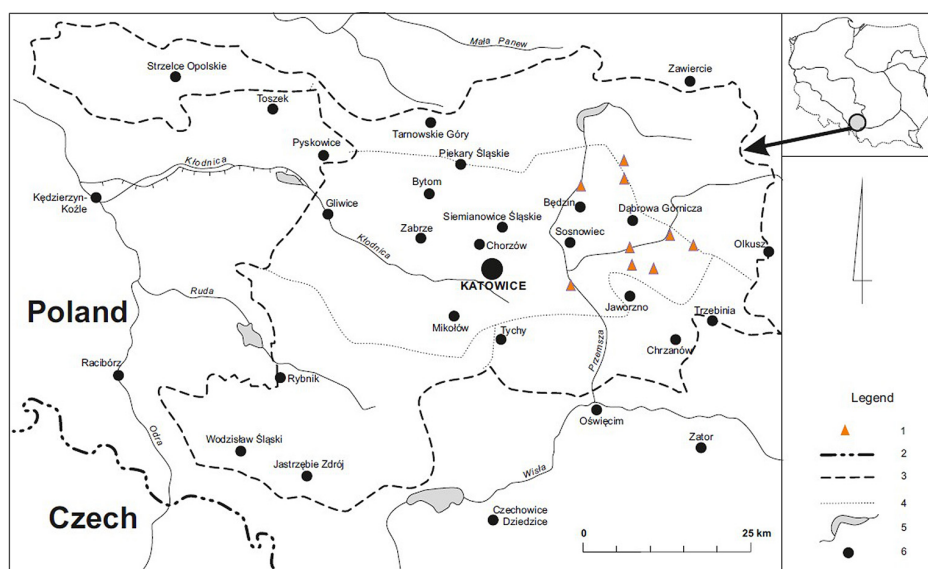


Figure 1. The distribution of the studied anthropogenic wetlands, (1) studied wetlands, (2) border of the country, (3) border of voivodship, (4) rivers, (5) water reservoir, (6) towns [Woźniak, 2010 – changed]

groundwater, but with time, the ombrogenous supply also gains importance. Apart from the mineral excavation sites, a few cases of small-scale anthropogenic wetlands were also recorded on railway sites, where construction of the infrastructure in specific orographic and hydrological conditions caused exudation and hindered water outflow, which created favorable conditions for the development of hygrophilous vegetation similar to low peat bogs. All the analyzed wetlands are located in Upper Silesia, Silesian Upland (southern Poland) on the outskirts of the cities of Sławków, Dąbrowa Górnicza, Jaworzno. The Upper Silesia region is an area of intense industrial development. Apart from the industry, there are also a few established open sandpits. The time of their establishment and excavation activity is estimated at between 20–70 years (sometimes different areas within one excavation were out of operation at different periods). The anthropogenic wetlands covered the site, from a dozen to several hundred m² while the excavations themselves often occupied several hundred hectares. Most often in excavation areas in the vicinity of wetlands, there was also the reed-dominated vegetation, along with contrasting psammophilous grasslands, ruderal habitats, and forests and thickets. However, the subject of this research has only been wetland vegetation. The excavations were adjacent to agricultural areas (arable fields, meadows), ruderal areas, and forests. In the Silesian Upland, the mean annual temperature is about 7–8°C with 700–800 mm annual precipitation in the studied region and 50–70 days of snow cover in a year.

Vegetation field research methods

Depending on the area of the wetland and the degree of development of the vegetation, 2–20 plots were marked considering their even distribution on the wetland surface, uniformity, physiognomically distinct plant cover, and size (usually 16 m²) to be in line with the methodology proposed by Hájek, Hekera and Hájková [2002] for natural peatlands. The locations of the studied plots were determined using a GPS device. Altogether 64 research plots were established on nine wetlands of anthropogenic origin. In each designated plot, a floristic inventory was made along with the percentage valuation of cover abundance of vascular plant species and bryophytes. The modified Braun-Blanquet scale (1%, 2%, 5%, 10%, 20%... 100%) was used to estimate the abundance.

Water sampling and analyses

The degree of habitat hydration on a 5-point scale was determined (1 – dry habitats – water did not flow to the surface under the pressure of the foot; 2 – slightly moist – under the pressure of the foot, the water flowed 1 cm above the surface; 3 – moist – under the pressure of the foot, the water flowed 2 cm above the surface; 4 – very moist – under the pressure of the foot, the water flowed 5 cm above the surface; 5 – stagnant water – water on the surface of the vegetation patch). Water was also collected from each research plot and selected physical (water level) and chemical parameters were determined. The oxygen content (O₂), pH, electrical conductivity (EC), redox potential (ORP), nitrate nitrogen (NO₃⁻), and chloride content (Cl⁻) were analysed directly in the field using the Professional Plus multi-parameter metre by YSI. Water samples were collected in 0.5 l polyethylene bottles from each vegetation patch and saved at +4°C with immediate transport to the laboratory. Filtering through a 0.45 µm filter (Millipore) of samples was performed before the analysis to determine the most significant cations and anions (Ca²⁺, Mg²⁺ and SO₄²⁻, PO₄³⁻), [Molenda, 2014].

Vegetation analyses

Floristic lists, together with the characteristics of environmental variables for each plot, were collected in the database of the TURBOVEG 2.0 computer program [Hennekens and Schaminée, 2001]. Habitat requirements concerning light, humidity, substrate pH, and fertility of the habitat were characterised by Ellenberg numbers (ecological indicator values) [Ellenberg and Leuschner, 2010]. For plots the means were calculated in accordance with the absence or presence of the ecological indicator values while for floristic list the plant species number distribution that represents the particular ecological indicator values were shown. The species that were assigned an “X,” i.e., no diagnostic value is available, were not included in the calculations.

The syntaxonomic classification of the plant species followed the Polish guide for vegetation type discrimination [Matuszkiewicz, 2018]. In order to analyse the role of the wetland vegetation types as potential biodiversity refuges, Poland’s protected plant species were assessed [Regulation of the Minister of the Environment

of 9 October 2014 on the protection of plant species]. Moreover, the records of endangered species in the studied vegetation in relation to the country, and European scale were also considered [Każmierczakowa et al., 2016]. Additionally, species rare and endangered on a national scale [Żarnowiec et al., 2004; Zarzycki and Szelaĝ, 2006] and found on the local “red lists” [Parusel and Urbisz, 2012; Stebel et al., 2012] were distinguished during this research. The nomenclature of the vascular plants was adopted after the Euro+Med PlantBase [https://ww2.bgbm.org/EuroPlusMed/query.asp].

Numerical analyses

In order to examine the impact of environmental variables, canonical correspondence analysis CCA was run using the function `cca()` and `ordisep()` for automatic stepwise model building in `vegan` package in R language and environment [https://www.R-project.org/]. Monte Carlo test was done with 999 iterations to calculate pseudo-F i.e. equivalent of F statistics in ANOVA and p-value of the entire model and significance of particular variables. The variance inflation factor (VIF) was checked by means of `vif.cca()` function. The biodiversity indices: species richness (S), Shannon-Wiener (H), Evenness (E) and Simpson index were computed (packages: `vegan` and `abdiv`). To assess whether biodiversity indices and EIV explain variation in species data, detrended correspondence analysis (DCA) was performed. The vector fitting onto ordination i.e. passive fitting of explanatory variables onto DCA space was run using 999 iterations of the permutation test.

RESULTS

Diversity of the wetland vegetation on anthropogenic post-mineral material excavation habitats

We recorded 205 plant species in the wetland habitats. The spectrum of species present in the studied wetland vegetation patches in terms of their syntaxonomic affiliation was analysed (Figure 2). *Scheuchzerio-Caricetea nigrae* class was the most phytosociologically diverse class (Figure 3). Anthropogenic wetlands are strongly distinguished by the presence of *Equisetum variegatum*,

which occurs in some patches of the vegetation. The share of calciphilous species representing the order *Caricetalia davallianae* is also significant: *Epipactis palustris*, *Campylium stellatum*, *Liparis loeselii*, *Tofieldia calyculata*. Among the species present in the anthropogenic wetlands, there were also species not directly related to fens, e.g. *Linum catharticum*, *Carex flacca*, *C. viridula*, but indicating habitats with high carbonate content. Other species, e.g. *Poa compressa*, *Tussilago farfara*, *Leontodon hispidus*, *Equisetum arvense*, *Calamagrostis epigejos*, *Prunella vulgaris*, colonise settle the habitats adjacent to the study patches, which sometimes had very different conditions to those naturally occurring.

A crucial role in the species composition of the recorded vegetation patches was performed by plant species representing meadow vegetation and particularly the plant species representing the *Molinietalia* order of wet meadows. The species of the *Scheuchzerio-Caricetea nigrae* are also frequent. Frequently recorded in the vegetation patches have been also the species characteristic of the calcium-rich fens of the *Caricetalia davallianae* order, such as sedges including *Carex davalliana*, *C. dioica*, and *C. flava*. Other species recorded were the following: *Eleocharis quinqueflora*, *Epipactis palustris*, *Eriophorum latifolium*, *Liparis loeselii*, *Parnassia palustris* and *Tofieldia calyculata* (Table 1).

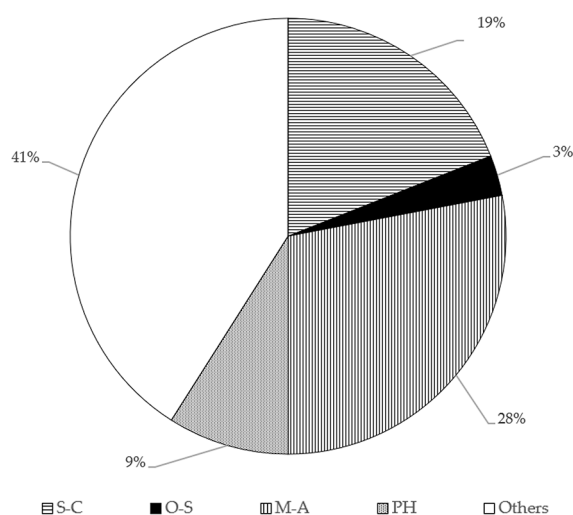


Figure 2. Percentage participation of recorded plant species in relation to phytosociological classes in the examined patches of anthropogenic wetland vegetation. (S-C) *Scheuchzerio-Caricetea nigrae*, (O-S) *Oxycocco-Sphagnetetea*, (M-A) *Molinio-Arrhenatheretea*, (PH) *Phragmitetea*

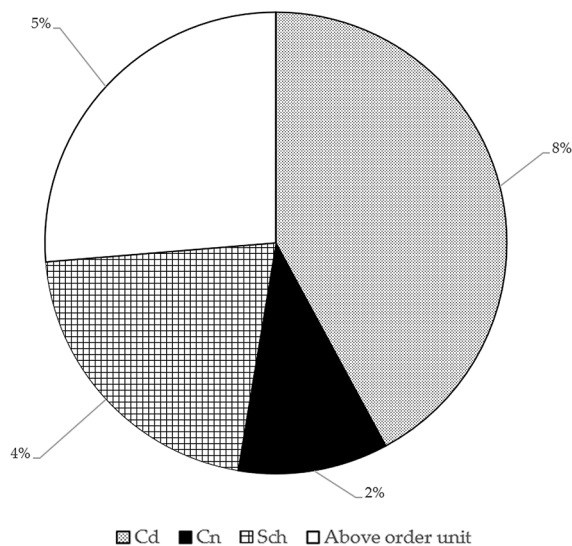


Figure 3. Phytosociological diversity of *Scheuchzerio-Caricetea nigrae* class; (Cd) *Caricetalia davallianae*, (Cn) *Caricetalia nigrae*, (Sch) *Scheuchzerietalia palustris*

Apart from the number and list of recorded plant species, the diversity of the Ellenberg indicator values was analysed. The analysed wetland vegetation was characterised mainly by non-woody vegetation. A few young shrubs and trees were also recorded (the light-seed species including *Alnus glutinosa*, *A. incana*, *Betula pubescens*, and *Pinus sylvestris*). There was some shading in a few of the studied vegetation patches. Most of the recorded plants representing open habitats species were frequent (the calculated light coefficient according to the Ellenberg indicator value was 7.01). The studied vegetation patches developed in habitats characterized by high water content. The analysis revealed that the dominant species represent

damp habitats. The average moisture ratio (F) was 6.8. Analysis of the chemical parameters showed high magnesium and calcium ions contained in the water from the studied sites which influenced the pH value. It has resulted in the occurrence of alkali-philic plant species. The mean R indicator reached a value of 5.9 in the studied sites. The presence of calciphilous species was recorded due to the occurrence of species characteristic of the *Caricion davallianae* order. However, the top 0-10 cm of the soil was the most acidic layer (pH 4.27); whilst in the rhizosphere layer this was slightly alkaline (pH 7.21). The species spectrum concerning trophy has been analyzed. Some species that have been recorded in the studied vegetation patches have indicated low values for soil trophy (N) is 3.1, (Figure 4).

There are following explanations of ecological indicators concluded in Figure 4:

- (L) light indicator: 1 – deep shade plant species, 2 – plant species between 1 and 3, 3 – shade plant species, 4 – plant species between 3 and 5, 5 – moderate shade plant species, 6 – plant species between 5 and 7, 7 – moderate light plant species, 8 – light plant species, 9 – full light plant species, x – no specified value;
- (R) acidity indicator: 1 – very acidic habitats, 2 – habitats between 1 and 3, 3 – quite acidic habitats, 4 – habitats between 3 and 5, 5 – medium acidic habitats, 6 – habitats between 5 and 7, 7 – subneutral habitats, 8 – habitats between 7 and 9, 9 – alkaline habitats, x – no specified value;
- (F) humidity indicator: plants connected with habitats: 1 – the driest areas, 2 – habitats between 1 and 3, 3 – dry habitats, 4 – habitats between 3 and 5, 5 – fresh habitats, 6 – habitats between 5 and 7, 7 – wet habitats, but not

Table 1. The most common species of plants recorded in examined wetlands (the table showing only the most significant phytosociological classes)

Phytosociological class	Order	The Latin name of plant species
<i>Scheuchzerio-caricetea nigrae</i>	<i>Caricetalia davallianae</i>	<i>Epipactis palustris</i>
	<i>Caricetalia nigrae</i>	<i>Carex nigra</i>
	<i>Scheuchzerietalia palustris</i>	<i>Sphagnum contortum</i> <i>Rhynchospora alba</i>
	above order unit	<i>Eriophorum angustifolium</i> <i>Menyanthes trifoliata</i>
<i>Oxycocco-Sphagnetea</i>		<i>Sphagnum fallax</i> <i>Oxycoccus palustris</i> <i>Comarum palustre</i>
<i>Molinio-Arrhenatheretea</i>	Including <i>Molinietalia</i>	<i>Equisetum palustre</i> <i>Leontodon hispidus</i>
<i>Phragmitetea</i>		<i>Carex rostrata</i> <i>Phragmites australis</i>

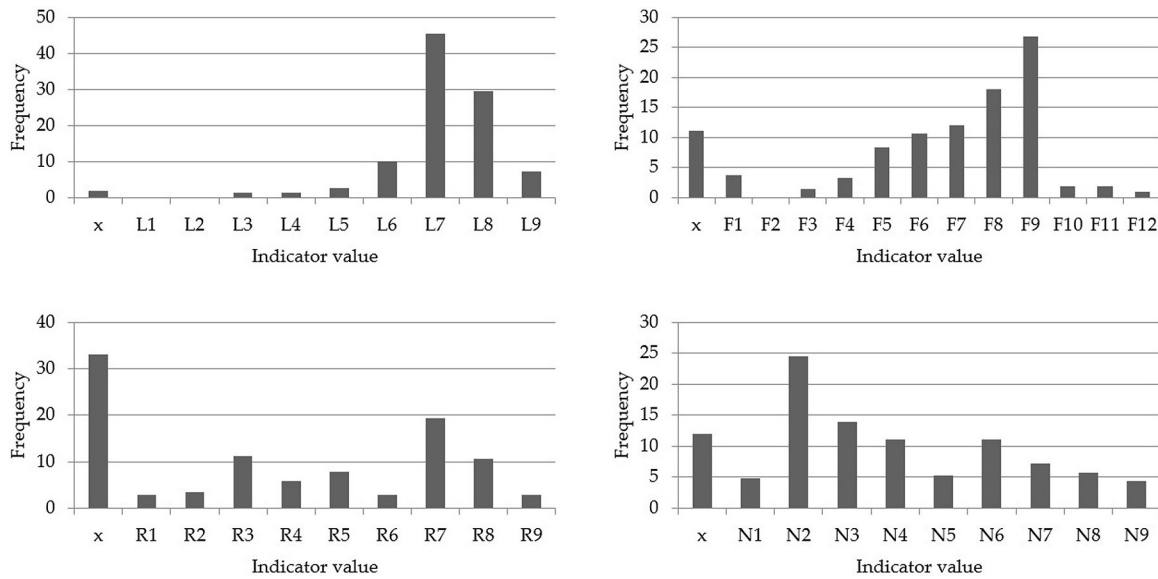


Figure 4. The distribution of the species that reflect Ellenberg indicator values: L – light, R – soil reaction, F – moisture, N – nitrogen

flooded by water, 8 – habitats between 7 and 9, 9 – soaked habitats, 10 – aquatic plant species that survive without water, 11 – an aquatic plant that is rooted under water, but at least temporarily with leaves above it, 12 – water, x – no specified value;

- (N) eutrophication indicator: 1 – extremely infertile sites, 2 – habitats between 1 and 3, 3 – more or less infertile sites, 4 – habitats between 3 and 5, 5 – sites of intermediate fertility, 6 – habitats between 5 and 7, 7 – plant often found in richly fertile places, 8 – habitats between 7 and 9, 9 – extremely rich sites, x – no specified value.

Plants associated with hydrogenic (with constant high water level) habitats, mainly wet meadows and peat bogs, are among the most endangered types of flora, constituting a high percentage of plants on the “red lists” both at the country [Żarnowiec et al., 2004; Zarzycki and Szeląg, 2006] and at the regional levels [Parusel and Urbisz, 2012; Stebel et al., 2012], (Table 2).

This is related to the threat to their habitats and confirms the key role of wetland protection in preserving biodiversity. This research shows that in the Silesia Upland and Krakow-Częstochowa Upland anthropogenic wetlands play an important role as refuges for species usually found in peat bogs. Their role is crucial, considering the fact that natural transitional bogs and fens in the study area have declined, and are about to disappear due to the human impact associated with changes in water quality. In anthropogenic wetlands, peatland species account for about 18% of all species. There are often species of fens representing the order *Caricetalia davallianae*. This is especially true for plants such as: *Pinguicula vulgaris* ssp. *bicolor*, *Tofieldia calyculata*, *Carex dioica*, which occur almost exclusively in anthropogenic wetlands. Often in anthropogenic wetlands there are also: *Epipactis palustris*, *Eriophorum latifolium*, *Pedicularis palustris* and *Parnassia palustris*. Particular emphasis should be placed on the importance of anthropogenic wetlands for the preservation and protection of

Table 2. Share (number and percentage) of peat bog species, which are protected and endangered in anthropogenic wetlands

Species of peat bogs (<i>Scheuchzerio-Caricetea nigrae</i> and <i>Oxycocco-Sphagnetea</i>)	37 (18%)
Protected species	31 (15%)
Endangered species in Poland	14 (7%)
Endangered species in the Silesian Province	65 (32%), including 23 (11%) with VU, EN, CR category

resources of *Liparis loeselii*, a species of European importance [Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora]. This species has the status of E – an extinct species on the “red list” of vascular plant species in Poland [Zarzycki and Szela, 2006] and VU in the “red book” of plant species [Kaźmierczakowa et al., 2014], and in the Silesian Voivodeship it is considered an endangered species and is in the EN category [Parusel and Urbisz, 2012]. In the Silesian Upland, *Liparis loeselii* has so far been known from eight localities in natural habitats, mainly peat bogs and wet meadows, but its populations are not very numerous here. It is equally common in secondary habitats (sandpits, quarries, railway areas), and its largest populations (from several dozen to several thousand individuals) occur mainly in unexploited sand pits in Dąbrowa Górnicza (Pogoria, Kuźnica Warężyńska) and Jaworzno Szczakowa. In addition to typical peat bog species, anthropogenic wetlands have become safe havens for other valuable species subject to legal protection. It was found here, among several others representatives of orchids. In addition to the already mentioned lime and marsh helleborine, the following were also recorded: *Dactylorhiza incarnata*, *D. majalis*, *Malaxis monophyllos*, and *Gymnadenia conopsea*.

Among the analysed wetland vegetation types, two represent the Natura 2000 areas. This is the area “Lipienniki in Dąbrowa Górnicza”, comprising two isolated areas PLH240037, and “Torfowisko Sosnowiec-Bory” PLH240038 [natura2000.gdos.gov.pl]. They were designated mainly due to the occurrence of *Liparis loeselii* individuals, a rare orchid species in Poland. In addition, wetland habitats with interesting vegetation community types have been identified in the studied area. The most frequent habitat type 7230 is composed of species known from mountain and lowland alkaline fens of the natural flush fens, sedges, and moss fens sites. In such vegetation patches, the succession is usually initiated by *Equisetum variegatum*, that occurring massively, and it creates its community with abundant presence of *Liparis loeselii* orchid individuals, as well as another species typical of the habitat 7230 type including numerous *Epipactis helleborine*, *Parnassia palustris*, *Eleocharis pinquiflora* and *Carex lepidocarpa*. Locally, there are also particularly valuable species, such as the two-leaved buttercup and the single-leaved icegrass *Pinguicula bicolor* and *Malaxis monophyllos*, both of which are included in the Polish Red

Book of Plants, or the mountain *Tofieldia calyculata*, all typical of the country for the best developed and preserved patches of habitat 7230 vegetation communities [natura2000.gdos.gov.pl, A. Błońska, 2015, pers. comm.]. The Sosnowiec-Bory mire (PLH240038) covers a small (0.25 ha) site of natural habitat 7140 – Transition bogs and quagmires (mainly with vegetation from the *Scheuchzeria-Caricetea fuscae* class) and is preserved in the area only in the form of a few clearings, located in the central-eastern parts of the enclave forming a mosaic with *Alnus glutinosa*, *Betula* spp., *Frangula alnus*, and *Salix* spp. The species individuals formed a population of a maximum of several dozen individuals, which then decreased to a few shoots observed only in one locality. This species has not been observed for over 5 years [natura2000.gdos.gov.pl, A. Błońska, 2015, pers. comm.]. Since peat bogs in southern Poland are rare and occupy small areas, anthropogenic wetlands are very important for maintaining these disappearing habitats and the species associated with them.

Water quality and development of the anthropogenic wetlands

The anthropogenic wetlands are characterised by their specific electrolytic conductivity and high concentration of calcium, magnesium, and sulphate ions. In this case, when the waters supplying the wetland area of the calcium bicarbonate type (HCO_3Ca) or (SO_4Ca), then a unique carbonate wetland will develop (Table 3).

The waters of the initial wetlands are similar in characteristics to the groundwater. With time, as the *Sphagnum* “pillows” grow, the waters become acidic, and the concentration of bicarbonate ions decreases. Then, sulphates remain the dominant anion, and the waters represent the sulphate-calcium type (SO_4Ca). The processes in anthropogenic wetlands are identical to those in natural ones. From the abandonment of economic activity, sand pits are subject to the universal laws of nature. Thus, the ongoing biological, geo-morphological, and hydrological processes are untouched. However, they may be disturbed by secondary anthropogenic influences. An example of such a site is the “Jaworzno Szczakowa” wetland. This wetland is fed with infiltration water from rivers polluted with mine water. As a consequence, the hydrochemical type of the wetland waters is different from that which would result from the natural geochemical features of the catchment area. In

Table 3. The mean values of the variables measured in the anthropogenic wetland habitats. The table shows the means \pm SD; except where the median and the interquartile range are given

The chemical parameters	The means \pm SD
Ca ⁺² [mg/dm ³]	51.2 \pm 56,4
Cl ⁻ [mg/dm ³]	59.5 \pm 30,3
Mg ⁺² [mg/dm ³]	22.6 \pm 19,1
NO ₃ [mg/dm ³]	23.4 \pm 20,2
O ₂ [mg/dm ³]	54.2 \pm 22,8
ORP [mV]	60.2 \pm 80,5
EC [mS/cm]	0.53 \pm 0.54
pH	6.74 \pm 1,04
PO ₄ ⁻³ [mg/dm ³]	0.21 \pm 0,4
SO ₄ ⁻² [mg/dm ³]	46.7 \pm 34,6
Hydration	2.0 \pm 0,9

wetlands with no secondary anthropogenic impacts, the seasonal variability of selected physical and chemical parameters is small and does not exceed 10%. It is, therefore, comparable to that found in natural objects. The situation is different for objects exposed to secondary anthropogenic impacts. Very high variability of selected physical and chemical parameters is observed in these objects. Coefficients of variation for specific ion concentrations may exceed 50% [Woźniak, 2010; Molenda et al., 2012; Molenda et al., 2013].

The relationship between species composition, species diversity and environmental variables

Of the eleven environmental variables, nine significantly explained the species diversity of these wetlands (Figure 5A). Magnesium and ORP ordinate opposite different groups of species *Pinguicula bicolor* vs. *Alnus glutinosa* likewise others ordinate with pH and phosphorus (Figure 5B). Nitrates, sulphates and oxygenation are correlated and the above species are confined to these parameters. Moisture (F) was not a significant factor while light, pH and nitrogen significantly explain species variation (Figure 5B). The Shannon-Wiener index was not a significant biodiversity index however its probability was close to an arbitrary level for type I error ($p = 0.065$) whereas other: Evenness (0.1322) and Simpson dominance (0.160) did not explain species data. Only species richness was a significant variable, indicating that some species are associated with

sites with lower numbers of species e.g. *Bidens frondosa* whereas other plants species occur in conditions of higher species richness e.g. *Dactyloctenium aegyptium* (Figure 5c).

DISCUSSION

Excavation of the mineral resources, particularly by the open-cast method, such as sand open pit extraction, is causing the removal of vegetation cover and significant changes in the relief and water quality. Open-cast mining is causing severe interaction with the hydro-geological structure. In the study area, the same changes have been observed all over the areas where open-cast mineral resource mining has taken place [Dulias, 2016]. Significant transformations take particularly in the hydrological and hydro-geological conditions, including the water's escape (infiltration) from the neighbouring river into the bottom of the open-cast sandpit [Jabłońska-Czapla et al., 2016].

Submerging of the sand pit with water rich in calcium and magnesium ions paves the way for calciphilic plants to colonise, which steadily changes to vegetation patches being similar in plant species composition to alkaline *Caricion davallianae* fens (according to the NATURA 2000 habitat code 7230 and also 7210: Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*). In natural conditions, these vegetation patches of alkaline bog type are present at sites where the water is flowing (infiltrates) through geological layers of limestone which enriches the water with minerals, including calcium carbonate [Matuszkiewicz, 2018]. Such vegetation occurs in nature in scarce habitats. In this respect, the highly mineralized anthropogenic wetlands are the habitats of refuge for some endangered and rare plant species. Most of them are characterised by narrow ecological niches.

The development and persistence of *Caricion davallianae* bog vegetation in abandoned sandpits are noteworthy and should be a significant conservation issue. Most frequently, the open sand habitats of unmanaged sandpits are colonised by species assembled from psammophilous grasslands, arid grasslands, ruderal plant species, shrubs and trees. In comparison, wetter or infiltrated/ flooded sand pit sites are covered with rushes, the common reed (*Phragmites australis*) and broad-leaf cattail (*Typha latifolia*) [Nowak et al., 2015].

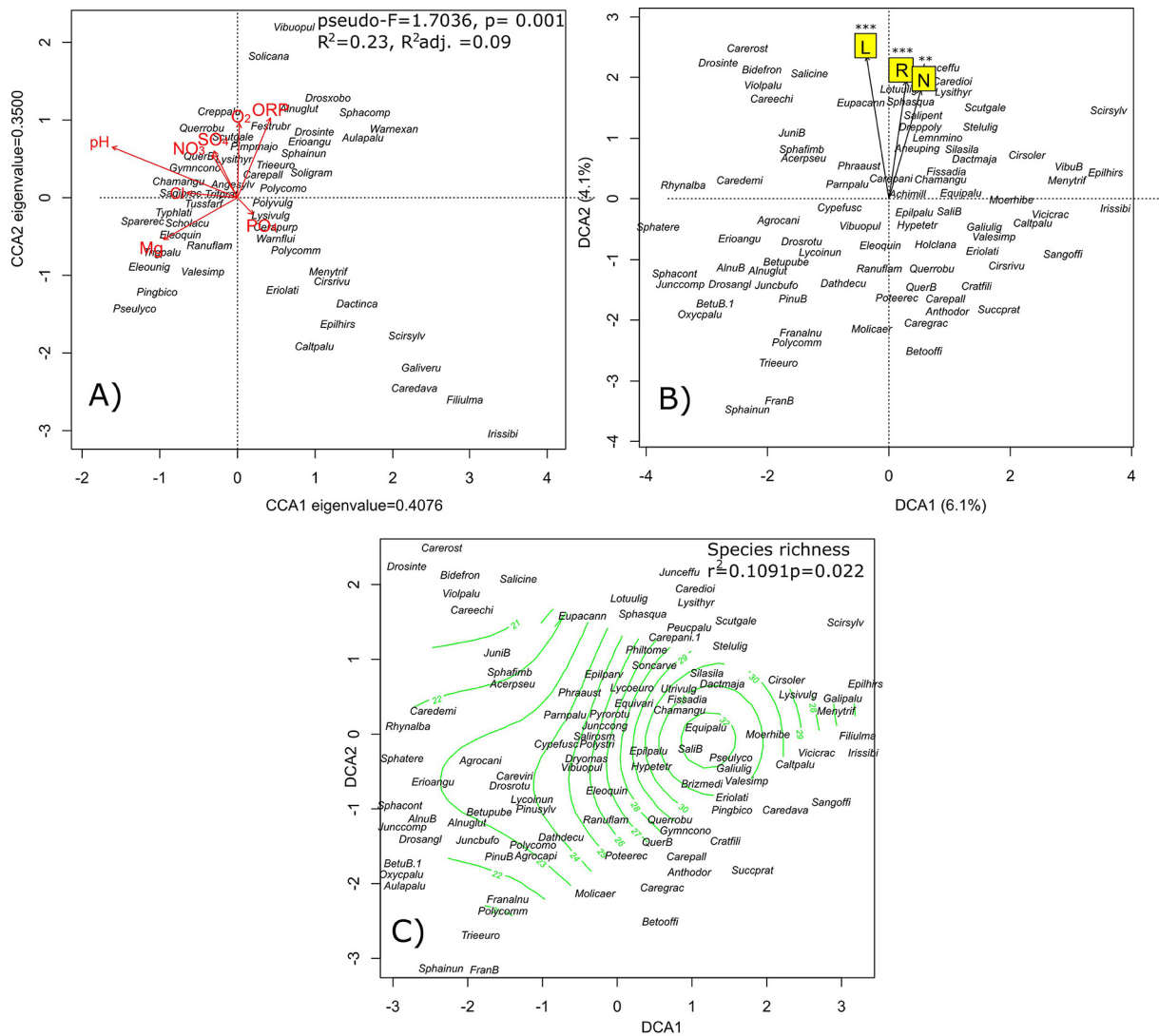


Figure 5. The ordination analyses of the studied anthropogenic wetlands; (a) CCA biplot based on species abundances and environmental variables (only significant ones are shown), (b) Passive projection of ecological indicator value (only significant variables are shown), (c) Isotropic surface of species composition (only significant biodiversity index that explains species variation). The species names are shortened: the first four letters indicate genus names, and the next four letters are the species names. Explanations: N – nitrogen, R – reaction, **- p<0.01, ***-p<0.001

The water infiltrating the mining areas sometimes bring a load of ions, which can, in turn, affect the properties of the natural water supply conditions and subsequently, wetland ecosystem establishment. The most significant of these are magnesium and calcium ions as well as sulphates, which are considered to affect the electric conductivity in the flooded soil element relations. The amount of these ions in the studied vegetation patches was more significant than the amount that have been frequently found in the surface water and groundwater in other areas [Nocoń et al., 2012]. The higher amount of magnesium and calcium ions in the water might be related to the

surrounding dolomite rocks. In some anthropogenic wetlands, a higher level of calcium ions in the wetland has been recorded compared to the water of nearby rivers, which partially supply water to the wetland. This phenomenon can be explained by water evaporation from the wetland and vegetation surface.

The above-presented habitat conditions and the following processes are the consequence of the novel system of biotic and abiotic components that, under human impact, differ from those that are known from the prevailing natural and semi-natural historical habitat conditions. These novel habitats are creating new self-organised

biotic (plants) assemblages that provide novel conditions which are a consequence of intensive human management. Novel ecosystems because of some limitations are different from hybrid ecosystems sensu Rotherham [Rotherham, 2017]. The concept of a novel ecosystem assumes the crossing of environmental thresholds preventing historical ecosystems from recovering [Morse et al., 2014; Evers et al., 2018]. The above characteristics of abiotic and biotic anthropogenic wetland vegetation provide evidence that this type of novel ecosystem consists of biodiversity hotspots within an urban-industrial landscape.

The processes of evaporation observed in the water bodies on the swamp's surface along with the growing salinity explains the observed phenomenon e.g. in the vegetation species composition. There is an anthropogenic wetland where the following evaporites were identified: calcium carbonate (CaCO_3) and gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). The higher amount of sulphates in the post-mineral excavation mining waters was the weathering effect of sulphide ore minerals [Motyka et al., 2017]. The same was observed and described by Molenda [2011], who studied other hydrographic objects of anthropogenic origin.

Vegetation patches of bog with calciphilous plant species were only recorded in southern [Czylok et al., 2008; Czylok and Szymczyk, 2009; Rahmonov and Szymczyk, 2010] and northeastern Poland [Bzdon, 2009]. The occurrence of species that are listed as endangered or rare is a prerequisite for biodiversity conservation at the regional and the country scale. In this respect, the records of the abundant occurrence of *Liparis loeselii* – a species of European importance [Kaźmierczakowa et al., 2016] in anthropogenic wetland vegetation are of particular significance. These natural wetland vegetation communities are endangered and continuously decreasing. The significance of Ca^{2+} and pH is underlined for developing and persisting vegetation patches of alkaline swamps [Duval and Waddington, 2018]. Plant communities with the participation of *Liparis loeselii* individuals and other helophilic species that have been recorded in the Rospuda Valley grow in habitats in which the following soil and water parameters characterise the water: pH – 7.0, EC – 0.466 (max 0.694), Mg^{2+} – 15.9, Ca^{2+} – 21.7 (the unites are provided in Table 3), [Jabłońska et al., 2011]. The amount of calcium and magnesium ions compared to some anthropogenic wetlands was much higher. The plant

species colonisation and vegetation patch assemblage processes were not influenced. The studied anthropogenic wetlands are significant because of the increase in calcium and magnesium ions.

In contrast, there is a negative correlation between magnesium and calcium ions in soils of other studied anthropogenic habitats (pastures, agriculture, managed forests), [Kuscu et al., 2018]. The relationship recorded between the spectrum of environmental requirements (presented by Ellenberg's indicator values) and the moisture and soil pH, recorded along with the plants colonising the anthropogenic wetland habitats, supports the idea that the patterns of plant species distribution reflect the plant species response to the gradient habitat conditions [Horsáková et al., 2018]. The level of water in the anthropogenic wetlands might be the environmental filter that limits the encroachment of ruderal plants, both native expansive and invasive alien species, that threaten the biodiversity of alkaline bogs, as well as overgrowing woody plants (shrubs and trees).

The individuals of *Liparis loeselii* species were counted in their hundreds in some of the studied sites [Błońska, 2013]. The analyses revealed twelve protected and eight “red list” species, including *L. loeselii*, in some studied sites [Błońska et al., 2020]. The plant vegetation community in the wetlands was characteristic of the alkaline fens of the community of the *Caricion davallianae* alliance.

The presented example of anthropogenic wetlands are an important element of water resources and should be included when modelling water resources on a regional scale. There are attempts to apply modelling methods that link streamflow to climate characteristics. In order to estimate the precipitation elasticity a modelling approach has been employed. The water retention provided mainly by wetlands is closely related to the precipitation level. The introduction of the concept of elasticity in estimation of streamflow sensitivity is a method of predicting the future wetlands' hydrological relations. The concept of elasticity can be described with the characteristics of a ratio between the proportional changes occurring in the streamflow i.e., precipitation (P), temperature (T), and evapotranspiration (ET), which are the representatives of the precipitation elasticity. Some studies made a comparison of climate elasticity with other popular available models for streamflow sensitivity and found a robust coherence between them [Khan et al., 2022].

CONCLUSIONS

Identifying, preserving, and restoring wetland and aquatic ecosystems and their functions are globally significant [Fois et al., 2022].

This study has shown that anthropogenic wetlands could provide habitats for the development of biodiversity and can be a refuge for oligotrophic alkaline plant species and the subsequently assembled vegetation. The high moisture levels of these habitats of post-mineral excavation sites and the high amount of calcium and magnesium ions in anthropogenic wetlands are possible factors that enhance the colonisation of calciphilous plant species. Rare and protected species have been recorded among the studied vegetation patches. The maintenance of their specific water quality is essential for the protection and persistence of the habitats at these sites. The results of the study revealed that, in some circumstances, human-induced changes provide the right conditions for the establishment of habitats which act as refuges for these rare plants and that this is magnificent from a nature conservation perspective.

Our results can bridge a gap in science about wetland areas. Nowadays, the area of wetland ecosystems is constantly decreasing. These sites are extremely valuable habitats from the natural point of view, requiring attention due to their insufficient knowledge of study. Wetlands can be used for the comparative studies of similar areas developing in specific hydrological and orographic conditions in another region of country, Europe or in the world. It should be noted that wetlands play an essential role in the circulation of water and mineral salts in the ecosystem between individual elements of the environment, including between living organisms and their habitat. Thanks to its interdisciplinary approach to the subject, we provide a comprehensive knowledge of ecosystems. Thus, we can integrate these anthropogenic wetlands into urban planning and industrial site management to enhance biodiversity conservation. Only rational water management is necessary for the proper functioning of ecosystems. Undoubtedly, different hydrological phenomena are observed wherever mining processes take place. In turn, their good condition affects the state of the climate. This problem is extremely important in relation to the global climate change, carbon storage, and water retention.

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