

Article

Impact of Land Use Type on Macrophyte Occurrence in Ponds in a Changing Climate

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Abstract: Small ponds are essential environmental elements that perform many ecological functions. We tried to answer whether the macrophytes in ponds may be influenced by environmental factors and the neighboring areas' land-use type. We also tried to determine the trend of changes in the ponds' depth and size over the decade (2008–2018). The research was carried out on eight ponds in four types of land use (agricultural, horticultural, urban, and industrial areas). The study covered ponds' morphometric parameters, macrophytes' occurrence, and physicochemical water parameters. All data collected were statistically processed using CCA, linear regression, and Pearson's correlation. The results indicated a continuous tendency for the ponds' size and depth to decrease, particularly in urbanized areas. During the study, most macrophytes' genera increased their area. Our research allowed us to separate two homogeneous groups of ponds in terms of environmental conditions. The first was horticultural area ponds, for which higher nutrient concentrations in water were determined. Those ponds were inhabited by *Ceratophyllum* and *Sparganium* genera. The second was urban and industrial area ponds characterized by higher water temperature, transparency, pH, and were richer in Mg and Ca. *Carex*, *Potamogeton*, and *Schoenoplectus* genera preferred such conditions.

Keywords: depth change; agriculture areas; urban areas; environmental variables; statistic model



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1. Introduction

Due to its small size, the role of ponds concerning biogeochemical processes and biodiversity at the landscape scale has largely been ignored [1]. Only recently, the pivotal role of small-standing water bodies as hotspots of biodiversity [2], e.g., macrophytes [3–5], has been emphasized. About 3.7% of the non-glaciated land area is covered by inland waters of >0.2 ha [6]. Ponds with a water surface area <0.001 km² have been estimated to account for 8.6% of the global surface area of lakes and ponds and contribute disproportionately highly to the worldwide carbon emissions from surface waters [1,7]. Ponds usually are not connected to a stream network. However, typical characteristics of ponds such as size (<1 ha), short water residence time within the basin, shallow depth, and a high perimeter-to-volume ratio indicate that they are more intimately interlocked with their terrestrial environment compared to larger lakes [8,9]. Input from the terrestrial environment occurs through the groundwater system, interflow, surface runoff, or direct input via deposition or anthropogenic discharge [1]. Ponds often exhibit very rapid biological and biogeochemical kinetic processes compared to large deep lakes [10]. That is especially true for most of the ponds in Germany and Poland, located in regions of intensive agriculture [11]. High nutrient concentrations lead to eutrophication and fast algae bloom or coverage of floating macrophytes [1,12]. Generally, ponds usually exhibit enormous spatial and temporal variability of pond water quality [8,13].

The role of small water reservoirs—ponds—is significant in the context of flood protection and climate change consequences. Ponds are natural retention reservoirs, thanks to which rainwater is stored, limiting the rapid surface runoff. Also, studies on threats resulting from extreme weather events in the studied area of the Wielkopolska region indicated the potential in the form of natural retention reservoirs (ponds, water courses), thanks to which the effects of climatic hazards (heavy precipitation) could be limited [14]. However, it is shown that this potential is not widely used in Poland due to the specificity of flood risk governance [15]. Furthermore, not only heavy rainfall is a growing threat because of climate change in Poland. Research indicates more frequent and more severe droughts [16]. Also, in this context, the role of ponds is growing. Therefore, small retention is becoming increasingly crucial in plans for adaptation to climate change, both in urbanized areas and in agricultural areas, to reduce the vulnerability to threats resulting from droughts.

The biogeographical theory has been put into practice in nature conservation [17,18]. The biogeographical principle that a larger area supports more species has been established over a century [19,20]. Ponds are essential for biodiversity conservation but have been lost mainly during the twentieth century, reaching 40–90% for various northwestern European countries [21,22]. But the information available about the ecology of ponds and the consequences of their management [23] is sparse and contradictory. Data are available for lakes, but ponds are a different type of freshwater system, and it is doubtful that results from lakes apply to ponds [24]. Low diversity limits the ecosystem's resistance to disturbances, which may be particularly detrimental to urban ponds vulnerable to anthropogenic impacts [25]. Both theoretical and empirical studies have shown that a certain level of disturbance is beneficial to maintaining species diversity, plant growth, and community productivity [26]. While numerous studies have examined the effects of flooding and extreme droughts on plant individuals' and communities' performance in terrestrial ecosystems [27,28], relatively little attention has been paid to aquatic ecosystems [29]. Aquatic plants, especially submerged macrophytes that grow only under the water, seem less likely to experience flooding and drought directly. Still, the dynamics of the water regime caused by these disturbances may reconstruct aquatic plant communities [30,31]. During the last few years, there has been an increase in the number of studies examining the biodiversity of ponds [32,33]. However, most studies have focused on how ecological and landcover variables or water chemistry affect the biodiversity of ponds [34,35].

Growing recognition of the importance of ponds for maintaining biodiversity [36] extends to conservation programs for endangered species [37]. For example, it has been revealed that urban stormwater management ponds can provide a similar level of biodiversity as urban wetlands in Ottawa, Canada [38]. Similarly, Le Viol et al. [39] investigated diversity in highway stormwater ponds. They concluded that these ponds supported communities at least as rich and diverse as pond communities in the surrounding landscape. One of the main functions of ponds is landscape water retention [25]. Ponds receive stormwater and snowmelt and are used to mitigate stormwater flows into rivers [40]. They are usually shallow, unstratified reservoirs with short retention times and high seasonal fluctuations in water levels [41]. Due to rapid sedimentation, plant overgrowth, or other effects of eutrophication, ponds are often unable to perform their functions [25]. Additionally, various human pressures on these waters cause further degradation and impairment [42]. Besides, the water's high nutrient content is enhanced by its internal load—for these reasons, restoration of ponds is necessary [43].

Water depth significantly affects aquatic vegetation's growth, reproduction, and distribution [26,44]. In addition, water level fluctuation can modify light availability [26,45] and influence nutrient cycling pathways [46,47]. These processes may impact the growth of aquatic vegetation [26,48].

Our research aimed to (1) determine whether small ponds statistically change their surface with time; (2) to investigate whether different macrophytes genera prefer selective habitat and environmental conditions; (3) to answer whether neighboring areas' use-type can determine the physicochemical water composition and the macrophytes presence, and

(4) to determine whether macrophyte species occurring in the studied ponds may be the plants indicating a changing climate.

2. Materials and Methods

The research was conducted on eight ponds in the Wielkopolska region, Poland. No specific permissions were required for the locations, and the field studies did not involve any endangered or protected species. The ponds differed in location, surface area, shape, and aquatic vegetation. However, they did not vary in the amount of rainfall (the average for the Wielkopolska region is about 550 mm) or altitude (they are located at the height of 90–100 m above sea level). The geographical coordinates and changes in the morphometric parameters of the ponds under analysis are presented in Table 1 and Figure 1.

Table 1. The morphometric parameters of ponds.

	Agriculture Area (1)		Horticulture Area (2)		Urbanized Area (3)		Industrial Area (4)	
	1.1	1.2	2.1	2.2	3.1	3.2	4.1	4.2
location	52° 05' 38.3" N 16° 47' 16.4" E	52° 03' 27.7" N 16° 50' 12.5" E	51° 42' 55.6" N 18° 07' 20.4" E	51° 43' 11.8" N 18° 09' 48.1" E	52° 25' 50.0" N 17° 05' 11.3" E	52° 21' 41.8" N 16° 52' 35.2" E	52° 14' 51.7" N 18° 15' 50.1" E	52° 13' 11.7" N 18° 12' 23.0" E
year	area [m ²]							
2008	432	4756	536	782	1596	3526	1200	956
2010	445	5062	570	780	1590	3456	1266	1001
2012	425	3212	525	745	1496	3351	1159	963
2014	413	893	507	741	1289	2986	1102	941
2016	427	3257	500	751	1230	2950	1098	914
2018	397	3357	499	732	1190	2789	1089	899
mean	423.17	3422.83	522.83	755.17	1398.50	3176.33	1152.33	945.67
SD	16.50	1479.23	27.36	20.95	183.87	306.09	70.33	36.53
year	depth [m]							
2008	0.38	0.41	0.65	0.75	0.65	0.95	0.80	0.50
2010	0.37	0.42	0.66	0.77	0.64	0.95	0.81	0.52
2012	0.36	0.21	0.59	0.71	0.62	0.91	0.75	0.45
2014	0.35	0.15	0.51	0.65	0.55	0.79	0.71	0.42
2016	0.36	0.20	0.48	0.63	0.51	0.73	0.65	0.39
2018	0.30	0.22	0.44	0.59	0.50	0.71	0.62	0.37
mean	0.35	0.27	0.56	0.68	0.58	0.84	0.72	0.44
SD	0.03	0.12	0.09	0.07	0.07	0.11	0.08	0.06

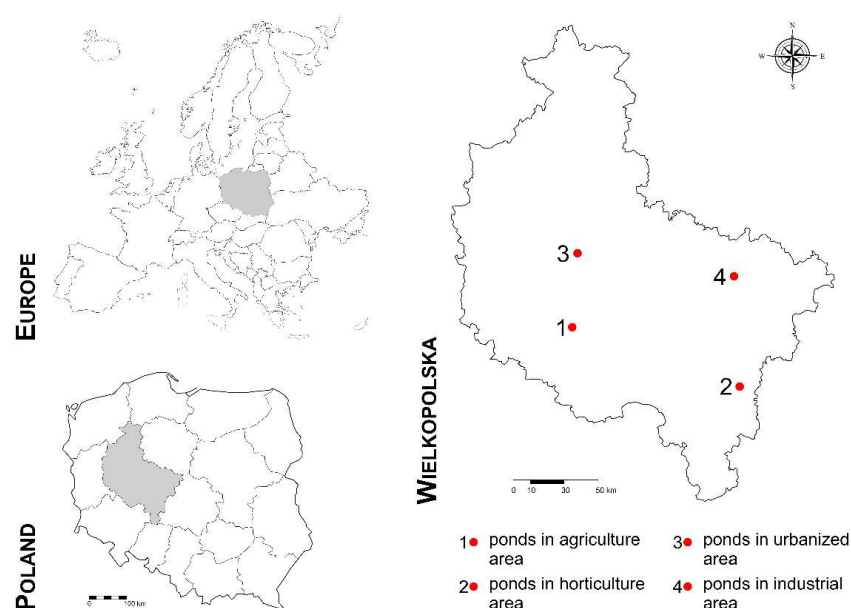


Figure 1. Location of the analyzed ponds.

The research spanned ten years (2008–2018), with measurements made every second year. All the parameters and macrophytes composition were determined three times a year (June, August, and October) in 2008, 2010, 2012, 2014, 2016, and 2018. The surface of the studied ponds was measured by a qualified surveyor using the Pentax R-1500N (TI Asahi Co., Ltd., Saitama, Japan) Total Station Theodolite with TopoLite software (TI Asahi Co., Ltd., Japan). The mean depth was measured by a depth pole (Figure 2). The macrophytes were identified using the available vascular plant identification keys and phytosociological assessment. The Latin names of the macrophytes were used according to the Plant List [49].

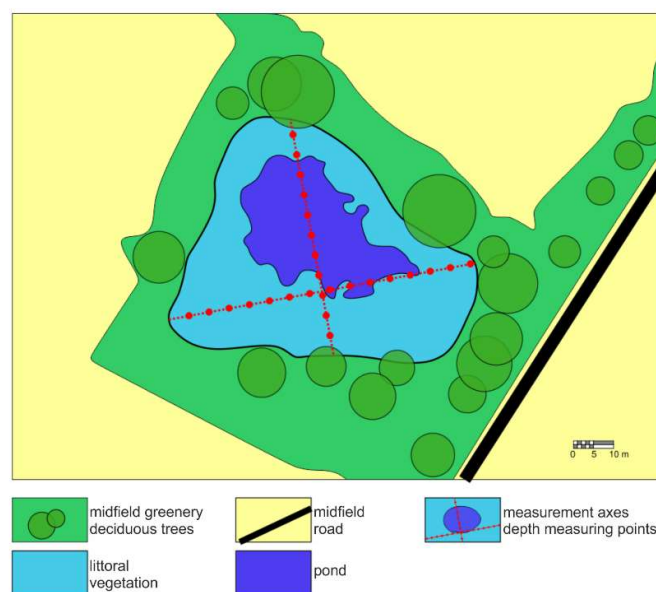


Figure 2. Pond depth and temperature measurement scheme.

2.1. Water Analyses

According to standard methods, water samples were analyzed for NH_4^+ , NO_3^- , NO_2^- , TP, PO_4^{3-} , Na, K, Mg, Ca, and Fe [50]. The pH and temperature were also measured using a waterproof CP-411 device (Elmetron Sp.j., Zabrze, Poland) with a glass electrode EPS-1 (Elmetron Sp.j., Zabrze, Poland). Ammonium nitrogen was analyzed using a Nessler's reagent (PN-C-04576-4); nitrate nitrogen with sodium salicylate (PN-82 C-04576.08) (Merck Life Science Sp.z.o.o., Poznan, Poland); nitrite nitrogen with sulfanilic acid and 1-naphthylamine (PN-73 C-04576) (Merck Life Science Sp.z.o.o., Poznan, Poland). Dissolved phosphates were analyzed with ammonium molybdate and ascorbic acid (PN-89 C-04537) (Merck Life Science Sp.z.o.o., Poznan, Poland). Total phosphorus was analyzed similarly after prior mineralization (PN-91 C-04537/09). We collected water samples at depths of 20–50 cm, about 1 m away from the shore of ponds. Water transparency was measured using a 200 mm Secchi disk. The disk was made of 10 mm thick white plastic, additionally equipped with a cylindrical stainless steel weight (diameter 50 mm) [51].

The following methods were used to analyze the content of elements in the AAS AAnalyst 200 spectrometer (PerkinElmer, Markham, Canada) with specific optimization parameters (Table 2):

- Flame Atomic Absorption Spectrometry (F-AAS)—Ca, Mg, and Fe;
- Atomic Emission Spectrometry (AES)—Na, K.

Table 2. The values of optimization parameters in the Flame Atomic Absorption Spectrometry (F-AAS) and Atomic Emission Spectrometry (AES) methods.

Optimization Parameters	F-AAS			AES	
	Ca	Mg	Fe	Na	K
lamp current (mA)	10	6	30	-	-
wavelength (nm)	422.67	285.21	248.33	589.00	766.49
gap (nm)	2.7/0.6	2.7/1.05	1.8/1.35	1.8/0.6	1.8/0.6
oxidizing gas (air) flow (L/m)	10.00	10.00	10.00	10.00	10.00
flammable gas (acetylene) flow (L/m)	2.70	2.50	2.50	2.50	2.50
integration time (s)	3.0	3.0	3.0	3.0	3.0
readout time (s)	5.0	5.0	5.0	5.0	5.0

2.2. Chlorophyll Content Measurement

Five leaves were collected from each plant. A fragment of the lamina was cut along the midrib. Four samples weighing 0.5 g were prepared in this way. First, they were flooded with dimethyl sulfoxide (DMSO) (Merck Life Science Sp.z.o.o., Poznan, Poland) and left in darkness at room temperature for one hour. Next, they were incubated at a temperature of 65 °C (water bath) for 30 min. After cooling, 5 mL of distilled water was added. Next, the content of chlorophyll *a* and *b* was measured by a Beckman DU70 spectrophotometer (ALT, San Diego, CA, USA) operating at adequate wavelengths. The chlorophyll *a* extract absorbance was measured at a wavelength of 663 nm, whereas chlorophyll *b*—at a wavelength of 645 nm. The content of chlorophyll *a* and *b* was calculated according to the following formulae [52]:

$$\text{Chlorophyll } a = (12.7 \times A_{663} - 2.7 \times A_{645}) \times V \times (1000 W)^{-1} \quad (1)$$

$$\text{Chlorophyll } b = (22.9 \times A_{645} - 4.7 \times A_{663}) \times V \times (1000 W)^{-1} \quad (2)$$

where:

A—absorbance at a specific wavelength,

V—total extract volume (cm³),

W—sample weight (g).

The amounts of individual pigments were expressed as µg g⁻¹.

2.3. Statistical Analyses

Statistical analyses and models were based on discriminant analysis. The analyses assessed which variables might affect the distribution of the plants' genera. Canonical variate analysis (CVA), the canonical variation of Fisher's linear discriminant analysis (LDA), was used to construct a model. The CVA enabled the creation of the canonical correlation analysis (CCA) model. Progressive stepwise analysis was used to find the variables which determined the distribution of plants in the ponds to the greatest extent. All the variables were assessed. Those contributing most to the groups' discrimination, based on *p* and *F* values, were included in the model. This process was repeated until the *p*-value increased above 0.05 or the *F*-value dropped below 2.00 for a particular variable. A Monte Carlo permutation test was applied to determine the significance limit (the number of permutations: 9999). We have also applied linear regression and correlations in the presented paper. The Canoco for Windows and Microsoft Excel programs were used to calculate, compare, and graphic elements. The Canoco for Windows tools were used: Canoco for Windows 4,5 (Microcomputer Power, Ithaca, NY, USA), CanoDraw for Windows (Microcomputer Power, Ithaca, NY, USA), and WCanoIMP (Microcomputer Power, Ithaca, NY, USA) [53].

3. Results

The study analyzes changes in the surface and depth of ponds over ten years. A regression analysis was performed to determine whether the studied relationship was statistically

significant (statistical parameters are given in Figures 3 and 4). There was a tendency to reduce the surface in all locations (regression analysis confirmed that these relationships were significant in seven out of eight cases). Only in the case of one pond located in an agricultural area the expected relationship was not found (it was not statistically confirmed) (Figure 3).

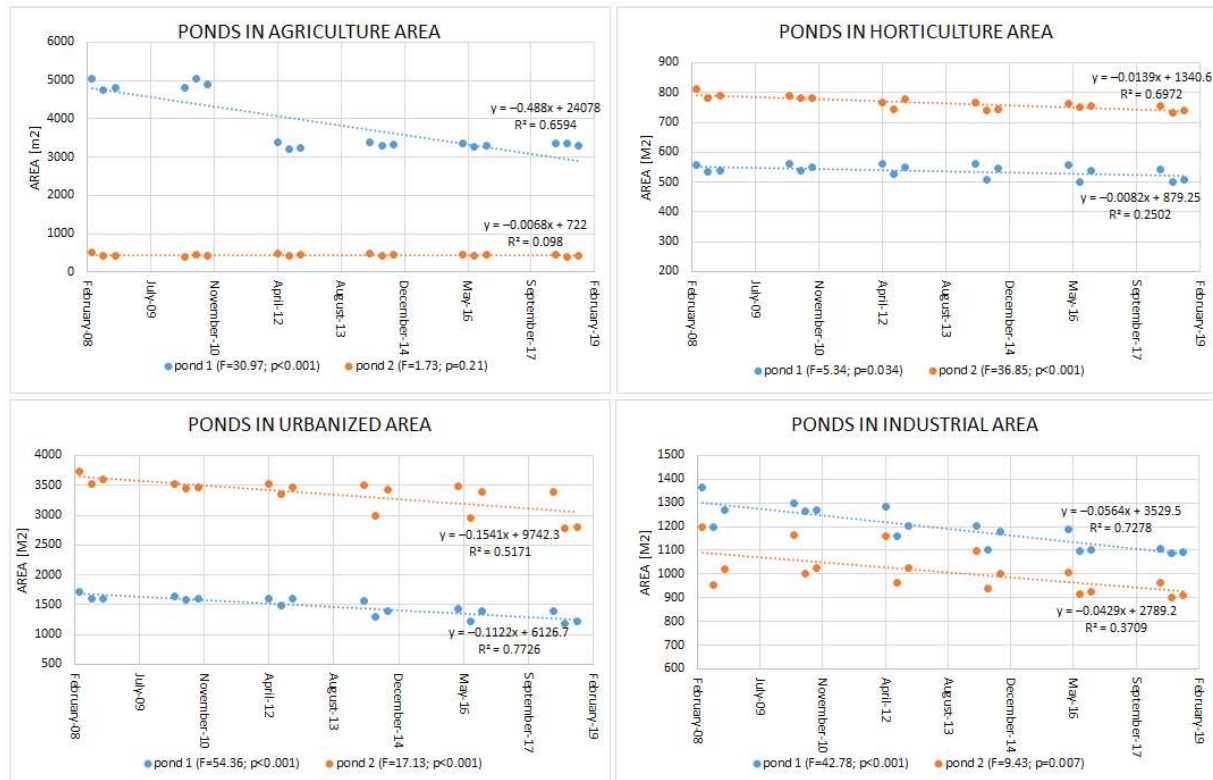


Figure 3. Changes in surface area of analyzed ponds.

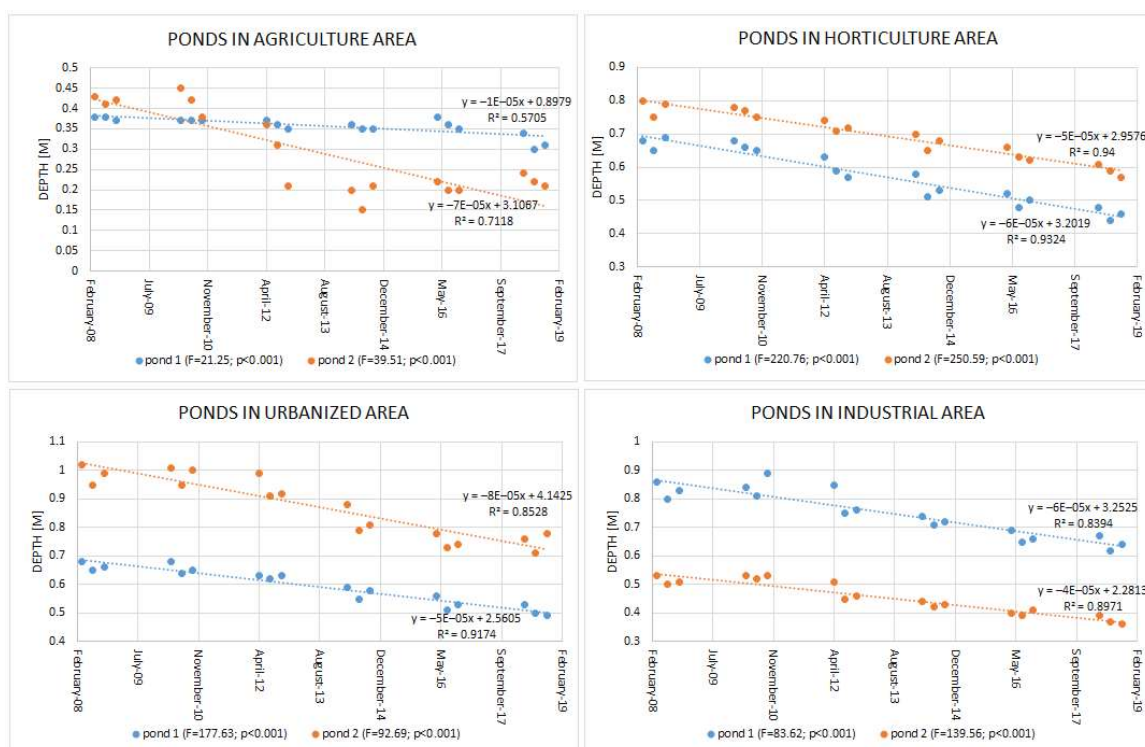


Figure 4. Changes in depth of analyzed ponds.

When analyzing the depth of the ponds during the study period, a tendency to reduce the depth of the ponds located in horticultural, urban, and industrial areas can be observed. Furthermore, the regression analysis showed that the ponds' shallowing dependence over time was statistically significant and was confirmed in all eight ponds (Figure 4).

The location of ponds may affect water parameters, as shown in Table 3. The highest average water temperature was recorded for ponds located in industrial areas (near Konin). That could be due to the discharge of cooling water to large reservoirs, and then, through a permanent outflow, warm water could enter into the hydrological system of the area. As demonstrated by Pearson's analysis (Table 4), the water temperature was strongly positively correlated with pH, which is confirmed by the fact that the cooling waters were alkaline (source). The highest Fe concentrations were recorded in the water of ponds in the urbanized area. The water of industrial zone ponds was characterized by higher Mg and Ca levels associated with higher pH values (Figure 5). Our research shows differences in water composition regarding the content of analyzed N, P, K, and Na forms. Water collected from ponds in agricultural and horticultural locations was characterized by higher concentration levels of the substances mentioned above. That may result from chemical fertilizers used in areas intended for cultivation. The highest water transparency was recorded in ponds located in urban areas.

Table 3. Statistical parameters for the examined variables.

Variables	Location															
	Agriculture Area (n = 36)				Horticulture Area (n = 36)				Urban Area (n = 36)				Industrial Area (n = 36)			
	min	max	mean	SD	min	max	mean	SD	min	max	mean	SD	min	max	mean	SD
temp. [C°]	10.37	13.90	11.87	1.09	9.50	13.10	10.92	1.16	12.50	15.20	13.81	0.84	13.20	15.50	14.67	13.20
ice [days]	9.00	29.00	15.58	6.43	3.00	12.00	7.92	2.68	5.00	14.00	9.08	2.71	0.00	13.00	5.42	0.00
pH	7.21	7.96	7.56	0.18	7.10	7.40	7.24	0.10	7.20	7.65	7.46	0.14	8.00	8.40	8.25	8.00
Fe [mg dm ⁻³]	0.02	0.62	0.25	0.20	0.07	0.51	0.25	0.16	0.20	0.68	0.44	0.15	0.01	0.10	0.02	0.01
Ca [mg dm ⁻³]	17.00	110.00	49.50	31.53	15.00	66.00	44.83	16.29	11.00	41.00	25.92	9.34	41.00	80.00	64.58	41.00
Mg [mg dm ⁻³]	2.30	25.00	11.15	7.41	6.60	21.50	15.73	5.60	3.60	15.00	7.81	3.26	20.00	31.00	25.25	20.00
K [mg dm ⁻³]	33.00	175.00	102.42	62.21	29.00	110.00	66.33	26.15	2.30	20.00	10.88	6.20	4.50	9.00	6.88	4.50
Na [mg dm ⁻³]	73.00	247.00	150.50	73.40	41.00	152.00	91.17	39.05	29.00	120.00	57.92	29.24	15.50	22.30	20.05	15.50
NH ₄ ⁺ [mg dm ⁻³]	0.76	2.10	1.30	0.37	0.56	2.36	1.36	0.49	0.45	0.90	0.72	0.14	0.14	0.62	0.43	0.14
NO ₃ ⁻ [mg dm ⁻³]	0.41	1.72	1.11	0.46	1.69	2.51	2.16	0.24	0.36	1.11	0.71	0.26	0.21	0.52	0.37	0.21
TP [mg dm ⁻³]	0.02	2.52	1.15	1.14	0.78	2.25	1.44	0.46	0.08	0.25	0.15	0.05	0.01	0.31	0.16	0.01
PO ₄ ⁻ [mg dm ⁻³]	0.01	0.89	0.44	0.37	0.29	1.78	0.84	0.50	0.02	0.52	0.15	0.15	0.00	0.19	0.09	0.00
Secchi [m]	0.05	0.31	0.14	0.08	0.20	0.61	0.35	0.14	0.25	0.81	0.53	0.19	0.18	0.62	0.31	0.18
chl a [μg dm ⁻³]	63.00	146.00	97.83	25.06	32.00	157.00	74.83	40.12	24.00	120.00	65.08	31.71	27.00	211.00	112.25	27.00

The correlation analysis (Table 4) showed the relationships between the tested parameters. The strongest positive correlation was found between Na and K concentrations in the water of the tested ponds. Besides, a directly proportional relationship was observed for the concentration levels of TP, PO₄⁻, K, Na, and NH₄⁺. On the other hand, the water temperature was negatively correlated with concentration levels of K, NH₄⁺, NO₃⁻, and both forms of phosphorus. Similar relationships were observed for pH, NH₄⁺, and NO₃⁻ as well as Fe, Ca, and Mg.

The study also examined changes in the area occupied by individual genera of macrophytes over time. Only those genera that met the condition of occupying the area of over 5% were studied. Most genera of macrophytes (16 out of 20) increased their area during the study period (Table 5). In the case of *Oenanthe* sp., *Phragmites* sp., and *Typha* sp., continuous growth, and space occupied by these genera were observed. That could have contributed to the overgrowth of ponds and their shallowing over the years.

Table 4. Pearson's correlation for the analyzed variables (yellow—negative correlation; green—positive correlation; h—pond depth; Sec—Secchi disc; chl a—chlorophyll a).

	Temp	Area	h	Ice	pH	Fe	Ca	Mg	K	Na	NH ₄ ⁺	NO ₂ [−]	NO ₃ [−]	TP	PO ₄ [−]	Sec
Area	0.14	1														
h	0.10	0.12	1													
Ice	−0.49	0.38	−0.29	1												
pH	0.70	−0.11	−0.11	−0.30	1											
Fe	−0.29	−0.03	0.26	0.14	−0.56	1										
Ca	0.21	0.14	−0.23	−0.17	0.39	−0.78	1									
Mg	0.31	−0.25	0.04	−0.42	0.54	−0.65	0.70	1								
K	−0.65	−0.37	−0.38	0.37	−0.34	0.35	−0.35	−0.35	1							
Na	−0.58	−0.24	−0.35	0.43	−0.37	0.44	−0.46	−0.53	0.94	1						
NH ₄	−0.77	−0.19	−0.23	0.34	−0.63	0.29	−0.24	−0.35	0.69	0.66	1					
NO ₂	−0.06	0.47	−0.39	0.30	−0.03	−0.21	0.32	−0.17	−0.03	−0.01	0.16	1				
NO ₃	−0.71	−0.13	−0.09	0.15	−0.69	0.02	0.04	−0.14	0.25	0.18	0.59	0.19	1			
TP	−0.66	−0.56	−0.15	0.16	−0.43	0.38	−0.41	−0.24	0.88	0.79	0.68	−0.21	0.40	1		
PO ₄	−0.65	−0.44	0.05	0.11	−0.48	0.43	−0.43	−0.26	0.69	0.62	0.65	−0.21	0.50	0.86	1	
Sec	0.03	0.35	0.87	−0.08	−0.23	0.34	−0.28	−0.18	−0.37	−0.29	−0.21	−0.26	−0.12	−0.25	0.00	1
chl a	0.13	−0.28	−0.24	−0.18	0.41	−0.18	0.28	0.30	0.11	0.04	−0.01	−0.05	−0.19	0.01	−0.12	−0.46

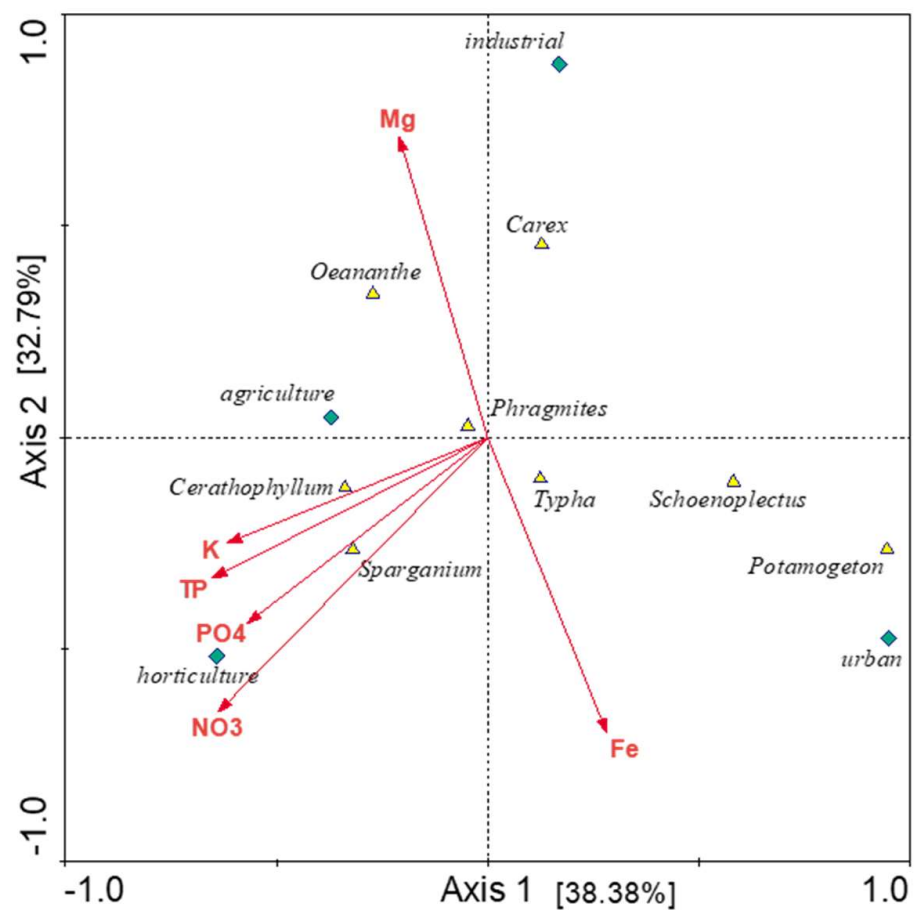
**Figure 5.** CCA analysis ($n = 144$)—depicting the dependence among the chemical variables, location, and area occupied by the identified macrophytes genera.

Table 5. Linear regression of changes in the area occupied by individual genera of macrophytes over time (red—negative trend line; green—positive trend line; $n = 18$).

	No of Ponds	Genus	Trendline	R ²	R ² adj.	SE	F-Value	p-Value
agriculture	1	<i>Typha</i>	$y = 0.022x - 0.04$	0.89	0.86	0.017	31.36	0.005
	1	<i>Oenanthe</i>	$y = 0.055x - 0.02$	0.92	0.91	0.033	49.06	0.002
	2	<i>Phragmites</i>	$y = 0.049x + 0.46$	0.81	0.76	0.050	16.68	0.015
horticulture	1	<i>Phragmites</i>	$y = 0.024x + 0.24$	0.84	0.80	0.022	21.00	0.010
	1	<i>Oenanthe</i>	$y = 0.031x - 0.05$	0.91	0.89	0.020	39.90	0.003
	1	<i>Ceratophyllum</i>	$y = -0.017x + 0.37$	0.71	0.64	0.023	10.00	0.034
	1	<i>Sparganium</i>	$y = -0.017x + 0.37$	0.72	0.65	0.033	10.45	0.032
	2	<i>Oenanthe</i>	$y = 0.038x - 0.07$	0.90	0.87	0.027	35.10	0.004
	2	<i>Ceratophyllum</i>	$y = -0.024x + 0.38$	0.83	0.78	0.023	19.10	0.012
urban	1	<i>Typha</i>	$y = 0.018x + 0.04$	0.79	0.74	0.020	15.11	0.018
	1	<i>Carex</i>	$y = 0.010x + 0.05$	0.73	0.66	0.013	10.75	0.031
	1	<i>Ceratophyllum</i>	$y = 0.024x + 0.01$	0.84	0.80	0.022	21.00	0.010
	2	<i>Phragmites</i>	$y = 0.013x + 0.04$	0.77	0.71	0.014	13.26	0.022
	2	<i>Potamogeton</i>	$y = 0.016x + 0.15$	0.66	0.57	0.025	7.60	0.051
industrial	1	<i>Oenanthe</i>	$y = 0.009x + 0.18$	0.83	0.78	0.009	18.99	0.012
	1	<i>Ceratophyllum</i>	$y = 0.035x - 0.05$	0.95	0.94	0.016	80.76	0.001
	2	<i>Phragmites</i>	$y = 0.017x + 0.49$	0.72	0.65	0.023	10.42	0.032
	2	<i>Typha</i>	$y = 0.015x + 0.04$	0.82	0.77	0.014	17.82	0.013
	2	<i>Ceratophyllum</i>	$y = 0.023x + 0.08$	0.99	0.99	0.005	339.36	0.000
	2	<i>Schoenoplectus</i>	$y = -0.018x + 0.13$	0.95	0.94	0.008	83.03	0.001

CCA analysis showed the relationship among the examined variables, location, and area occupied by the identified macrophytes. Relationships between the location of ponds and the chemical parameters in the water and macrophytes have been observed. In the water of ponds in horticultural areas, higher concentrations of NO_3^- , PO_4^- , and TP were recorded (average of 2.16, 0.84, and 1.44 mg dm^{-3} , respectively) (Table 3, Figure 5), which could be caused by intensive fertilization with these components. Species belonging to the genus *Sparganium* and *Ceratophyllum* occurred more frequently than in other locations. Water tested in agricultural areas was characterized by higher K concentrations (on average 102.42 mg dm^{-3}). Mg dominated in the water of the industrial area ponds (25.25 mg dm^{-3} on average) and Fe (0.44 mg dm^{-3})—in urban areas ponds. The species distribution was also characteristic: *Carex* sp. dominated industrial areas' ponds, and *Potamogeton* sp. dominated urban ponds (Figure 5).

The conducted research also confirmed higher water temperatures for industrial and urban areas ponds (Figure 6). There can be many variables influencing this relationship—including technological processes in the case of industrial sites, the urban heat island effect (UHI), the predominance of built-up areas, or an unfavorable albedo index for these areas, which may be caused by adverse climate change. In the case of urban area ponds, the lowest CoC index was found, which causes the most significant ponds' exposure and, consequently, their rapid heating because of the solar operation. The most alkaline pH was determined for water in industrial areas ponds. The models (Figures 5 and 6) rejected the variables of the lowest significance: chlorophyll *a*, Ca, Na, NH_4^+ , NO_2^- (Table 6).

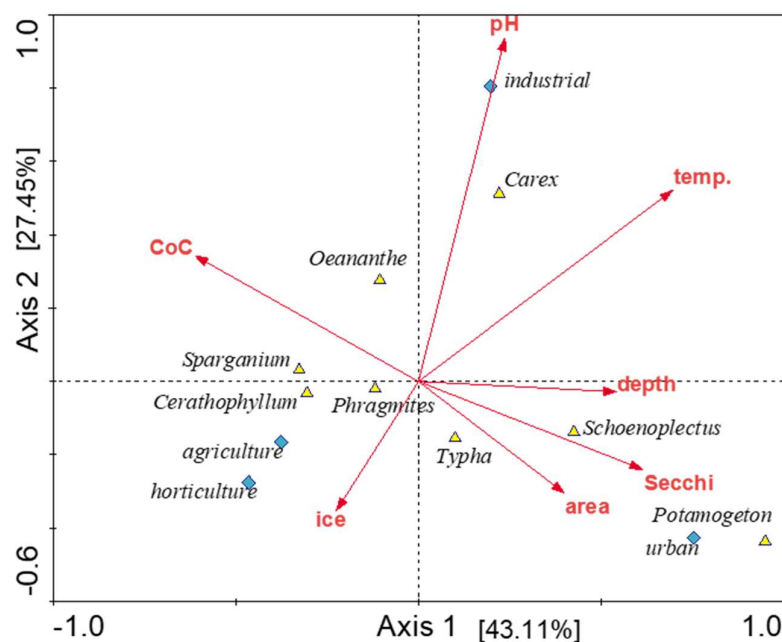


Figure 6. CCA analysis ($n = 144$)—depicting the dependence among the physical variables, location, and area occupied by the identified macrophyte genera ($p < 0.05$; CoC—coefficient of pond coverage by macrophyte genera).

Table 6. Correction coefficients for the CCA model for the chemical variables (Figure 5) and the physical variables (Figure 6) (E%—the percentage of the model explanation by the variable).

Model 1 (Figure 5)				Model 2 (Figure 6)			
number of included variables: 6 number of rejected variables: 4 number of permutations: 999				number of included variables: 7 number of rejected variables: 1 number of permutations: 999			
	E%	p-value	F-value		E%	p-value	F-value
NO_3	15.4	0.001	13.59	pH	12.2	0.001	14.26
Fe	13.3	0.001	12.55	Temp.	11.0	0.001	13.95
Mg	11.3	0.001	12.15	CoC	10.7	0.001	12.59
TP	10.9	0.001	11.04	Secchi	9.8	0.001	10.63
PO_4	9.0	0.001	9.26	depth	9.1	0.001	9.12
K	8.9	0.004	7.44	area	8.5	0.001	7.99
				ice	7.9	0.003	6.71

4. Discussion

Many ponds and small water bodies have been filled up during the past few decades, but there is an increasing trend to restore and create new water bodies in many European cities [21,22,54]. Recently, Sweden has focused on increasing the value of these ponds for biodiversity. In addition, some projects have been initiated to restore ponds to improve their ecological value [55]. However, to our knowledge, no studies have focused on the

relationships between the primary function of a pond, pond management intensity, and pond biodiversity. Such knowledge is essential because it can help design and manage, enhance ecological value, and provide biodiversity-rich habitats in the environment matrix.

Effects of land use in the perimeters on macrophytes did not provide higher correlations than land use around ponds [56]. Our research partially contradicts these findings. We have demonstrated a high positive correlation between (1) horticulture and agriculture areas and the presence of the *Ceratophyllum* and *Sparganium* genera macrophytes, and (2) urbanized and industrial areas and the presence of *Carex*, *Potamogeton*, and *Schoenoplectus* genera macrophytes. However, we have not found such correlations in the cases of *Oenanthe* sp., *Phragmites* sp., and *Typha* sp. Alahuhta et al. [57] came to a similar conclusion—they also found that local variables define the niches of aquatic macrophytes.

Both water chemistry and land use variables indicate that these factors are correlated [56]. Our research confirms this relationship. For example, we found a positive correlation between (1) horticultural areas and increased content of TP, PO_4^- , NO_3^- in water; (2) industrial areas and increased content of Mg, high pH in water, and increased water temperature; (3) the water clarity of urban areas ponds and the high Fe content, as well as increased surface area and depth of those ponds; and (4) increased content of K and the degree of ponds' overgrowth in agricultural areas and the presence of ice cover.

Our research shows that the pond's surface area decreases in all the studied land use types. This process recorded the most significant dynamics for ponds in urbanized areas and the lowest in agricultural areas. Liou et al. [58] reached similar conclusions by analyzing satellite images taken between 1978 and 2012. Other authors found that urban expansion was the main reason for the decline in ponds number and surface area in the case of China. It was 2.8 times higher in 2000–2010 than in 1990–2000 [59]. On the other hand, the team of Seyedhashemi et al. [60] came to entirely different conclusions. They found that anthropogenic impoundments (e.g., small reservoirs and ponds) are expanding globally.

The results of our research show that the depth of the studied ponds is also decreasing. According to our analyses, this shallowing process is the fastest in urbanized ponds and the slowest—in agricultural areas. Pawlikiewicz and Jurasz [61] came to similar conclusions. Furthermore, the conducted analyses found that pond depth strongly correlated with the level of urbanization. However, our results only partially confirmed the studies carried out in Spain, where a decrease in depth was recorded in 37.5% of the ponds [62].

4.1. *Ceratophyllum* sp. and *Sparganium* sp.

Sites occupied by the submerged *Ceratophyllum* sp. macrophytes were differentiated by three environmental variables related to depth and light transmission [45]. Our research confirms this observation—the occurrence of both *Ceratophyllum* sp. and *Sparganium* sp. was favored by the lower water depth and transparency in ponds. Nagengast and Gábka [45] found that *Ceratophyllum* sp. occupied different water depths, but watercolor and chlorophyll *a* concentrations in the water were necessary to define these species' habitats. However, our research shows lower water depth was positively correlated with the chlorophyll *a* content in the water. *Ceratophyllum* sp. are submerged plants, so the underwater light transmission should be more important to these species than to *Typha* sp. [63,64]. Our research only partially confirms these observations. A shallower and less transparent water favored the *Ceratophyllum* sp. and *Sparganium* sp. occurrences.

4.2. *Carex* sp., *Potamogeton* sp. and *Schoenoplectus* sp.

A positive relationship between pond size and species richness could be a valid generalization [24]. The same positive relationship was also shown in the studies of Gee et al. [23] and Jeffries [65], although the work of Linton and Goulder [66] provides exceptions. Further, the same positive trends have been shown for lakes [67]. In the study by Oertli et al. [24], a set of small size ponds had more species, and many species occurred in both large and small ponds. On the other hand, according to Zapfe and Freeland [64], sites

that appeared in ditches were likely to have a narrower range of water depths compared to open marsh habitats, potentially reducing the scope for detecting niche segregation. In our research, we could not confirm the existence of such a positive relationship. We could only show a positive correlation between the pond area and the *Schoenoplectus* and *Potamogeton* genera occurrence and a negative correlation in the case of the genus *Ceratophyllum*. Our research indicated that the occurrence of macrophytes of the *Carex*, *Potamogeton*, and *Schoenoplectus* genera was favored by the greater pond depth, which was positively correlated with the higher water clarity. The increased content of Mg in water, its high pH, and higher water temperature favored the presence of those macrophytes. Similar conclusions were reached by Fukami [68], who noted that water depth is only one of several factors that may affect the spatial patterns of plants within sites. On the other hand, Silvertown [69] came to a different conclusion. He stated that the water depth in the reservoir did not affect the species composition of macrophytes.

4.3. *Oenanthe* sp., *Phragmites* sp., and *Typha* sp.

Pieper et al. [39] found that water depth cannot on its own explain patterns of macrophytes occupancy. They concluded that niche partitioning by water depth does not promote mating isolation in *Typha* sp. Previous findings of habitat segregation by depth may be attributable to a combination of distinctive features of individual sites, multi-dimensional niches, and phenotypic plasticity, preventing consistent niche segregation among *Typha* taxa. Our research confirms the conclusions of the studies by Pieper et al. [44]. Neither the changes in the depth of the studied ponds nor the changes in their surface area can be the only explanation for the macrophytes' occurrence patterns. Our research allows us to formulate a thesis that the macrophytes of the genus *Phragmites*, *Oenanthe*, and *Typha* increased the area occupied in the reservoirs in all years of study. The spatial distribution of *Typha* sp. may be driven by a combination of abiotic variables, which might include water depth, but not by water depth on its own [44]. Each *Typha* taxa exhibits plasticity in response to other environmental variables, including reproductive allocation and investment in nutrient acquisition in different habitat types, variation in height under different temperature/photoperiod combinations [12,44,70], and patterns variation of water-depth occupancy [63]. The results of our research confirm the above observations. Macrophytes of the genus *Oenanthe* and *Phragmites* and *Typha* are the plants with the broadest ecological spectrum. They are macrophytes that adapt very well to various environmental conditions. That is also confirmed by Vretare et al. [71] and Hanslin et al. [72]. They noted that *Phragmites* sp. exhibit plastic responses to water depth by allocating proportionally more biomass to leaves than roots and rhizomes and by producing fewer, taller ramets with increasing water depth.

5. Conclusions

1. The water of ponds in agricultural and horticultural areas was characterized by higher concentrations of K, TP PO_4^- , and NO_3^- . These reservoirs had a more frequent freezing condition, and the macrophyte coverage index was higher than in other ponds. Species of the genera *Ceratophyllum* and *Sparganium* dominated here. The water in ponds in industrial areas was warmer with a higher Mg concentration and pH value, and the dominant type was *Carex* sp. On the other hand, the city ponds were deeper, with more transparent water containing more Fe.
2. The regression analysis confirmed the disturbing tendency of area reduction and the shallowing of the studied ponds over time. These relationships were confirmed in seven ponds (of the eight tested) in the surface case and in all ponds in the depth case.
3. Most of the examined macrophytes genera (*Oenanthe*, *Phragmites*, and *Typha*) increased their surface area during the study, contributing to the pond's overgrowth. They could have indirectly contributed to the eutrophication process as well.

4. Some expansive macrophytes genera, e.g., *Oenanthe* sp., *Typha* sp., and *Phragmites* sp., may increase the surface area occupied in the ponds along with their shallowing—which may be caused by climate change (temperature rise).

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