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Abundance, biomass and community structure of pond phytoplankton related to the catchment characteristics

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Abstract – Studies were conducted in 2010 on phytoplankton assemblages in ponds in North-East Poland with catchment areas in village environments, mid-forest, mid-meadow and mid-field settings. Differences in phytoplankton abundance, biomass and structure and the environmental requirements of dominant species were assessed in the studied ponds. These features were related to variable physicochemical water parameters and nutrient presence; with the highest phytoplankton abundance and biomass dominated by chlorophytes and diatoms in the village ponds and the greatest diversity of species' assemblages recorded in the mid-forest and mid-field ponds. In addition, CCA analysis of general trends in phytoplankton growth determined that NH_4 and TN enhanced growth in the mid-meadow and mid-field ponds, and P-PO_4 and pH influenced growth in the mid-forest pond. The relationships established in this study between phytoplankton and environmental conditions can directly influence future directions in small water-body conservation.

Keywords: phytoplankton / ponds / catchment character / nutrients / CCA

Résumé – Abondance, biomasse et structure communautaire du phytoplancton de mares de différents bassins versants. Les études ont été menées en 2010 sur des assemblages de phytoplancton dans des mares dans le nord-est de la Pologne avec des bassins versants en milieu villageois, forestier, prairial et cultivé. Des différences dans l'abondance, la biomasse et la structure du phytoplancton et les exigences environnementales des espèces dominantes ont été évaluées dans les mares étudiées. Ces caractéristiques étaient liées aux paramètres physicochimiques variables de l'eau et à la présence de nutriments; avec la plus grande abondance et biomasse de phytoplancton dominée par les chlorophytes et les diatomées dans les mares du village et la plus grande diversité d'assemblages d'espèces enregistrés dans les mares du milieu forestier et cultivé. En outre, l'analyse CCA des tendances générales de la croissance du phytoplancton a déterminé que la croissance accrue par NH4 et TN dans les mares prairiale et en champ cultivé, et que le P-PO4 et le pH ont influencé la croissance dans la mare forestière. Les relations établies dans cette étude entre le phytoplancton et les conditions environnementales peuvent influencer directement les orientations futures dans la conservation des petites mares.

Mots-clés : phytoplancton / étang / bassin versant / nutriment / CCA

1 Introduction

While biodiversity is mainly directed to nature protection areas under European Union guidelines, especially in Nature 2000 sites and reserves (Directive 92/43/EEC), ponds are very important because they contribute to increase of national aquatic biodiversity and catchment functions. Ponds also create links between existing aquatic habitats and provide ecosystem services such as nutrient interception, hydrological regulation and natural scenery enrichment (Carvalho *et al.*, 1995; Biggs *et al.*, 2005; Lombardo, 2005; Gligora *et al.*, 2007; Céréghino *et al.*, 2008a,b, 2014). Pond surface water quality is largely dependent on different land use in agriculture and village life and consequent catchment environments. These small water bodies differ greatly in origin and in morphological conditions such as surface area, depth and volume, and natural and anthropogenically altered ponds experience different precipitation, insolation, water temperature and catchment nutrient inflow. This great variability therefore contributes to forming different habitats and increasing organism species diversity (Wiliams *et al.*, 2008).

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Phytoplankton with different environmental requirements profit from changes in water physicochemical parameters and their assemblages therefore differ. While phytoplankton are critical to the pond food chain, providing food for the multiplicity of animals, fish and invertebrates, they occasionally form blooms (Celewicz-Gołdyn *et al.*, 2008). Phillips *et al.* (2008) and Teissier *et al.* (2012) also consider that nutrients are the main determinants of phytoplankton biomass levels in lakes and ponds.

The hypothesis asserts that pond catchment character affects the physicochemical water parameters and subsequent development and differentiation of phytoplankton assemblages. The purpose of this study was to determine the differences in phytoplankton abundance, biomass, structure, species diversity and environmental requirements of dominant species related to the physicochemical water parameters in village, mid-meadow, mid-field and mid-forest pond catchment areas.

2 Materials and methods

2.1 Study area

The phytoplankton study concentrated on ponds; small water bodies located in the Jonkowo village adjacent to Warmińskie Buczyny Nature 2000 sites and Kamienna Góra reserve in the Warmia Mazury Region of North-East Poland. The study area has 8 ponds with different catchment character: 2 in each of the village (VIP), mid-meadow (MEP), mid-forest (FRP) and mid-field (FLP) environments (Fig. 1).

– *VIPs*: The 3000 and 400 m^2 Węgajty village ponds have 1.5 m maximum depth and the urbanized catchment areas (100%) close to a major road promote polluted inflow to the ponds. The pond banks are overgrown by macrophytes; dominated by *Typha latifolia* L. One pond is connected to fish ponds, and while one bank of the second pond has underground outflow with a surplus of spring waters flowing towards the village centre, the remaining banks are clay and sandy and the bottom of the pond is muddy.
– *MEPs*: The 80 and 50 m^2 mid-meadow ponds are natural small water bodies with maximum 0.5 and 0.8 m depths, have muddy bottoms and are surrounded by meadows (68%) and pastures (32%). They contain the following macrophytes: *Myriophyllum spicatum* L., *Acorus calamus* L., *Iris pseudacorus* L., *Spirodela polyrhiza* (L.) Schleid. and *Lemna minor* L.
– *FRPs*: The mid-forest ponds have natural character with 2000 m^2 and 1.5 ha areas at 1.5 and 1 m maximum depth, respectively. The first pond is based on peat and surrounded by coniferous forest, while the second lies in mixed forest near the Buczyny Warmińskie Nature 2000 sites. These ponds have 100% forest catchment areas. They contain the *Ricciocarpos natans* L. macrophyte characteristic of static acidic waters and peat pits, and also *Spirodela polyrhiza* (L.) Schleid., *Lemna minor* L., *Calla palustris* L., *Iris pseudacorus* L. and *Menyanthes trifolia* L.
– *FLPs*: The two mid-field ponds are small water bodies with 7 and 200 m^2 area and maximum 0.5 m depth. They have approximately 70% agricultural and 30% pasture catchment areas and form water-holes for cattle and horses. The first pond is overgrown by *Typha latifolia* L., *Eriophorum vaginatum* L., *Lemna minor* L., *Lemna trisulca* L. and *Polygonum amphibium* L., and the second by *Acorus calamus* L., *Phragmites australis* (Cav.) Trin. Ex Steud, *Spirodela polyrhiza* (L.) Schleid. and *Lemna minor* L.

2.2 Materials and methods

Phytoplankton samples were collected at the same time in three seasons (April, July and October) in 2010 at 8 ponds of different catchments: village (VIP), mid-meadow (MEP), mid-forest (FRP) and mid-fields (FLP) ponds. The samples were taken from euphotic zone of the surface open water with a 10 L calibrated bucket (20 L at each site), sieved through a plankton net no. 25 and preserved with a Lugol's solution and then with a 4% formaldehyde solution. In total, 24 phytoplankton samples were tested. The following physicochemical properties were measured directly at the phytoplankton sampling sites: water temperature with 0.1 °C precision and oxygen content exact to 0.01 mg O_2 L^{-1} (HI 9143 oxygen meter), and pH and electrolytic conductivity at 1–1500 $\mu S\ cm^{-1}$ (CONMET 1).

The following groups of phytoplankton, were analyzed in this study; cyanobacteria, diatoms, chlorophytes, dinoflagellates, chrysophytes, and cryptomonads. Qualitative and quantitative determinations of phytoplankton were performed with an Alphaphot YS2 optical microscope at magnifications of 100×, 200×, 400× and 1000×. Numbers in 1 mL samples of phytoplankton were determined in 5000 fields of vision with 200× magnification in each planktonic chamber to account for differences in organism densities and their abundance and biomass expressed in identical basic 1 mL volumes. Diatoms were prepared following the standard method in Battarbee (1979). Algal biomass for 10 individuals was calculated by comparing algae with their geometric shape (Rott, 1981). The scope of water analysis in the laboratory included: orthophosphates P-PO_4, TN and N-NH_4 concentrations using Spectroquant Merck tests with NOVA 400 spectrophotometer.

2.3 Statistical analysis

In the analysis, means were applied as the average values of phytoplankton abundance or biomass from the three months (April, July and October) separately in each from 8 studied ponds in 2010. The mean values of water physicochemical properties were calculated in the same way. The standard deviations were also calculated. In addition, the chi^2-square test was used for comparing the differences in phytoplankton community structure. The species diversity for phytoplankton abundance was analyzed to calculate the Shannon–Wiener index (Shannon and Weaver, 1949; Maurer and McGill, 2011). The modified *t*-test (Hutcheson, 1970) was used to statistically comparison of the species diversity.

Total algal abundance and biomass, and abundance of taxonomic groups and dominant species were correlated with physical and chemical water parameters using non-parametric methods because these data are not normally distributed (test Shapiro-Wilk, STATISTICA version 10). To reduce the

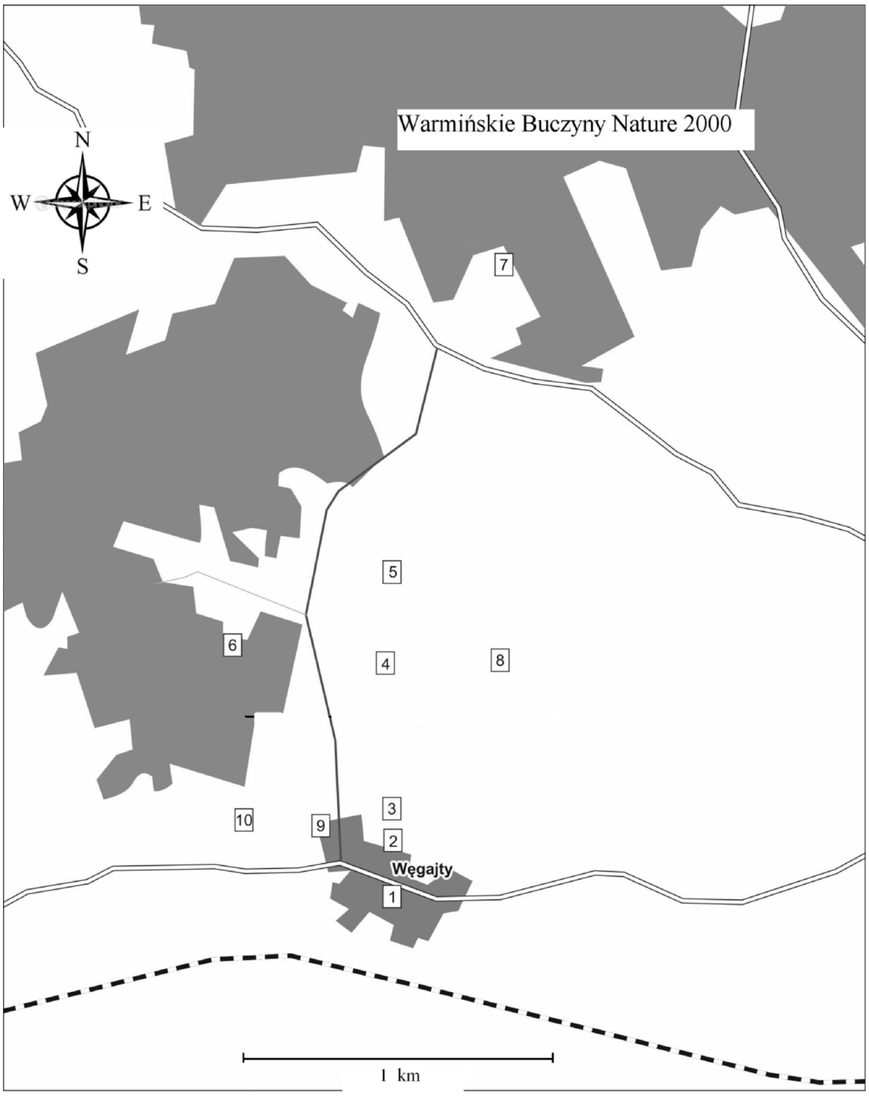

Fig. 1. Map of pond localization: 1, 9 – village (VLP), 4, 5 – mid-meadow (MEP), 6, 7 – mid-forest (FRP) and 8, 10 – mid-fields (FLP) ponds, N-E Poland. Black bar is distance reference of 1 km.

number of variables a forward selection procedure using the Monte Carlo test with 999 permutations. Relationships were confirmed by calculating Spearman's rank correlation coefficient (significance at $p < 0.05$) with STATISTICA version 10. A canonical correspondence analysis CCA was performed to relate water chemistry variables to phytoplankton abundance and biomass, phytoplankton groups and dominant species. Finally, these relationships were presented on a biplots graph using Canoco for Windows 4.5 software.

3 Results

3.1 Physicochemical water parameters

The study recorded the following differences in the physicochemical properties (Tab. 1):

- the lowest water temperature and oxygenation, and the highest conductivity (466 $\mu S\,cm^{-1}$) and orthophosphates (2.22 $mg\,PO_4\,L^{-1}$) in mid-meadow ponds (MEP);
- the lowest N-NH_4 and TN, and the highest water temperature of 18.8 °C and pH of 8.29 in village ponds (VLP);
- the highest oxygen content of 7.35 $mg\,O_2\,L^{-1}$ and the lowest conductivity of in mid-forest ponds (FRP);
- the lowest pH and P-PO_4, and the highest N-NH_4 (0.22 $mg\,L^{-1}$) and TN (1.5 $mg\,L^{-1}$) in mid-field ponds (FLP).

3.2 Differentiation of phytoplankton abundance and biomass

The lowest mean abundance and biomass was found in MEP (2672 ind. mL^{-1} and 0.02 $mg\,mL^{-1}$) and the highest abundance in VLP (17 166 ind. mL^{-1}) and biomass in FRP (0.16 $mg\,mL^{-1}$) (Fig. 2).

The chi^2-square tests exhibited significance level at 0.001 indicating significantly differences between community structure of phytoplankton abundance (174.1, $p < 0.0001$) and biomass (170.71, $p < 0.0001$). Phytoplankton abundance

Table 1. Physicochemical water parameters (mean ± standard deviations) in village (VLP), mid-meadow (MEP), mid-forest (FRP) and mid-fields (FLP) ponds in 2010.

Water parameters	VLP	MEP	FRP	FLP
Water temperature (°C)	18.8 ± 7.0	15.3 ± 2.1	17.3 ± 2.8	17.1 ± 5.6
Oxygen content (mg O_2 L^{-1})	3.27 ± 2.17	1.40 ± 0.09	7.35 ± 4.71	5.03 ± 3.90
pH	8.29 ± 0.30	7.94 ± 0.03	8.18 ± 0.52	7.29 ± 1.19
Conductivity (nS cm^{-1})	432 ± 153	466 ± 51	147 ± 106	194 ± 117
Ammonium (mg NH_4 mL^{-1})	0.17 ± 0.03	0.21 ± 0.03	0.20 ± 0.12	0.22 ± 0.19
Total nitrogen (mg N mL^{-1})	1.0 ± 1.2	1.1 ± 1.4	1.0 ± 1.6	1.5 ± 1.4
Orthophosphates (mg PO_4 L^{-1})	1.40 ± 1.02	2.29 ± 0.20	1.46 ± 1.33	0.18 ± 0.01

was dominated by chlorophytes in VLP and FLP (78.9% and 55.0%, respectively) and diatoms in the remaining ponds, MEP – 55.4% and FRP – 45.6%, while dinoflagellates in MEP and euglenins in FRP reached a significant proportion of total phytoplankton abundance. Cyanobacteria had the low 4.3% abundance in FLP. In the case of phytoplankton biomass, chlorophyte share amounted to 85.3% in FRP and diatom share amounted to 78.9% in MEP. Other algal groups contributed in less than 10.0% of the phytoplankton biomass (Fig. 3).

3.3 Phytoplankton diversity and dominant species

The highest Shannon–Wiener species diversity index was recorded for phytoplankton in FLP at 4.86 bit $ind.^{-1}$ and the lowest in VLP at 2.49 bit $ind.^{-1}$ at 60 and 96 taxa, respectively (Tab. 2). The *t*-tests were significant at 0.001 indicating differences between VLP and MEP, VLP and FRP, VLP and FLP, MEP and FRP but not between MEP and FRP ($p = 0.6250$, Tab. 3).

The Euclidean diagram demonstrated that the greatest similarity in species composition is shown by the smallest distance between algae in FLP and FRP, and the least similarity was between algae in FLP and VLP (Fig. 4). CCA analysis also highlights the greatest similarity between phytoplankton in MEP and FLP and the most difference in FRP.

These phytoplankton assemblages were dominated by chlorophytes and diatoms (Fig. 3). Cyanobacteria were represented by *Aphanizomenon gracile* and chlorophytes by the genera *Chlamydomonas* sp. in all ponds, and *Spirogyra* sp. (FRP), *Closterium cynthia* (FRP, FLP), *Closterium echrenbergii* (MEP, FLP), *Pediastrum duplex* and *Monoraphidium concortum* (VLP), *Ulothrix tenuissima* (MEP) and *Pediastrum boryanum* species (FLP). Diatoms were represented by *Pinnularia* sp. and *Fragilaria capucina* (MEP) and *Diatoma vulgaris var. linearis* (FRP) and *Diatoma vulgaris* (VLP, FLP), euglenins by *Euglena viridis* and *Euglena acus*, cryptomonads by *Cryptomonas* sp. and dinoflagellates by *Peridinium* sp. genera.

3.4 Relationships between phytoplankton and physicochemical water parameters

The Monte Carlo test revealed that the correlation between phytoplankton abundance and biomass, phytoplankton groups and dominant species and physicochemical properties from the canonical correspondence analysis was significant both for Axis 1 and Axis 2 (eigenvalue 0.032 and 0.022, 0.295 and 0.185, and 0.801 and 0.628, respectively). CCA analysis shows that N-NH_4 and TN most commonly promoted algal growth in MEP and FLP, P-PO_4 in FRP (Fig. 5). Chlorophytes were mainly correlated with temperature and P-PO_4 in FLP, cyanobacteria and euglenins with O_2 in VLP, while dinophytes with pH in FRP, and dinophytes and diatoms with TN in VLP and MEP (Fig. 6). The data in Figure 7 show correlation between phytoplankton species and physicochemical variables confirming these tendencies. Similarly, chlorophyte and cyanobacterial species correlated with temperature, P-PO_4 and pH in MEP and FLP and diatoms with O_2 and N-NH_4 in FLP, FRP, VIP, and with TN in MEP. The following correlations were determined between

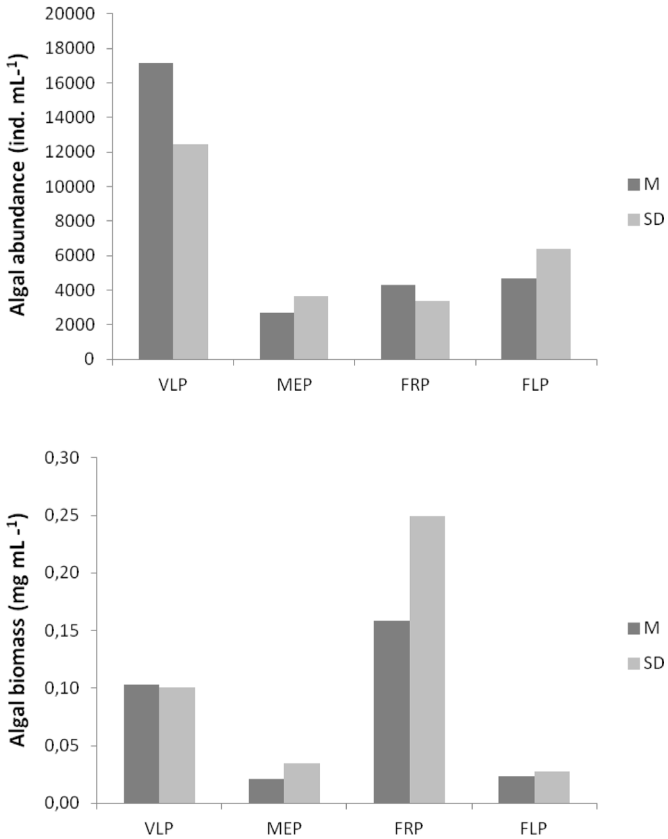

Fig. 2. Mean abundance and biomass (M), and standard deviations (SD) of phytoplankton in village (VLP), mid-meadow (MEP), mid-forest (FRP) and mid-fields (FLP) ponds in 2010.

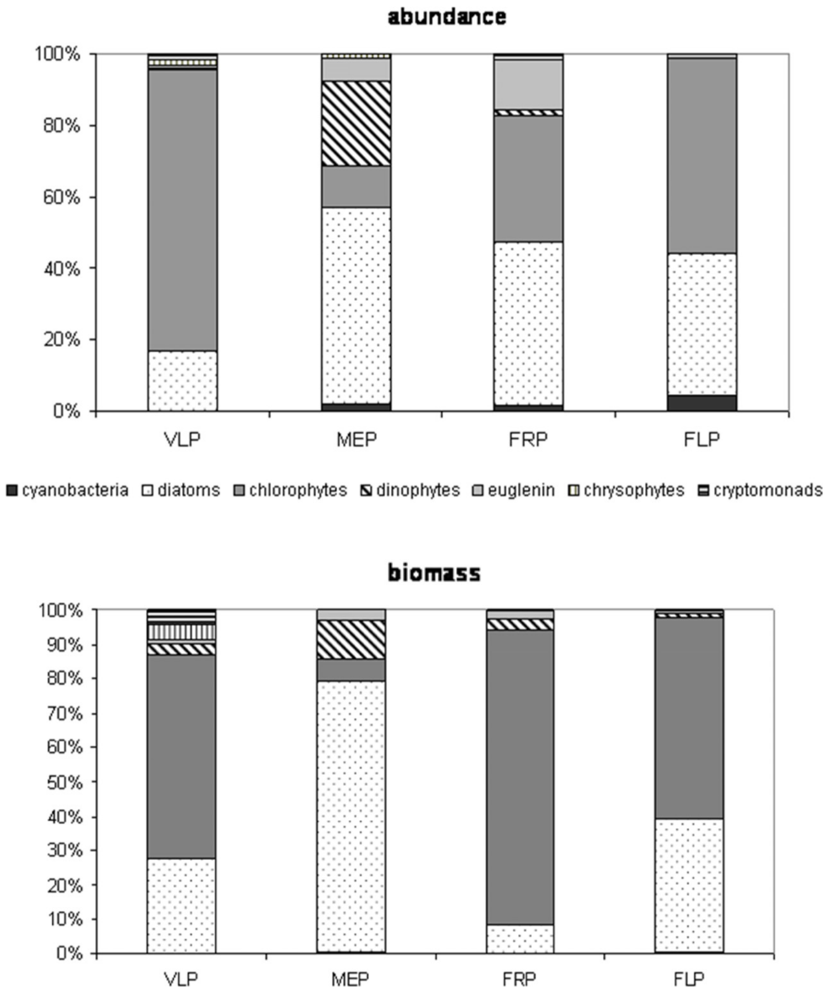

Fig. 3. Structure of phytoplankton in village (VLP), mid-meadow (MEP), mid-forest (FRP) and mid-fields (FLP) ponds in 2010.

phytoplankton species and physicochemical water parameters at $p < 0.05$:

- *Positive correlations*: Diatom species *Amphora veneta* correlated with oxygen content ($r = 0.46$), *Diatoma vulgaris*, *Cocconeis placentula*, *Fragilaria ulna*, *Navicula gregaria*, *Pinularia* sp. and *Nitzschia palea* with N-NH_4 ($r = 0.47$, $r = 0.48$, $r = 0.56$, $r = 0.54$, $r = 0.62$ and $r = 0.51$, respectively) and the following correlated with pH; *Amphora veneta* at $r = 0.49$ and *Fragilaria delicatissima* at $r = 0.55$ and euglenin species *Euglena acus* at $r = 0.46$.
- *Negative correlations*
  - diatom species: *Diatoma vulgaris* and *C. placentula* correlated with conductivity ($r = -0.73$ and $r = -0.54$, respectively);
  - diatoms: *F. delicatissima* and *F. ulna* ($r = -0.56$ and $r = -0.47$, respectively), and the genera *Trachelomonas* sp. ($r = -0.49$) and *Cryptomonas* sp. ($r = -0.56$) correlated with P-PO_4;
  - chlorophytes: the genus *Spirogyra* sp. and species *Pediastrum boryanum* correlated with N-NH_4 ($r = -0.53$ and $r = -0.47$, respectively);
  - genus *Trachelomonas* sp. correlated with water temperature ($r = -0.50$).

4 Discussion

The limited water depth and volume and type of catchment area ensured great variability in the environmental conditions of the studied ponds. Moreover, the biotic and abiotic parameters can be very seasonally unstable (Joniak *et al.*, 2006). These especially related to the density and quality of fish and invertebrate communities and physical factors including temperature and available nutrients. In this study, high conductivity and orthophosphates recorded in mid-meadow ponds (MEP) and the highest N-NH_4 and TN in mid-field ponds (FLP) agree with similar investigation into field ponds by Kocarkova *et al.* (2004) and Celewicz-Gołdyn *et al.* (2008). This is related to land use practices in the ponds' vicinity affecting the catchments by nutrient loading and fertilizer and pesticide contamination (Declerck *et al.*, 2006). Moreover, intensified agriculture has far more influence at pond catchment scale than in larger river and lake catchment areas (Céréghino *et al.*, 2008a). Similar to Owsianny and Gąbka's (2006) and Celewicz-Gołdyn *et al.* (2008) results in dystrophic small water bodies, the highest oxygen content and the lowest conductivity were recorded in mid-forest ponds (FRP).

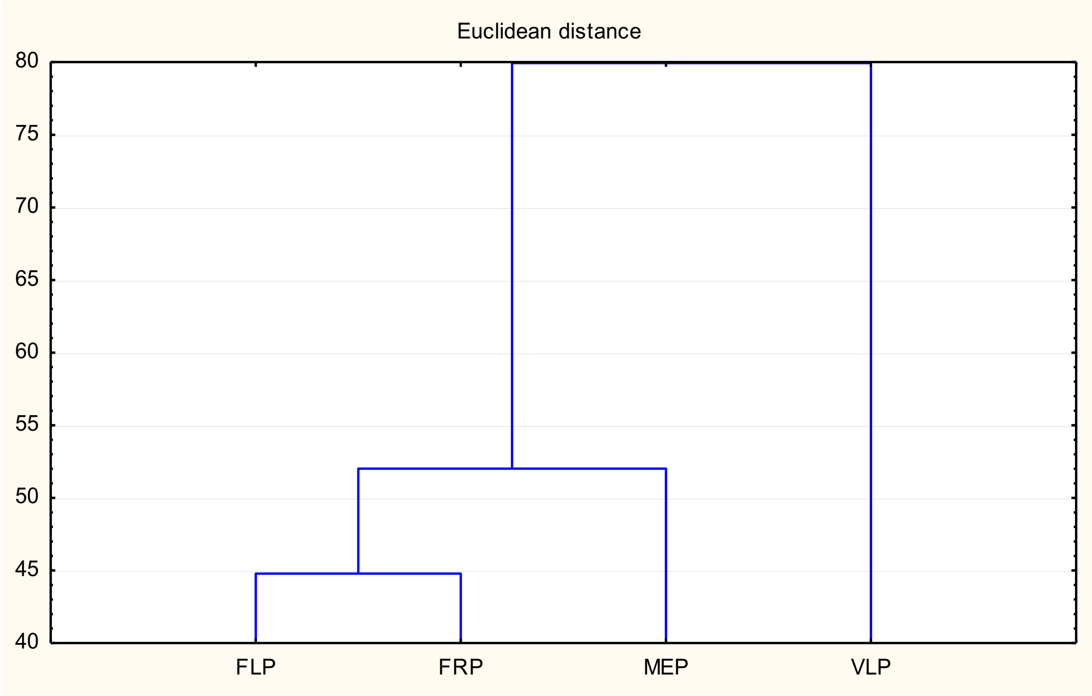

Fig. 4. Euclidean diagram of species phytoplankton similarity in village (VLP), mid-meadow (MEP), mid-forest (FRP) and mid-fields (FLP) ponds in 2010.

Table 2. Species diversity Shannon–Wiener's indices based for the logarithms of phytoplankton abundance in village (VLP), mid-meadow (MEP), mid-forest (FRP) and mid-fields (FLP) ponds in 2010.

Ponds	VLP	MEP	FRP	FLP
Shannon–Wiener species diversity index (ind. bit^{-1})	2.49	4.00	4.52	4.86
Number taxa	95	58	62	60

Table 3. Comparison species diversity expressed as Shannon–Wiener's between of phytoplankton in village (VLP), mid-meadow (MEP), mid-forest (FRP) and mid-fields (FLP) ponds in 2010. The values of the *t*-test, corresponding to *F* statistic value and associated *p*-values (*p*) are displayed for each comparison.

Ponds	*t*	*F*	*p*
VLP–MEP	−0.31	4.20	$p < 0.0001$
VLP–FRP	−0.44	3.69	$p < 0.0001$
VLP–FLP	−0.08	206.45	$p < 0.0001$
MEP–FRP	−0.07	−1.13	$p = 0.6250$
MEP–FLP	−0.02	47.96	$p < 0.0001$

While some authors reported clear associations between algal assemblages and a variety of environmental factors such as surface area, catchment character and nutrient loading (Boix *et al.*, 2008; Céréghino *et al.*, 2008b; Gascon *et al.*, 2008; Oertli *et al.*, 2008), this study determined differences in pond algal abundance and biomass based on catchment area type. Although Kocarkova *et al.* (2004) found a low abundance of algae communities in mid-forest ponds and higher algal densities in mid-field ponds due to high nutrient concentrations, despite high P-PO_4 and N-NH_4. In this study, the lowest mean abundance and biomass was found in MEP, and the highest abundance in VLP and biomass in FRP at the highest water temperature and pH, and oxygen content, respectively.

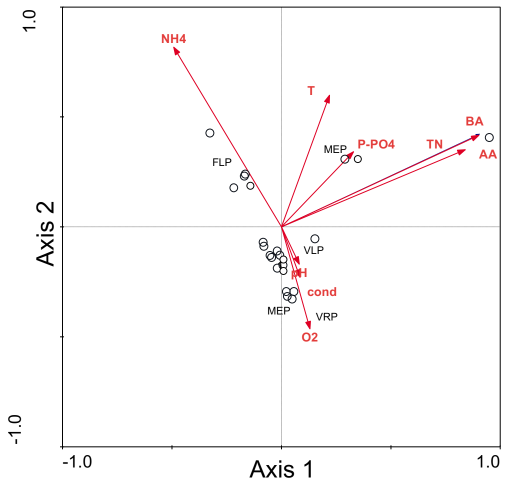

Fig. 5. CCA analysis physicochemical water parameters forming phytoplankton growth (AA – algal abundance, BA – algal biomass) in village (VLP), mid-meadow (MEP), mid-forest (FRP) and mid-fields (FLP) ponds in 2010.

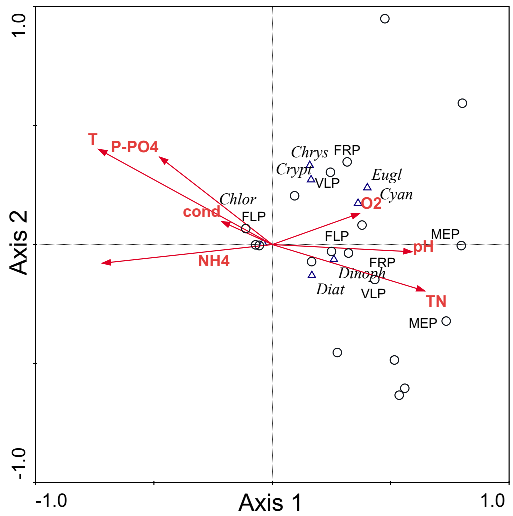

Fig. 6. CCA analysis between phytoplankton taxonomic groups (*Cyan* – cyanobacteria, *Diat* – diatoms, *Chlor* – chlorophytes, *Dinoph* – dinophytes, *Eugl* – euglenins, *Chrys* – chrysophytes, *Crypt* – cryptomonads) and physicochemical water parameters in village (VLP), mid-meadow (MEP), mid-forest (FRP) and mid-fields (FLP) ponds in 2010.

CCA analysis illustrated that high N-NH_4 in MEP and FLP and low P-PO_4 in FRP determined phytoplankton growth. These water parameters influenced particular phytoplankton group growth. Similar to Celewicz-Gołdyn *et al.* (2008) findings, high percentages of chlorophytes and diatoms composed the taxonomical structure in the studied ponds. This was especially noticeable in the positive relationships of high N-NH_4 with the highest proportion of chlorophytes in total FLP phytoplankton abundance and high oxygenation with diatoms in the FRP. In addition, nutrient-rich MEP and FLP waters enhanced dinoflagellates growth and high water

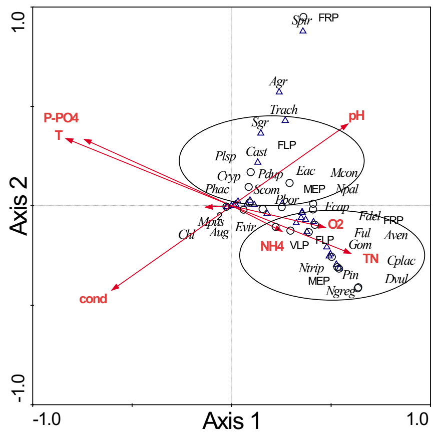

Fig. 7. CCA analysis between dominant species of taxonomic phytoplankton groups (Agr – *Aphanizomenon gracile*, Aug – *Aulacoseira granulata*, Aven – *Amphora veneta*, Chl – *Chlamydomonas* spp., Cplac – *Cocconeis placentula*, Cast – *Coleastrum astroideum*, Cryp – *Cryptomonas* sp., Dvul – *Diatoma vulgaris*, Eac – *Euglena acus*, Evir – *Euglena viridis*, Fcap – *Fragilaria capucina*, Fdel – *Fragilaria delicatissima*, Ful – *Fragilaria ulna*, Gom – *Gomphonema* spp., Mpus – *Micratinium pusillum*, Mcon – *Monoraphidium concortum*, Ngreg – *Navicula gregaria*, Ntrip – *Navicula tripunctata*, Npal – *Nitzschia palea*, Pin – *Pinnularia* sp., Pbor – *Pediastrum boryanum*, Pdup – *Pediastrum duplex*, Phac – Phacus sp., Plsp – *Planctoccoccus sphaerocystiformis*, Scom – *Scenedesmus communis*, Sgr – *Staurastrum gracile*, Spir – *Spirogyra* sp., Trach – *Trachelomonas* sp.) and physicochemical water parameters (cond – conductivity) in village (VLP), mid-meadow (MEP), mid-forest (FRP) and mid-fields (FLP) ponds in 2010.

temperature stimulated cryptomonad development in the VIP. Moreover, low percentage share of cyanobacteria in the study ponds suggests that nutrient availability (especially P) was probably insufficient to trigger cyanobacteria blooms (Downing *et al.*, 2001).

Della Bella *et al.* (2008) reported that high phytoplankton species richness is characteristic of small water bodies, and this was especially evident in nutrient-rich FLP waters. Moreover, the lowest diversity (Shannon–Wiener index) in VLP is most likely related to high chlorophyte domination; especially by genera *Chlamydomonas* spp. In addition to differences in species diversity, there was also differentiation in algal species composition. The greatest similarity in species composition is shown between algae composition in FLP and FRP, and the least similarity was between algae in FLP and VLP. CCA analysis also confirmed similarity between phytoplankton in MEP and FLP, while the most distinctive were in FRP. Phytoplankton in the studied ponds was characteristic for small water bodies, with chlorophyte and diatom domination accompanied by cyanobacteria and euglenin presence (Kuczyńska-Kippen and Nagengast, 2006; Napiórkowska-Krzebietke *et al.*, 2011; Asha Nair *et al.*, 2015).

This study results agree with the findings in agricultural ponds reported by various authors (Sahin, 2000; Kuczyńska-Kippen and Nagengast, 2006; Asaduzzaman *et al.*, 2010; Napiórkowska-Krzebietke *et al.*, 2011), where the diatoms *Diatoma*, *Fragilaria*, *Pinularia*, *Melosira*, *Navicula*, *Nitzschia*, *Pediastrum* and *Scenedesmus* dominated together with

Euglena and *Phacus*. Diatom genera *Pinnularia* sp., *Diatoma vulgaris* and *Fragilaria capucina* dominated MEP and FLP ponds with chlorophytes *Closterium echrenbergii, Ulothrix tenuissima* and *Pediastrum boryanum.* Euglenins *Euglena viridis* and *Euglena acus*, genus *Phacus* sp. and *Trachelomonas* sp. were present in these and other pond types with *Peridinium* sp. dinoflagellates and *Aphanizomenon gracile* cyanobacteria. Dinoflagellates were often noted in mesotrophic waters and cyanobacteria in eutrophic waters, with euglenophytes common and abundant in the natural shallow water bodies and cryptomonads ubiquitous (Hašler et al., 2008). In addition, the presence of *Euglena*, *Phacus*, and dinoflagellates in some ponds suggests a high availability of dissolved organic matter (DOM), as these algae can complement photosynthesis with organic matter uptake from the water column (Taylor and Pollingher, 1987). Moreover, the greatest abundance of the genus *Chlamydomonas* in nutrient-rich water was registered in VLP, accompanied by *Monoraphidium concortum* and *Diatoma vulgaris* and *Cryptomonas* sp. The eutrophic environments especially contained large unicellular elongate *Closterium* sp., the filamentous *Mougeotia* sp., *Spirogyra* sp. and *Chlamydomonas* sp. flagellates (Naselli-Flores and Barone, 2000; Hašler et al., 2008; Asha Nair *et al.*, 2015). In addition, *Closterium cynthia, Pediastrum duplex* and *Spirogyra* sp. chlorophytes and *Diatoma vulgaris var. linearis* dominated in FRP; corresponding with Owsianny and Gąbka (2006) mid-forest pond results.

Differentiation between diatoms, chlorophytes and others algal groups is closely allied to the availability of their preferred physicochemical parameters in the particular pond-types. This further explains the environmental differences determined by CCA analysis for the correlations between diatom dominant species and oxygen (*Amphora veneta)*, N-NH_4 (*Diatoma vulgaris*, *Cocconeis placentula*, *Fragilaria ulna*, *Navicula gregaria*, *Pinularia* sp. *Nitzschia palea*); and pH (*Apmhora veneta*, *Fragilaria delicatissima*). Asaduzzaman *et al.* (2010) also reported that *Diatoma*, *Fragilaria*, *Pinularia, Nitzschia* often correlated with nitrogenous compounds; especially in agricultural ponds. In addition, this study highlighted low water temperature favoured *Trachelomonas* sp. growth, chlorophyte *Spirogyra* sp. and *Pediastrum boryanum* abundance increased at low N-NH_4 and *Euglena acus* at high pH.

Phytoplankton-nutrient relationships are widely used by lake managers to asses eutrophication and set nutrient targets (Teissier *et al.*, 2012), and phytoplankton can remove phosphorous and nitrogen pollutants from ponds (Céréghino *et al.*, 2014). This is related with the following nutrient uptake resulting in negative correlations between algal species and N-NH_4 (*Spirogyra* sp., *Pediastrum boryanum*), conductivity (*D. vulgaris*, *C. placentula*) and P-PO_4 (*F. delicatissima*, *F. ulna*, *Trachelomonas* sp. and *Cryptomonas* sp.).

5 Conclusion

Their catchment area type and small surface area and volume make these ponds susceptible to accelerated eutrophication from their particular environments, and phytoplankton type is an evident coefficient of this phenomenon. Anthrophogenic activity also exerts impact through agricultural field fertilization and village proximity. Our results confirm these phenomena, where the highest phytoplankton abundance was recorded in the nutrient-rich village ponds. Moreover, phytoplankton assemblages were characterized by high biodiversity, differentiated structure and differences in environmental requirements for dominant species. The studied assemblages have great biodiversity and their consequent ecological role warrants special protection. Moreover, our results highlight important future directions for conservation of these ponds and the protection of their biodiversity; especially for those water bodies located in close proximitylized to the natural protected areas of Nature 2000 sites.

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