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# Response of cyanobacteria and algae community from small water bodies to physicochemical parameters

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**Key words:** cyanobacteria and algae, biodiversity, natural and artificial water reservoirs, physicochemical properties, canonical analyses, Poland

**Abstract**

The article presents the research into the taxonomic diversity of cyanobacteria and algae, as well as the relationships between these organisms and the habitat conditions of certain water ecosystems varying in origin and location (both rural and urban reservoirs in the Lower Silesia region − Poland). Another issue addressed in the paper is the influence of ecological conditions and the origins of the reservoirs on the structure of phytoplankton. The RDA enabled to identify the most important biological parameters (the biodiversity of cyanobacteria and algae described using the Shannon-Weaver Index) and the physicochemical properties of the studied basins. The results distinguished four groups of basins (I – artificial basins within urban areas; II – old river-beds within urban areas; III – ponds in rural areas; IV – an old river-bed in forest areas). This distinction shows major relevance of the reservoirs' origins and their presence in the landscape. Additional PCA and RDA analyses of the studied basins have shown that the biological parameters are more efficient in diversifying the basins in respect of their origins than the physicochemical parameters.

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## INTRODUCTION

Small water basins (ponds, old river-beds and artificial water reservoirs) are a significant environmental factor and a vital part of the landscape, especially in the region of Lower Silesia, with one of the smallest numbers of water basins in Poland. These kinds of ecosystems are usually characterized by a large diversification of surfaces, the level of fertility and the depth of water and by their origin, e.g.: natural old river-beds, anthropogenic ponds and clay-pits or small artificial ponds created for numerous purposes. These ecosystems are numerous and, to a large extent, dispersed, and because they are diversified in various aspects, they are suitable as complete model ecological systems, which can be used for ecological research and for studies of biodiversity. The interest in these ecosystems, as compared to lake ecosystems, is still relatively low, not only in Poland (Céréghino et al. 2008, Kuczyńska-Kippen et al. 2009). For that reason, a lot is known about the diversity of plants and microorganisms, their biocenotic and trophic relations in micro- and macro-habitats (plankton, benthos and littoral) in large water ecosystems (among others Kawecka, Kwadrans 2000; Celewicz et al. 2001; Rakowska 2001; Bucka, Wilk-Woźniak 2002; Celewicz-Gołdyn 2006; Pełechaty et al. 2007; Burchardt et al. 2009).

The research conducted by Paczuska (2002), Oerteli et al. (2002), Kuczyńską-Kippen et al. (2009) shows clearly that small water basins are characterized by a big diversity as compared to the ecosystems of large lakes. These ecosystems create distinct ecological relations with the surrounding area, they play a significant hydrological, biocenotic, ecotonal role and are an important part in the conservation and preservation of biodiversity in large areas and in various types of landscapes (Hillbricht-

Ilkowska 1955, Kuczyńska-Kippen et al. 2009).

As opposed to our knowledge of previously studied macrophytes (rushes, aquatic plants attached to the bottom of the reservoir but with leaves floating on the surface and plants attached to the bottom and totally submerged), we still know little about cyanobacteria and algae. That area has been particularly understudied when it comes to water ecosystems located in large urban agglomerations and rural areas (Wołowski 1998; Hindák, Hindáková 2003).

The existing lack of knowledge motivated us to conduct phycological research in selected types of small water basins located in the area of Wrocław and nearby forest and rural areas.

Part of the studied reservoirs is located in Wrocław, which has been since the 19th century an interesting area for phycological research as it has many various natural and artificial water reservoirs (ponds, lakes, clay-pits, the Odra river and its old water bed) (Hilse 1865, 1866; Kirchner 1878; Cohn 1884; Schröder 1897). The research of authors mentioned was mostly connected with closed reservoirs and, sometimes, with the river Odra and its arms (Schröder 1899). However, that research is now incomplete and obsolete. After WWII the research on algae in the Wrocław area was continued by Gołowin 1957; Panek 1976; Panek, Burzyński 1985; Panek et al. 1990; Panek et al. 1991. The studies resumed after a ten-year break (Richter, Matuła 2003, 2004) are a continuation of the studies from the 19th century.

However, the detailed information about the taxonomic diversity of cyanobacteria and algae in relation to the habitat conditions in small water basins was still lacking.

The article presents the following research as the main concern:

1. The taxonomic diversity of cyanobacteria and algae, as well as the relationships between these organisms and the habitat conditions of certain water ecosystems varying in origin and location (both rural and urban reservoirs in the Lower Silesia region-Poland.
2. The influence of ecological conditions (reaction, color, oxidation, conductivity, $N\text{-}NO_3$, $N\text{-}NO_2$, $N\text{-}NH_4$, total nitrogen, organic nitrogen, $P\text{-}PO_4$, total phosphorus, organic phosphorus, $Mg^{2+}$, $K^+$, $Na^+$, $Fe^{2+}$, $Ca^+$, N/P) and the origins of the reservoirs on the structure of phytoplankton.
3. The aim of this research was also to indentify groups of physicochemical factors of water, which have the most significant influence on the ecological characteristics typical of a given group of basins (PCA and RDA).
4. Another objective of the research was to evaluate the suitability of biodiversity of cyanobacteria and algae defined by the Shannon-Weaver index for characterizing and differentiating the types of small water basins based on the example of basins in the Wrocław area.

The above-mentioned research enriched the existing knowledge of the algae in the Wrocław area.

## MATERIALS AND METHODS

### *Study area*

Phycological studies were conducted in Lower Silesia-Wrocław (Poland) on five reservoirs within the area of Wrocław (Kozanów, South Park, Botanic Garden, Nowowiejski Park, Szczytnicki Park) and three outside the city (Solniki Małe, Solniki Wielkie, Kotowice) (Fig. 1). The studied reservoirs are small (0.10 – 6.5 ha), closed, and of both natural and artificial origin. The reservoirs within the area of Wrocław are as follows:

1. a pond originating from the old river bed; significantly transformed; cleaned and deepened multiple times for recreational purposes; the pond banks are reinforced with stones and concrete (Nowowiejski Park 51°7'11.46"N, 17°3'16.87"E)
2. an artificial pond created using an existing natural depression, the banks are reinforced with stones (South Park 51°4'31.42"N, 17°0'40.76"E)
3. an artificial clay-pit pond created on a clay source used for building a dike; the banks are diversified – steep and smooth – reinforced with wooden piles (Kozanów 51°8'22.38"N, 16°58'37.70"E)
4. and 5. natural old river-beds (Szczytnicki Park 51°6'29.63"N, 17°5'19.15"E; Botanic Garden 51°6'56.96"N, 17°2'54.39"E)

The reservoirs in rural and forested areas are as follows:

6. a village pond formerly used as a reservoir for water drained from fields; today, for lack of water supply, it began to dry and became overgrown (mostly with *Typha latifolia* L.) – (Solniki Wielkie 51°9'49.45"N, 17°28'12.54"E)
7. a small pond located in a cultivated field with

crop rotation (Solniki Małe 51°8’33.48”N, 17°31’42.03”E)

8. an old river-bed situated in a surrounding of a forest growing on dry land and a marshy meadow (Kotowice 51°2’20.08”N, 17°12’30.43”E)

No vegetation was found in reservoirs no. 1 and 2; in the other reservoirs, the vegetation covered from 20% to 90% of the surface.

### *Samples collection*

The samples of algae were taken once a month, every other mouth; January, February and from April to October between 2001-2005 and 2008-2009.

Phytoplankton samples was collected using a 25 μm mesh plankton net. Five liters of water were poured through the net and then concentrated to 200 ml. Benthic algae were collected from a surface of 20 $cm^2$ (a couple of samples from every habitat). All

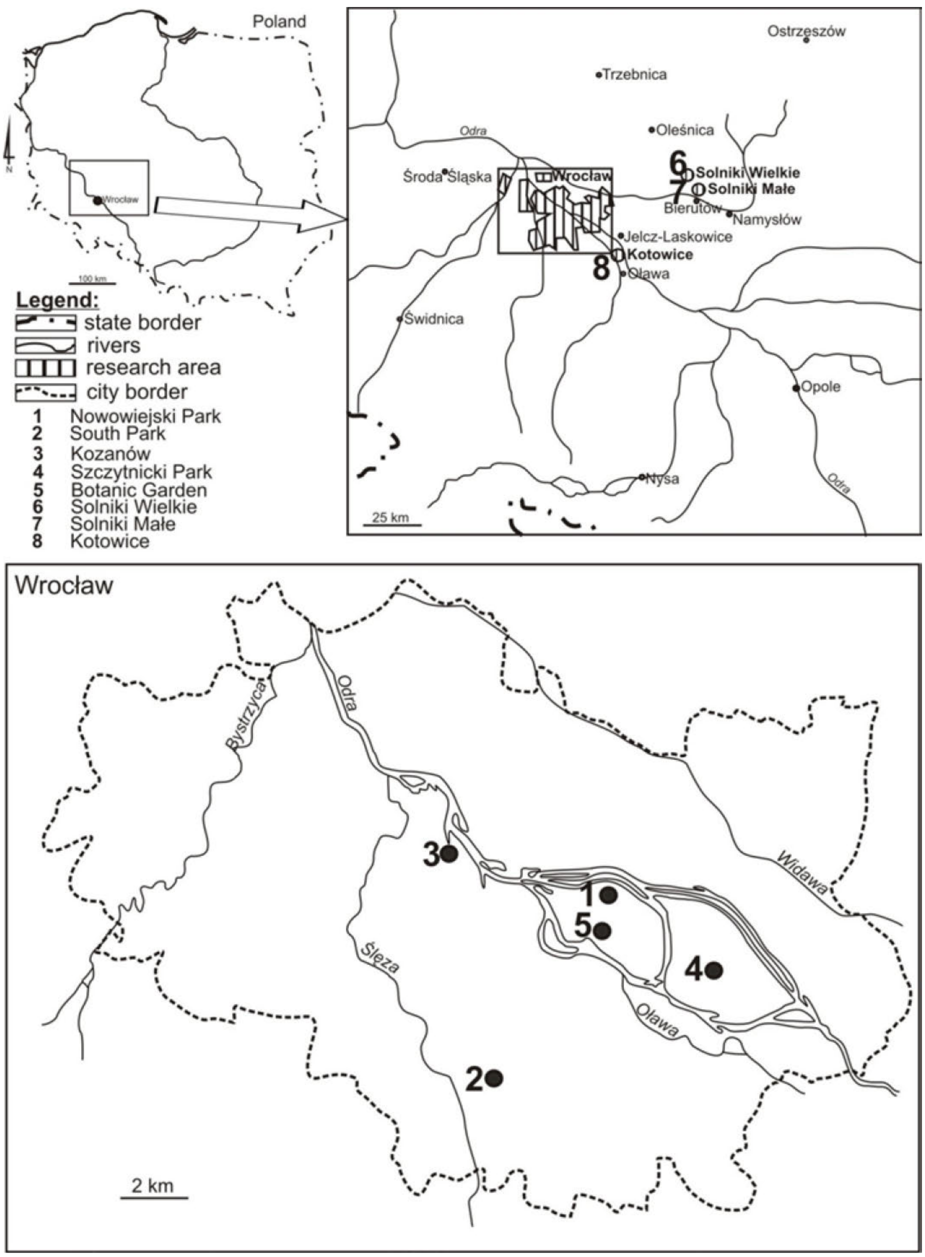


**Fig. 1.** The arrangement of towns with the studied water reservoirs in the Lower Silesia region, Poland. The map modified according to Kondracki (2002).

samples were collected using the same method, which was necessary for the comparison of water environments.

Also, a full physicochemical analysis was conducted on the water from the studied basins. Samples of water were collected in April and in October 2002 and 2004. The analysis was focused on the following parameters: pH, color (mg Pt $l^{-1}$), oxidability (mg $O_2$ $l^{-1}$), conductance (μS $cm^{-1}$); and the following elements: Ca (mg $l^{-1}$), Mg (mg $l^{-1}$), K (mg $l^{-1}$), Na (mg $l^{-1}$), Fe (mg $l^{-1}$). Also, the levels of total N (mg N $l^{-1}$), total P (mg P $l^{-1}$), organic N (mg N $l^{-1}$) and organic P (mg P $l^{-1}$) were determined.

Additionally, analyses of pH and conductivity were conducted between 2002 and 2005, and also between 2008 and 2009.

The taxonomy of algae is based on Hoek et al. (1995); Graham, Wilcox (2000). Cyanobacteria and algae were identified according to the following studies: Starmach (1966, 1968, 1972, 1989, 1980, 1983); Komàrek, Fott (1983); Komàrek, Anagnostidis (1999, 2005); Hindák (1980, 1984, 1988, 1990).

Cyanobacteria and algae communities were described using the following data: qualitative composition and Starmach's scale (Starmach 1955). The Shannon-Weaver Index was used to determine the variety of species (Kawecka, Eloranta 1994). The quantitativeness of particular taxa was determined under the microscope using Starmach's 6-grade scale (1955).

For chemical analyses, water samples were filtered through Millex - HV13, Sep - Pak PLUS CM and Sep- Pak C18 PLUS filters. Nitrates and phosphates were dtermined on a HPLC (Kalorymetr PhotoLab S12) ion chromatography, with the exception of organic nitrogen (PN-73 C-04576) and total phosphorus (PN-EN-ISO-11885). Ammonium was measured with the colorimetric method on a Braun+Luebbe no. II analyzer. The content of such elements as Ca, Mg, K, Na and Fe was measured with the ICP - AES method on a Varian (PN-EN-ISO 11885) spectrometer. The pH and conductivity were measured using PN-90/C-0440.01, oxygen concentration with (PN-EN-ISO 8467). Color was marked with the colorimetric method (Kalorymetr PhotoLab S12).

In order to create a model for data structuring and to determine the ordination technique, the DCA was conducted (Hill, Gauch 1980), which suggested the use of an ordination technique directly on the linear PCA (gradient analysis) data and RDA (redundancy analysis) data, which, consequently, enabled the study of relationships between the occurrence of species and the parameters of habitats.

A step-by-step selection of variables and Monte Carlo permutation test were conducted in order to confirm the statistical relevance of every environmental variable.

The statistical analyses were conducted with the *STATISTICA 5.1* Edition 98, CANOCO 4.5 software.

## RESULTS AND DISSCUSION

522 taxa of cyanobacteria and algae were identified in samples collected from eight water reservoirs, all belonging to five phyla: Cyanophyta (Cyanobacteria), Heterokontophyta, Euglenophyta, Chlorophyta and Dinophyta (Table 1). The research showed that the largest (in respect of the number and the quantitativeness of species) group in the studied reservoirs were Chlorophyta (green algae) and Heterokontophyta; each constituted over 35% of the identified species. Among Chlorophyta, the class Chlorophyceae was dominant, with over 26% of all species found. In this group, a relatively large number of species also belonged to the Zygnematophyceae class, whereas Charophyceae, Cladophoraceae and Ulvophyceae had a small share. Heterokontophyta were mainly represented by Bacillariophyceae (over 28%), whereas in the Xanthophyceae class, particular species were characterized by big quantity and formed water blooms in the studied reservoirs. The contribution of Cyanobacteria and Euglenophyta in the qualitative composition was similar (both constituted over 12% of all identified species).

**Table 1**

The number and proportion of the taxa of cyanobacteria and algae groups found in the researched water reservoirs.

| Division | Class | Genus | Species | Var. | f. | % |
|---|---|---|---|---|---|---|
| Cyanophyta (=Cyanobacteria) | Cyanophyceae | 27 | 77 | | | *14.75* |
| Heterokontophyta | Bacillariophyceae | 30 | 150 | 5 | 1 | *28.73* |
| | Chrysophyceae | 6 | 9 | 1 | | *1.72* |
| | Xanthophyceae | 10 | 35 | | | *6.70* |
| Euglenophyta | Euglenophyceae | 9 | 64 | 3 | 5 | *12.26* |
| Chlorophyta | Chlorophyceae | 44 | 140 | 10 | | *26.84* |
| | Ulvophyceae | 1 | 4 | | | *0.76* |
| | Zygnematophyceae | 8 | 37 | | | *7.10* |
| | Cladophorophyceae | 2 | 3 | | | *0.57* |
| | Charophyceae | 1 | 1 | | | *0.19* |
| Dinophyta | Dinophyceae | 2 | 2 | | | *0.38* |
| | **Total** | **140** | **522** | **19** | **6** | ***100*** |

Additionally, in the case of cyanobacteria, the species from this group quite often formed water blooms. Dinophyteae were represented by two species (Table 1).

The data concerning the origins of the reservoirs allowed a preliminary classification of the reservoirs into the following groups: artificial and semi-natural ponds; the old water bed within the city, artificial field and rural ponds, forest old water beds.

In order to estimate the significance of the selected biological factors and physicochemical properties of water in determining the types and grouping the reservoirs, PCA and RDA analyses were used. The results are presented in tables 4-6 and on the PCA and RDA ordination diagrams (Figures 2-4), which present the location of the studied reservoirs in the ordination space. The environmental and biological variables are shown as vectors. The physicochemical parameters of water in the reservoirs (Table 3) served as environmental variables, whereas the diversity of cyanobacteria and algae served as biological variables (Table 2).

The previous suggestion to group the reservoirs according to their origins was tested using PCA and RDA.

The PCA analysis with the data concerning the biodiversity of cyanobacteria and algae for particular water reservoirs confirmed the initial grouping of reservoirs (Fig. 2). However, the analysis of the physicochemical factors of water gave a spread of reservoirs less correlated with their origins (Fig. 3). This leads to the conclusion that the present chemical parameters of water in particular reservoirs were influenced by the anthropogenic pressure more than by the reservoirs' origin.

The comparison of diagrams clearly shows that phycoflora has a stronger relation with the origin of reservoirs than their chemical parameters. It is probably a result of the fact that the clusters of algae and cyanobacteria (their biodiversity) maintain their initial characteristics (adequate to the reservoirs' origins) longer than the physicochemical parameters, which are often and in different way modified by the anthropogenic influence, which alters the reservoir's

**Table 2**

The value of biodiversity index within the individual taxonomic groups of phycoflora in the studied water reservoirs. 1-8 – studied water reservoirs.

| | *Cyanobacteria* | *Bacillariophyceae* | *Chrysophyceae* | *Xanthophyceae* | *Euglenophyceae* | *Chlorophyceae* | *Ulvophyceae* | *Cladophorophyceae* | *Zygnematophyceae* | *Charophyceae* | *Dinophyceae* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.9774 | 1.8958 | 0.0219 | 0.0438 | 0.4894 | 1.5446 | 0.0438 | 0.0746 | 0.1755 | 0 | 0 |
| 2 | 0.7570 | 1.8082 | 0.0828 | 0.0828 | 0.1933 | 1.6887 | 0.0271 | 0.0765 | 0.3590 | 0 | 0.0276 |
| 3 | 0.8203 | 0.9176 | 0.0271 | 0.4344 | 0.5216 | 1.3864 | 0.0271 | 0.0271 | 0.8677 | 0 | 0 |
| 4 | 0.5195 | 1.5623 | 0.0352 | 0.2470 | 0.8842 | 1.1295 | 0.0352 | 0.0705 | 0.1764 | 0 | 0 |
| 5 | 0.4068 | 1.8190 | 0.1253 | 0.2944 | 0.7367 | 1.3661 | 0 | 0.0598 | 0.3259 | 0 | 0.0250 |
| 6 | 0.3948 | 0.8461 | 0.1128 | 0.8353 | 0.7333 | 0.8846 | 0.0564 | 0 | 0.2256 | 0 | 0.0564 |
| 7 | 0.6999 | 0.6499 | 0.0499 | 0.7613 | 0.7345 | 1.2345 | 0 | 0 | 0.1999 | 0.0499 | 0 |
| 8 | 0.9619 | 2.0072 | 0.0443 | 0.1772 | 0.6648 | 0.4432 | 0.0443 | 0 | 0.2216 | 0 | 0 |

**Table 3**

Mean values of the physicochemical properties of water in the studied reservoirs. 1-8 – studied water reservoirs.

| Variable | | Water reservoirs | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| reaction | pH | 8.85 | 7.40 | 7.15 | 7.60 | 7.55 | 7.50 | 7.10 | 7.10 |
| colour | (mg Pt $l^{-1}$) | 167.75 | 47.25 | 91.50 | 127.50 | 39.00 | 200.00 | 125.00 | 179.00 |
| oxidation ($COD_{Mn}$) | (mg $O_2$ $l^{-1}$) | 12.37 | 4.08 | 6.45 | 5.09 | 5.93 | 32.50 | 16.40 | 21.86 |
| conductance | (µS/cm) | 912.50 | 803.50 | 926.00 | 1180.00 | 832.50 | 1070.00 | 814.00 | 375.00 |
| $N\text{-}NO_3$ | (mg N $l^{-1}$) | 0.56 | 0.41 | 0.65 | 0.34 | 0.26 | 0.72 | 0.72 | 0.42 |
| $N\text{-}NO_2$ | (mg N $l^{-1}$) | 0.05 | 0.03 | 0.02 | 0.04 | 0.03 | 0.14 | 0.05 | 0.06 |
| $N\text{-}NH_4$ | (mg N $l^{-1}$) | 0.14 | 0.19 | 0.10 | 1.88 | 0.61 | 0.29 | 0.22 | 0.34 |
| total nitrogen | (mg N $l^{-1}$) | 7.25 | 4.00 | 7.50 | 5.57 | 5.75 | 3.50 | 3.00 | 4.75 |
| organic nitrogen | (mg N $l^{-1}$) | 6.51 | 3.40 | 6.73 | 3.29 | 4.86 | 2.50 | 2.10 | 3.96 |
| $P\text{-}PO_4$ | (mg P $l^{-1}$) | 0.39 | 0.22 | 0.12 | 0.41 | 0.66 | 2.63 | 0.63 | 0.43 |
| total phosphorus | (mg P $l^{-1}$) | 0.42 | 0.305 | 0.16 | 0.44 | 0.69 | 3.26 | 0.65 | 0.53 |
| organic phosphorus | (mg P $l^{-1}$) | 0.35 | 0.08 | 0.04 | 0.04 | 0.03 | 0.71 | 0.02 | 0.11 |
| N/P | | 17.3 | 13.3 | 47 | 12.7 | 8.2 | 1.04 | 4.6 | 9 |
| $Mg^{2+}$ | (mg $l^{-1}$) | 12.85 | 10.74 | 22.32 | 24.13 | 22.38 | 17.66 | 12.25 | 10.20 |
| $K^+$ | (mg $l^{-1}$) | 25.60 | 9.20 | 28.34 | 28.05 | 91.85 | 16.30 | 14.92 | 9.75 |
| $Na^+$ | (mg $l^{-1}$) | 66.11 | 44.97 | 68.10 | 71.02 | 38.86 | 47.24 | 77.73 | 35.45 |
| $Fe^{2+}$ | (mg $l^{-1}$) | 0.956 | 0.28 | 0.34 | 1.03 | 0.16 | 0.65 | 0.15 | 0.815 |
| $Ca^{2+}$ | (mg $l^{-1}$) | 92.72 | 54.26 | 85.65 | 122.55 | 125.80 | 110.10 | 39.79 | 64.42 |

**Table 4**

The summary of PCA analysis for the table of data concerning the diversity of cyanobacteria and algae in the studied water reservoirs.

| Axes | 1 | 2 | 3 | 4 | Total variance |
|---|---|---|---|---|---|
| Eigenvalues | 0.561 | 0.266 | 0.097 | 0.047 | 1.000 |
| Cumulative percentage variance of species data | 56.1 | 82.8 | 92.5 | 97.2 | |
| Sum of all eigenvalues | | | | | 1.000 |

**Table 5**

Summary of PCA analysis for the table of data concerning the physicochemical properties of water in the studied water reservoirs.

| Axes | 1 | 2 | 3 | 4 | Total variance |
|---|---|---|---|---|---|
| Eigenvalues | 0.912 | 0.062 | 0.018 | 0.004 | 1.000 |
| Cumulative percentage variance of environment data | 91.2 | 97.5 | 99.3 | 99.7 | |
| Sum of all eigenvalues | | | | | 1.000 |

**Table 6**

Summary of RDA analysis for the table of data concerning the biodiversity of cyanobacteria and algae, and the physicochemical properties of water in the studied water reservoirs.

| Axes | 1 | 2 | 3 | 4 | Total variance |
|---|---|---|---|---|---|
| Eigenvalues | 0.547 | 0.207 | 0.058 | 0.016 | 1.000 |
| Species-environment correlations | 0.968 | 0.923 | 0.861 | 0.518 | |
| Cumulative percentage variance | | | | | |
| of species data | 54.7 | 75.4 | 81.2 | 82.8 | |
| of species-environment relation | 66.0 | 91.1 | 98.1 | 100.0 | |
| | Sum of all eigenvalues | | | | 1.000 |
| | Sum of all canonical eigenvalues | | | | 0.828 |

initial characteristics.

This is particularly reflected in the RDA analysis, which reveals the positioning of the reservoirs in relation to the physicochemical and biological (biodiversity of particular cyanobacteria and algae) properties (Fig. 4). Such positioning of the studied reservoirs is mainly a result of the diversity between individual taxonomic groups affecting the phycoflora. The biological variables used in the RDA analysis explain as much as 82% of the total reservoir differences, whereas the ecological conditions only 17.2% (Table 6).

The analysis of redundancy, examined both the ecological conditions and the biodiversity of cyanobacteria and algae, shows that the phycoflora of the studied reservoirs displayed a specific relation

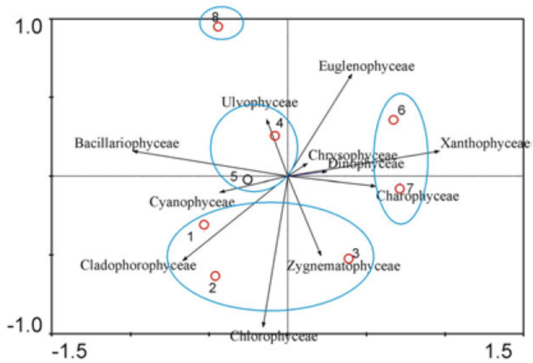


**Fig. 2.** The results of PCA analysis in the ordination space of the first and second PCA axis, describing the biodiversity of cyanobacteria and algae and their relation to the location of the studied water reservoirs (no. 1-8). Circles show selected groups.

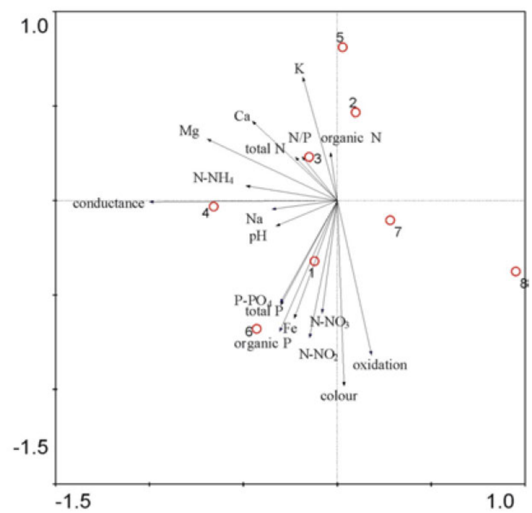


**Fig. 3.** The results of PCA analysis in the ordination space of the first and second PCA axis, describing the physicochemical properties and their relation to the location of the studied water reservoirs (no. 1-8).

with the chemical parameters of water, which is, influenced by human activity. The RDA diagram (Fig. 4) shows this type of relationships. Among the studied ecological factors, pH, nitrogen, particularly organic nitrogen, were negatively correlated with the biodiversity of the following groups: Chlorophyta (Chlorophyceae, Ulvophyceae, Cladophorophyceae) and Cyanophyceae. Higher concentrations of nitrogen caused an intensive development of individual species within the Cyanophyceae group, which led to the development of water blooms (*Microcystis*) Higher concentration of nitrogen may

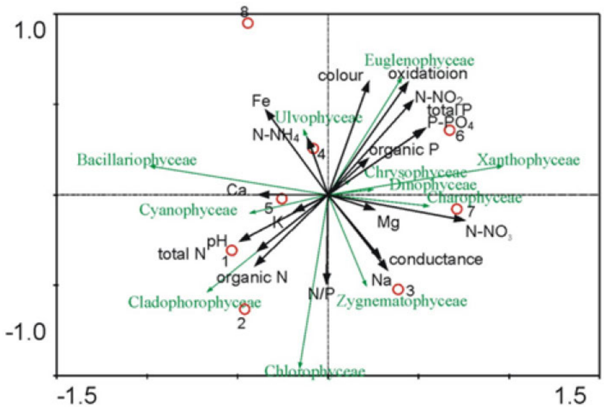


**Fig 4.** The results of the redundancy analysis in the ordination space of the first and second RDA axis, describing the biodiversity of cyanobacteria and algae and the physicochemical properties and their relation to the location of the studied water reservoirs (no. 1-8).

also resulted in high diversity of Chlorophyceae. The excessive supply of nutrients (nitrogen, phosphorus) from the outside, which resulted in the growth of algae biomass (especially cyanobacteria), was also the subject of papers by Bernal-Brooks et al. 2002; Zippel 1996; Nõges T., Nõges P. 1999; Kleeberg 2003. The high values of conductivity, N-$NO_3$ and the N/P ratio determined the quantitative dominance of the Zygnematophyceae group in the community. The intensive development of individual species from this group also led to the emergence of water blooms. The conditions also supported the existence of a large number of Chlorophyceae species. Skowroński et al. (2002) believes that the occurrence of filamentous green algae is characteristic of water reservoirs with high concentrations of nutrients. Previous works on the subject also suggest that these elements are conducive to the occurrence of coccal types of green-algae (Burchardt et al. 2003). Physicochemical factors, such as total phosphorus (phosphate phosphorus and organic phosphorus) and nitrogen N-$NO_3$ were positively correlated with biological diversity of the Xantophyceae group. It leads to the conclusion that the overall concentration of phosphorus and the concentration of N-$NO_3$ nitrogen created conditions favorable for the occurrence of Xantophyceae group, whose individual species formed water blooms (*Tribonema).* According to Round (1984), even a small increase in the content of sewage in a water reservoir may cause a growth of *Tribonema* and, sometimes, its dominance. Ammonia nitrogen, N-$NO_3$, color and oxygen concentration were negatively (N-$NO_3$) and positively (other factors) correlated with the biodiversity of the Euglenophyceae class. High concentration of N-$NH_4$ and N-$NO_2$ and a high value of color and oxygen concentration created suitable conditions for the growth of species representing the Euglenophyceae class. Euglenoids are placed on the lists of saprobes, which serve as a means to evaluate the pollution of water with organic substances, because their mass growth is an indication of their eutrophication (Wołowski 1998, 2003). A larger amount of euglenoids also indicates pollution of these reservoirs, polluted reservoirs with large quantities of nutrients which support the growth of *Euglena* species (Wołowski 1988, 2003). Ordination analyses (RDA and PCA) allowed to determine the most important biological factors, which influenced the position of the studied reservoirs in the ordination space. Both analyses gave exactly the same groups of water reservoirs in relation to biological factors. The results are presented in PCA and RDA ordination diagrams (Fig. 2 and 4).

Among the biological factors that influenced the grouping of the studied reservoirs in the ordination space (the highest correlation between the biological variables and the location of the reservoir) are Bacillariophyceae and Xantophyceae, which account for the first factor. The vector negatively correlated with the first axis was created diatoms (-0.9817). In the case of the second axis, Chlorophyceae and Euglenophceae (the second factor) showed the highest correlation (-0.9551, 0.6470). Chlorophyceae were negatively and Euglenophyceae positively correlated in relation to the second axis. Along the third axis the highest correlation is displayed by Cyanobacteria and Chrysophyceae (the third factor). Zygnematophyceae, Charophyceae, Ulvophyceae, Cladophoraceae and Dinophyceae had the smallest influence on the location of the studied objects in the ordination space.

Four groups of reservoirs emerged from the above-mentioned data. Their similarities are visible both in the PCA analysis, which used biological factors (Fig. 2), and the RDA analysis, which included both the biodiversity of particular groups of cyanobacteria and algae, and the physicochemical properties (Fig. 4).

In both cases phytoplankton in water reservoirs from the first group (reservoirs 1-3) had blue-green and green algae, which shows that these groups had the biggest influence on the phycoflora of this group.

This, however, proves that the similarity between the reservoirs was mostly caused by Chlorophyceae and Cyanophyceae (negatively correlated with the first axis), but also Euglenophyceae (correlated positively), which mainly influenced the reservoirs with the highest biodiversity.

The Zygnematophyeae class separated reservoir 3 because of its higher biodiversity in comparison to reservoirs 1 and 2, which, in turn, explains the occurrence of water blooms with species belonging to this class: *Mougeotia* sp. (dominant) and the sub-dominant *Spirogyra* sp., *Oedogonium* sp., *Microspora tumidula* Hazen, *Microspora stagnorum* (Kützing) Legerheim. Water with high concentration of biogenes has numerous species of *Mougeotia* and *Spirogyra* genera (Skowroński et al. 2002). What is more, *Oedogonium* species create wool-like clusters on the surface of water (especially in spring and summer) (Wołowski 2003). The clay-pit had a big variety of desmids, among which the following species were observed: *Closterium ehrenbergii* Menegh. ex Ralfs. *Closterium leibleinii* Kütz. ex Ralfs, *Closterium moniliferum* (Bory) Ehrenb. ex Ralfs, *Closterium parvulum* Neli, *Cosmarium formosulum* Hoff in Nordstedt, *Cosmarium meneghinii* Bréb. in Ralfs, *Cosmarium pyramidatum* Bréb. in Ralfs, *Cosmarium pygmaeum* Arche, *Staurastrum sebaldii* Reinsch var. *ornatum*, *Staurastrum sebaldii* Reinsch var. *sebaldii*.

In the studied reservoirs, desmids were mainly represented by *Cosmarium*, *Closterium* and *Stauroastrum*, which, according to Coesel (1983), occur in fertile habitats. Pond 1, however, was characterized by the highest biodiversity in the Cyanophyceae group, which manifested itself with long-term water blooms caused by plankton blue-green algae: *Microcystis aeruginosa* (Kützing) Kützing (dominant) and sub-dominant: *Microcystis wesenbergii* (Komárek) Komárek in Kondrateva, *Microcystis novacekii* (Komárek) Compére, *Pseudoanabaena galeata* Böcher, *Anabaena oscillarioides* Bory. *Microcystis aeruginosa* (Kützing) Kützing is a species typical of eutrophic reservoirs (Komárek, Anagnostidis 1999). Water blooms formed by *Pseudoanabaena galeata* Böcher were found in the studied water reservoir apart from the coccal types of cyanobacteria. The blooms of filamentous cyanobacteria are usually a symptom of advanced eutrophication (Ravera, Vollenweider 1968; Wołowski et al. 1990). Reservoir number 2 had the highest diversity of species of Chlorophyta. The green-algae in this pond were mainly represented by species from the Chlorophyceae class, among others: *Golenkinia radiata* Chod., *Pediastrum boryanum* (Turp.) Menegh., *Pediastrum duplex* Meyen, *Scenedesmus acuminatus* (Lagerh.) Chod., *Scenedesmus magnus* Meyen., *Tetraedron minimum* (A.Br.) Hansg. The *Pediastrum* genus is ecologically and taxonomically known from many freshwater reservoirs (Komárek, Fott 1983; Komárek, Jankovská 2001; Burchardt et al. 2003; Pasztaleniec, Poniewozik 2004).

The analysis of phycoflora in old water beds from group 2 (no. 4-5) revealed that the classes of Bacillariophyceae and Xantophyceae were the most important determiners of their similarity. These reservoirs had a high biodiversity in relation to diatoms, and, at the same time, relatively low in relation to Xantophyceae. The reservoirs in this group were also distinguished by euglenoids, whose biodiversity was high in the reservoirs. Among others, the following species belonging to this class were found in the reservoirs: *Lepocinclis acus* (O. F. Müller) Marin et Malkonian, *Lepocinclis oxyuris* (Schmarda) Marin et Malkonian, *Euglena proxima* Dangeard, *Phacus orbicularis* Hübner, *Phacus pleuronectes* (Ehrenberg) Dujardin, *Strombomonas acuminata* (Schmarda) Deflandre, *Strombomonas fluviatilis* (Lemmerman) Deflandre. However, biodiversity of Cyanobacteria was at the same level in both reservoirs, which also points to the similarity between them.

The first factor, represented by the groups of Xantophyceae and Bacillariophyceae, significantly influenced the similarity between reservoirs from group 3 (6 and 7). First of all, the Xantophyceae group had high biodiversity, whereas the biodiversity of diatoms was the lowest in rural reservoirs. The Xantophyceae species also had greater quantitativeness in both reservoirs and, additionally, created blooms in one of the reservoirs belonging to group 6. The bloom was also caused by *Tribonema vulgare* Pascher (dominant), *Ophiocytium bicuspidatum* Lemmermann, *Ophiocytium maius* Nägali, *Tribonema aequale* Pascher, *Tribonema elegans* Pascher, *Tribonema minus* Hazen, *Tribonema viride* Pascher. Starmach's research (1968) proves that *Ophiocytium parvulum* A. Braun is characteristic of reservoirs that are strongly polluted.

Factor two also had an important influence on the rural reservoirs, especially the Euglenophyta phylum, whose biodiversity in these reservoirs was at a similar level. The following species from that group were observed: *Lepocinclis acus* (O. F. Müller) Marin et Malkonian, *Euglena anabaena* Main, *Euglena clavata* Skuja, *Euglena pisciformis* Klebs, *Lepocinclis ovum* (Ehrenberg) Minkiewič, *Phacus orbicularis* Hübner, *Phacus pleuronectes* (Ehrenberg) Dujardin, *Euglena clavata* Skuja, *Euglena pisciformis* Klebs. The Chlorophyceae class and the third factor (the biodiversity of Cyanobacteria and Chrysophyceae) did not play a significant role in the case of these reservoirs. Reservoir 7, however, had one Charophyceae species, which significantly influenced the position of this reservoir in the ordination diagram. These reservoirs were characterized by the greatest influence of pollution on cyanobacteria and algae communities. The number of taxa was the lowest in the case of these reservoirs, however, the increase of nutrients led to the emergence of strong water blooms of certain species creating big biomass (pond 6).

The first factor was particularly relevant in distinguishing group 4 (old river bed 8). This group had the highest biodiversity in relation to diatoms (in comparison with other groups) and relatively low in relation to Xantophyceae. Factor two, with the classes of Chlorophyceae and Euglenophyceae, was also relevant to the position of this group in the ordination diagram. This old water bed had the lowest ratio of biodiversity to Chlorophyceae and a high ratio of biodiversity to Euglenophyceae, which was represented by the following species: *Lepocinclis acus* (O. F. Müller) Marin et Malkonian, *Euglena agilis* Carter, *Euglena viridis* Ehrenberg, *Lepocinclis ovum* (Ehrenberg) Minkiewič, *Phacus acuminatus* Stokes, *Phacus caudatus* Hübner, *Phacus longicauda* (Ehrenberg) Dujardin, *Phacus orbicularis* Hübner, *Phacus pleuronectes* (Ehrenberg) Dujardin, *Trachelomonas hispida* (Perty) Stein var. *hispida, Trachelomonas oblonga* Lemmermann, *Trachelomonas radiosa* Fritsch, *Trachelomonas rotunda* Swirenko, *Trachelomonas zorensis* Lefèvre. Cyanophyceae, with a high value of the Shannona-Weavera Index, played an important role in distinguishing this reservoir from the others. The species of this group were high in numbers, but were characterized by small quantitativeness. Among Cyanophycaea, the following species were observed: *Anabaena flos-aqua* Brébisson ex Bornet et Flahault, *Anabaena solitaria* Klebann, *Aphanocapsa incerta* (Lemmermann) Cronberg et Komárek, *Aphanothece stagnina* (Sprengel) Braun in Rabenhorst, *Chroococcus limneticus* Lemmermann, *Chroococcus turgidus* (Kützing) Nägeli, *Lyngbya limnetica* Lemmermann, *Merismopedia tenuissima* Lemmermann, *Oscillatoria limnosa* Agardh., *Oscillatoria mougeotii* (Kützing) Forti, *Oscillatoria planctonica* Wołoszyńska, *Oscillatoria tenuis* Agardh., *Woronichinia naegeliana* (Unger) Elenkin, *Woronichinia compacta* (Lemmermann) Komárek et Hindák, *Synechocystis salina* Wislouch.

PCA (analysis of physicochemical properties) and RDA (analysis of biological and physicochemical properties) placed the studied water reservoirs in a different ordination space (Fig. 3 and 4).

The distinguished groups of factors indicate a certain similarity, whereas the importance of particular groups in the ordination space and their impact on the groups in the ordination space differs.

Among the physicochemical factors in the RDA analysis, the changeability was reflected in pH, N-$NO_3$,, organic nitrogen and total phosphorus (including P-$PO_4$ and organic phosphorus), which constitute factor one (the highest correlation between environmental variables and the location of individual reservoirs in the ordination space). In the case of axis two, the highest correlation was evident in such physicochemical properties, as color, oxygen concentration, N-$NO_2$, the ratio between nitrogen and phosphorus, and iron (components of factor two). The PCA analysis showed the highest correlation between environmental variables and the location of water reservoirs for pH, conductance, N-$NH_4$, Ca, Mg, Na (axis one); color, oxidation, N-$NO_2$, N-$NO_3$, P-$PO_4$, total P, organic P, Fe (axis two); and K (axis three). The positioning of the studied water reservoirs was mostly influenced by the data correlated with axis one and two. The highlighted factors clearly influenced the positioning of individual reservoirs against ordination axis 1 and 2 (Fig. 3 and 4).

## CONCLUSION

PCA and RDA analyses determined the suitability of the biological parameter (biodiversity of cyanobacteria and algae described using the Shannon-Weaver Index) and the physicochemical properties of water in characterizing and differentiating small water basins based on the example of those found in the Wrocław area.

The four following types of basins were studied:

I – artificial basins in urban areas;
II – old river-beds in urban areas;
III – ponds in rural areas;
IV – old river-beds in forest areas.

PCA and RDA led to the conclusion that it is the biological parameter which is the most significant for the position of basins in the ordination space and for their division into groups. The aforementioned division is, to a large extent, relevant to the basins' origin and the landscape of their surroundings. The most important biological parameters are as follows: biodiversity of Bacillariophyceae and Xantophyceae groups, which is the first factor with over 54% of variability both in PCA and RDA (Tables 4 and 6); and the second factor, characterized by the biodiversity of Chlorophycae and Euglenophyceae, with over 20% variability in both analyses (Tables 4 and 6).

PCA of physicochemical properties of water from the studied basins was focused on such factors as pH, conductivity, $N-NH_4$, Ca, Mg, Na (the first factor, with 91.2 variability, Table 5), as well as color of water, oxygen concentration, $N-NO_2$, $N-NO_3$, P – total, P – organic, Fe (the second factor with 6.3%, Table 5). Meanwhile, RDA in the first factor included pH, $N-NO_3$, N-organic, $P-PO_4$, P-total, P-organic, (the first factor – 11.3% variability, Table 6) and $N-NO_2$, N/P, Fe, oxygen concentration, color (the second factor – 4.4% variability). The highlighted groups of physicochemical properties of water (factor 1 and 2) show similarities in both PCA and RDA, but their significance in the diversification and shaping of the ecological conditions of the studied basins varies.

The analyses lead to the conclusion that the physicochemical properties of water, despite being of lesser significance in the diversification of basins, significantly influence the ecological conditions, the taxonomic composition and the biodiversity of cyanobacteria and algae in the studied water ecosystems.

It is, therefore, safe to conclude that since algae clusters react more slowly to the anthropogenic pressure and the varying physicochemical properties of water, they can be successfully used to describe the initial characteristics of water basins after longer periods of time. And thus, one can conclude that biodiversity is a good indicator of the origins of small water basins.

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