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Characteristics of *Cladophora* and coexisting filamentous algae in relation to environmental factors in freshwater ecosystems in Poland

by

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Abstract

Potential factors affecting the occurrence of filamentous algae include the morphometry of water bodies, the type of substrate and physicochemical conditions of the habitat. This study attempts to describe the individual filamentous algae species recorded in Poland, taking into account the trophic and ecological characteristics based on our own research and available literature data. Filamentous algae attached to the substrate as well as those forming free-floating patches (loose or dense mats) and crusts occur in all types of water bodies. Among the representatives of filamentous algae species, *Cladophora* have the greatest time-spatial range for they grow abundantly in all types of water bodies. In other parts of Poland, *Cladophora* species are most common in rivers and shallow lakes. In the typical filamentous algae community, *Cladophora*, *Spirogyra* and *Oedogonium* occur with the highest frequency; *Zygnema*, *Mougeotia*, *Microspora* and *Rhizoclonium* are also present, but with smaller frequency. According to our studies, distribution of filamentous algae species is correlated with the eutrophic index ($PO4_3^-$, $N\text{-}NO_3^-$, Chl *a*), chlorides of anthropogenic origin and TDS.

Key words: filamentous algae, free-floating mat, *Cladophora*, *Oedogonium*, *Spirogyra*

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Introduction

Both (i) Chlorophyta – *Oedogonium*, *Cladophora* and (ii) Charophyta – *Spirogyra*, *Zygnema* as well as some taxa from (iii) Ochrophyta – *Vaucheria*, *Tribonema* are classified as macroscopic filamentous algae. Although filamentous algae have a simple structure, they are a very diverse group in terms of taxonomy and ecology (Van den Hoek et al. 1995; De Clerck et al. 2012). Taxonomic identification of filamentous algae is difficult and they grow in various habitats and environments. This group of algae is mostly cosmopolitan and occurs both in oligotrophic and eutrophic water ecosystems, from lentic to fast flowing water (Whitton 1970; Sheath & Cole 1992; Dodds & Gudder 1992). Traditional systematics of macroalgae is based on features such as morphology, cell biology, life history and reproductive strategies. There are many factors that affect the morphometric features, including the stage of development, seasonality, the content of nutrients in the water and the presence of all types of biotic/abiotic particles on the surface. Due to the morphological and phenotypical plasticity, many of the filamentous algae are difficult to identify.

Of the above-mentioned phylum, Chlorophyta (green algae) are most common in freshwater ecosystems, especially species from the *Cladophora* Kützing genus, which are primarily limited by phosphorus availability (Higgins et al. 2008; Malkin et al. 2010; Young et al. 2010; Messyasz et al. 2015a). *Cladophora* thalli may be attached to the aquatic plants or rocks, or they may float on the water surface. The thirty eight *Cladophora* taxa are represented by the following freshwater species: *Cladophora basiramosa* Schimdle, *C. pachyderma* (Kjellm.) Brand, *C. glomerata* var. *glomerata* (L.) Kütz., *C. glomerata* var. *crassior* (L.) Kütz., *C. rivularis* (L.) v.d. Hoek, *C. fracta* var. *fracta* (Mull. Ex.Vahl) Kütz., *C. fracta* var. *intricate* (Mull. Ex.Vahl) Kütz., *C. aegagropila* (L.) Rabenh. (=*Aegagropila linnaei*), *C. cornuta* Brand, *C. surera* Brand, *C. kosterae* Hoffm. & Tild.

They were classified into the genus of *Cladophora* by van den Hoek (1963), who reviewed in detail the history of this algal group in Europe. Much of the knowledge about *Cladophora* species in Poland comes from the reports of Starmach (1972), Chudyba (1965) and Pliński & Hindák (2012).

According to Leliaert & Coppejans (2003), *Cladophora* are characterized by a simple, siphonocladous thallus structure: branched, uniseriate filaments with multinucleate cells. Starmach (1972) described six taxonomic criteria for the identification of these genera, which include: thalli color, branching types, structure and dimensions of cells, the general structure of a plant, basal cells and the shape of zoospores. *Cladophora* are often the main components in the structure of the "mat" (patch), while other types of filamentous algae are only detached fragments, tangled into *Cladophora* filaments. This is consistent with the literature data according to which mainly monoalgal mats occur (created by the *Cladophora* genus) or a small number of patches, consisting of several coexisting species (Khanum 1982; Pikosz & Messyasz 2015).

The most common species from this genus described in the available literature is *Cladophora glomerata*. Morphometric variability of *Cladophora glomerata* thalli from the mountain regions of the Skawa river in Poland, where the strong water flow has a positive effect on the development of *Cladophora*, was described in detail by Chudyba (1965). Furthermore, during her research on Oedogoniales, Mrozińska (1984) most frequently noted the occurrence of *Oedogonium intermedicum* and *Oedogonium undulatum*. Taxonomic identification of this algae group is based on generative cells (Mrozińska 1984). Likewise, *Spirogyra* spp., *Mougeotia* spp. and *Zygnema* spp. are the most popular filamentous algae in water ecosystems from Zygnemataceae (Kadłubowska 1972). However, the Spirogyra species identification has to be based on the process of conjugation and zygospores. Typical features of *Spirogyra* vegetative growth are: the type of cross walls, the cell width, and the number of chloroplasts (Berry & Lembi 2000; Hainz et al. 2009).

The previous studies of *Cladophora* in freshwaters have related to problems arising from nuisance blooms and food web interactions in water ecosystems, primarily in rivers (Whitton 1970; Graham et al. 1982; Dodds & Gudder 1992; Higgins et al. 2008; Power et al. 2008). However, filamentous algae are still poorly researched. This article deals with the role of individual species of filamentous algae in relation to habitat parameters. The objectives of this study were to determine (i) the diversity of filamentous algae and (ii) intraspecific differences within *Cladophora glomerata, C. rivularis* and *C. fracta*, and to describe (iii) the abiotic conditions, in which filamentous algae occur. The information about genera of filamentous algae and their preferred water ecosystems was obtained from the available literature.

Materials and methods

Study area

Samples of filamentous green algae were collected in summer of 2012, 2013, 2014 in different ecosystems, such as 3 rivers, 2 ponds, 1 lake and 1 water reservoir in the Wielkopolska Province. Sites of the filamentous algae distribution were marked on the map of the Wielkopolska Province (Fig. 1). Macroscopic filamentous algae with the dominance of *Cladophora glomerata* were sampled in Oporzyńskie Lake (52°55'N, 17°9'E) and in the lowland rivers: Nielba (52°48'N, 17°12'E; near Wągrowiec, ca. 50 km from Poznań), Samica Stęszewska (52°16'N, 16°41'E; Stęszew) and Mogilnica (52°9'N, 16°31'E; near Kamieniec), *C. rivularis* in a pond located in the village of Konojad (52°10'N, 16°31'E), *C. fracta* in the Malta reservoir (52°24'N, 16°58'E) and in a small, artificial pond (52°27'N, 16°55'E; Poznań).

Field sampling and laboratory analyses

The color of thalli as well as the presence or absence and the type of branching were observed during the sampling. Purified thalli were stored in plastic containers and their small portions were preserved in 4% formalin solution. Morphometric measurements to identify the species were carried out on the living and preserved material. Microscopic observations of the collected material were performed using a light microscope (Zeiss Axioskop 2 MOT), measurements of the length and width of cells from the main axes of filamentous algae were taken at ×200 and ×400 magnification. To determine the number of pyrenoids, the samples were stained with Lugol's solution. To determine the number of nuclei, the staining method with acetocarmine was used. The results were compared with morphometric data on filamentous algae from Poland included in the identification keys by Starmach (1972), Mrozińska (1984), Kadłubowska (1972), Pliński & Hindák (2012) and papers by Zulkifly et al. (2013), Malkin et al. (2008).

During the sampling, physicochemical parameters of water were measured: temperature (°C), pH, dissolved oxygen (DO%), electrolytic conductivity (EC µS cm^{-1}), and the Total Dissolved Solids (TDS mg l^{-1}) using a YSI Professional Plus multifunctional probe. For a detailed analysis of the chemical parameters, water samples (500 ml) were collected and preserved with chloroform ($CHCl_3$) and stored at -10°C for further analysis. Using a spectrophotometer HACH DR 2800, the

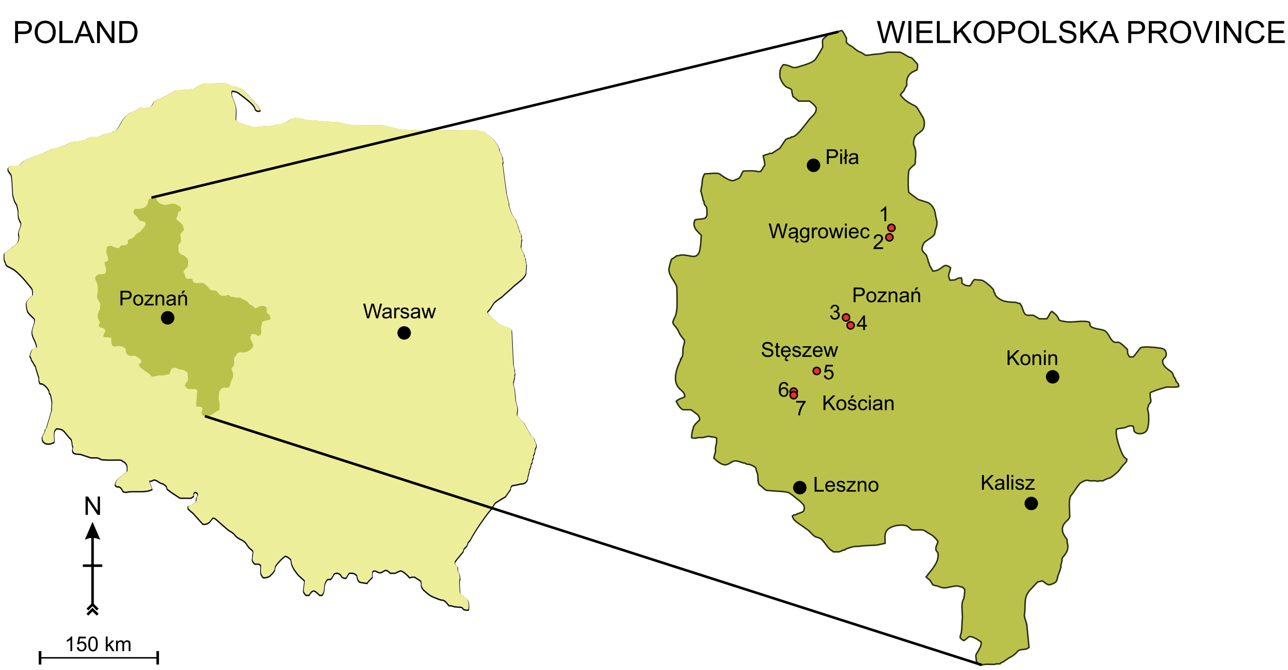

Figure 1

Location of the study sites: 1 – Lake Oporzyńskie, 2 – Nielba river, 3 – Pond in Poznań, 4 – Malta Reservoir, 5 – Samica Stęszewska river, 6 – Pond in Konojad, 7 – Mogilnica river color, the water turbidity and the concentration of orthophosphates, nitrates, ammonium nitrogen and sulfates were determined. Chlorophyll *a* (Chl *a* μg g^{-1}) concentration was determined by a spectrophotometer using ethanol as an extraction solvent. Water samples (1.5 l) for pigment analysis were filtered onto Whatman GF/F filters according to the ISO 10260 standard method.

Determination of frequency

Frequency of filamentous algae (belonging to 15 genera) was estimated as the number of observations on the basis of the total number of samples from own samplings and those from the literature data – 70 sites (Czerwik-Marcinkowska 1997; Maciejczak & Czerwik-Marcinkowska 2010; Czerwik-Marcinkowska & Ziętarski 2011; Czerwik-Marcinkowska & Vončina 2012; Chudyba 1968; Krzyk 2001; Szymańska et. al. 2015; Pieczyńska & Tarmanowska 1996; Starmach 1969; Endler et al. 2011; Pieczyńska 2008; Celewicz-Gołdyn & Kuczyńska-Kippen 2008; Celewicz-Gołdyn & Klimko 2008; Kuczyńska-Kippen et al. 2004; Messyasz & Rybak 2011; Messyasz et al. 2015a; Pikosz & Messyasz 2015; Jakubas et al. 2014; Ozimek 1990; 1992; Wołowski & Kowalska 2009; Żelazna-Wieczorek 2002; Jekatierynczuk-Rudczyk et al. 2012; Szoszkiewicz et al. 2010; Staniszewski et al. 2012; Grabowska 2006; Owsianny & Gąbka 2006; Hutorowicz 2006; Lenarczyk 2012; Dondajewska & Budzyńska 2009; Piątek & Piątek 2005).

Numerical analyses

All the statistical analyses were performed using the CANOCO ver. 4.5 software (ter Braak & Šmilauer 2002). The Canonical Correspondence Analysis (CCA) to determine the relations between the species distribution and environmental variables was used. The Monte Carlo permutation test shows that chlorides, orthophosphates, total dissolved solids, nitrates and chlorophyll *a* were statistically significant (P<0.05).

Results

Floristic diversity of filamentous algae in Poland

Based on the literature data (70 sites) and our own research (7 sites), the most frequently recorded filamentous algae in freshwater ecosystems of Poland belong to 15 genera: *Cladophora, Rhizoclonium, Microspora, Oedogonium, Bulbochaete, Draparnaldia, Stigeoclonium, Hydrodictyon* and *Ulothrix* classified into the phylum Chlorophyta, *Spirogyra, Mougeotia, Zygnema, Sirogonium* classified into the phylum Charophyta, *Vaucheria* and *Tribonema* classified into the phylum Ochrophyta. The dominant (>10% of all genera) genus was *Cladophora* – about 30%, followed by *Spirogyra* – 16% and *Oedogonium* – 11% (Fig. 2).

Based on the data, the most common habitats of filamentous algae were flowing (lotic) waters such as rivers and streams (50%), and standing (lentic) waters: ponds and lakes (Fig. 3). Only *Cladophora* occurred in all types of ecosystems. *Cladophora* and *Ulothrix* were usually found in lotic waters. *Cladophora* and *Spirogyra* were common in ponds and lakes.

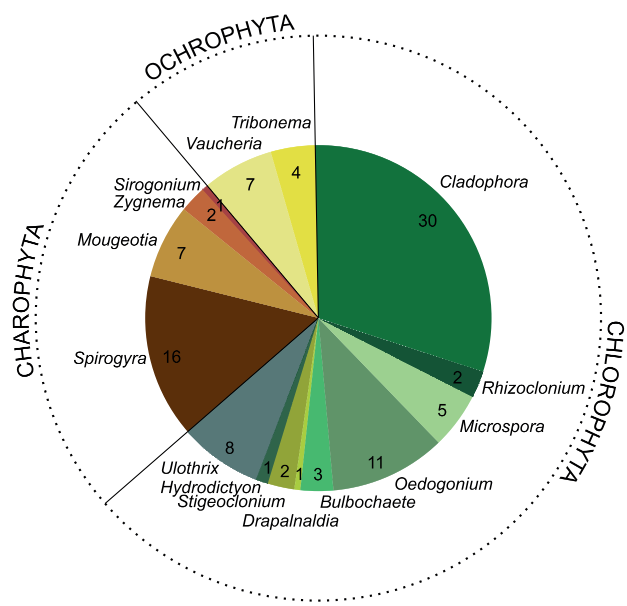

Figure 2

Floristic diversity of filamentous algae in freshwater ecosystems in Poland (numbers indicate the percentage contribution)

Characteristics of filamentous algae

Cladophora glomerata (L.) Kützing (Fig. 4) was observed in rivers with comparable water velocity (0.15-1.85 m s^{-1}) and a water depth ranging from 0.5 to 1.5 m. Long, dark green filaments of *Cladophora glomerata* occurred alone in the Samica Stęszewska river. Representatives of macroscopic filamentous

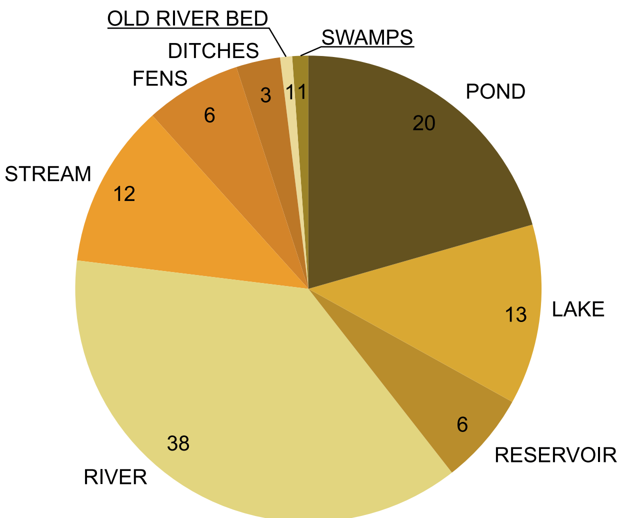

Figure 3

Types of ecosystems, in which filamentous algae were noted (numbers indicate the percentage contribution)

algae belonging to the genera: *Cladophora*, *Rhizloclonium*, *Oedogonium*, *Stigeoclonium* and *Vaucheria* were observed in the Mogilnica river (Table 1). There were 2 types of substrate: sand and hard substrate. Up to 2 m long filaments of *C. glomerata* with a small number of branching occurred on the former, and less than 20 cm long filaments with numerous branches dominated on the latter. Single filaments of *Stigeoclonium nanum* (Dillwyn) Kützing, *Rhizoclonium* sp. Kütz. and *Oedogonium* sp. Kütz. ex Hirn occurred and tangled together. In the Nielba river, young filaments of *C. glomerata* were attached to the stones and mature filaments were free-floating on the water surface between macroscopic tubular forms of *Ulva* thalli. *Cladophora glomerata* occurred also in Oporzyńskie Lake, where it formed a dense, mostly monoalgal mat. *Cladophora rivularis* (L.) Hoek was often observed as filaments coexisting with *Oedogonium capillare* in a small agriculture pond. *C. rivularis* exhibits a great morphological variation due to the fact that cells of a varying width occur in the same filament (Fig. 5). Moreover, taxa from the genera *Tribonema*, *Ulothrix*, *Microspora*, *Spirogyra* and *Mougeotia* were observed, but only in early spring and only a few filaments. *Cladophora fracta* (Müller ex Vahl) Kütz. is the most characteristic taxon of the studied *Cladophora* species; its first, delicate and slender filaments are followed by yellow-green filaments, which do not reach a significant dominance in a mat. Species from Zygnemataceae (*Spirogyra* sp., *Zygnema* sp., *Mougeotia* sp.) often occurred as accompanying algae in the examined water ecosystems – the artificial pond in Poznań and the Malta Reservoir.

Environmental gradients

The water temperature in the studied ecosystems was similar – about 20°C. Concentrations of ammonium nitrogen, nitrates and phosphates in

Table 1

Characteristics of various filamentous algae patches at the study sites

dominant taxon	length and width of cells in μm (min-max)	shape of chloroplast	diameter of pyrenoids (μm)	accompanying filamentous algae	forms	color	sites
Cladophora glomerata	223-634 47-131	reticulate	3-12	*Rhizoclonium* sp. *Vaucheria* sp.	attached to the bottom and stones	dark green	Nielba river
Cladophora glomerata	84-388 27-82	reticulate	4-10	absent	long filaments, attached to the bottom	dark green	Samica Stęszewska river
Cladophora glomerata	116-756 28-133	reticulate	3-6	*Rhizoclonium* sp. *Stigeoclonium nanum* *Oedogonium* spp. *Vaucheria* sp.	attached, free-floating	dark green	Mogilnica river
Cladophora glomerata	132-225 26-50	reticulate	5-7	*Oedogonium* sp. *Tribonema vulgare*	free-floating, dense mat	bright green	Lake Oporzyńskie
Cladophora rivularis	97-301 36-130	parietal	4-9	*Cladophora* sp. *Oedogonium capillare* *Ulothrix variabilis* *Tribonema aequale* *Tribonema vulgare* *Spirogyra* spp., *Mougeotia* sp. *Microspora* sp.	cotton-wool-like thick mat	bright green	Pond in Konojad (agriculture)
Cladophora fracta	50-135 17-25	parietal	3-7	*Cladophora glomerata* *Spirogyra* spp. *Mougeotia* sp.	dense mat in littoral zone (4 m from the shore), soft to the touch	yellow green	Malta Reservoir
Cladophora fracta	48-146 21-30	parietal	3-6	*Spirogyra* spp. *Mougeotia* spp. *Zygnema* spp. *Sirogonium* sp. *Cladophora* sp.	mat mainly slippery to the touch	yellow green	Pond in Poznań (artificial)

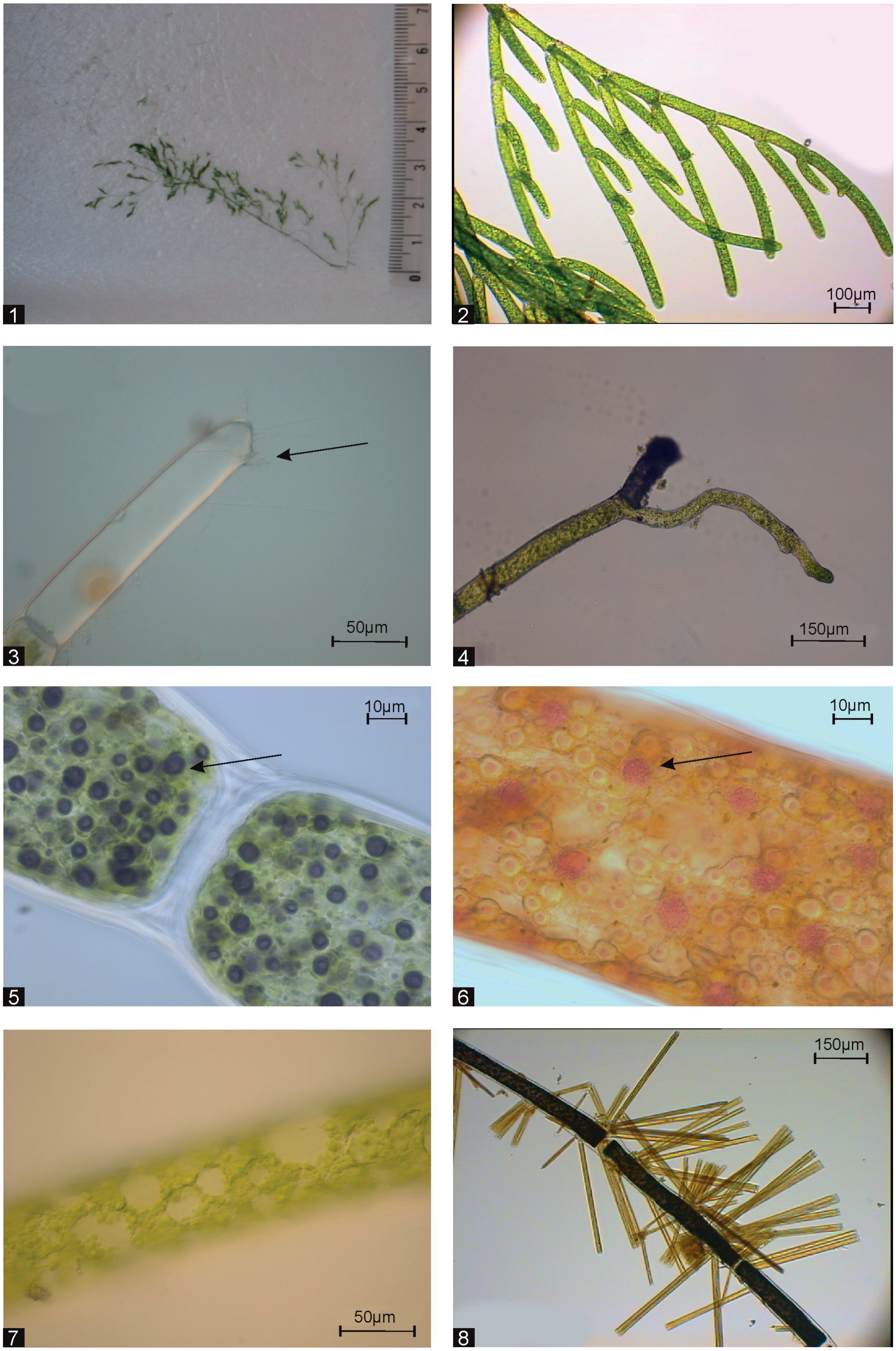

Figure 4

Photos of *Cladophora glomerata*: 1 – the overall view of young thalli; 2 – the number of thalli branched in the apical part; 3 – apical cell with a hole; 4 – basal cell; 5 – stained pyrenoids; 6 – stained nuclei; 7 – reticulate chloroplast; 8 – diatoms on the surface of cell wall

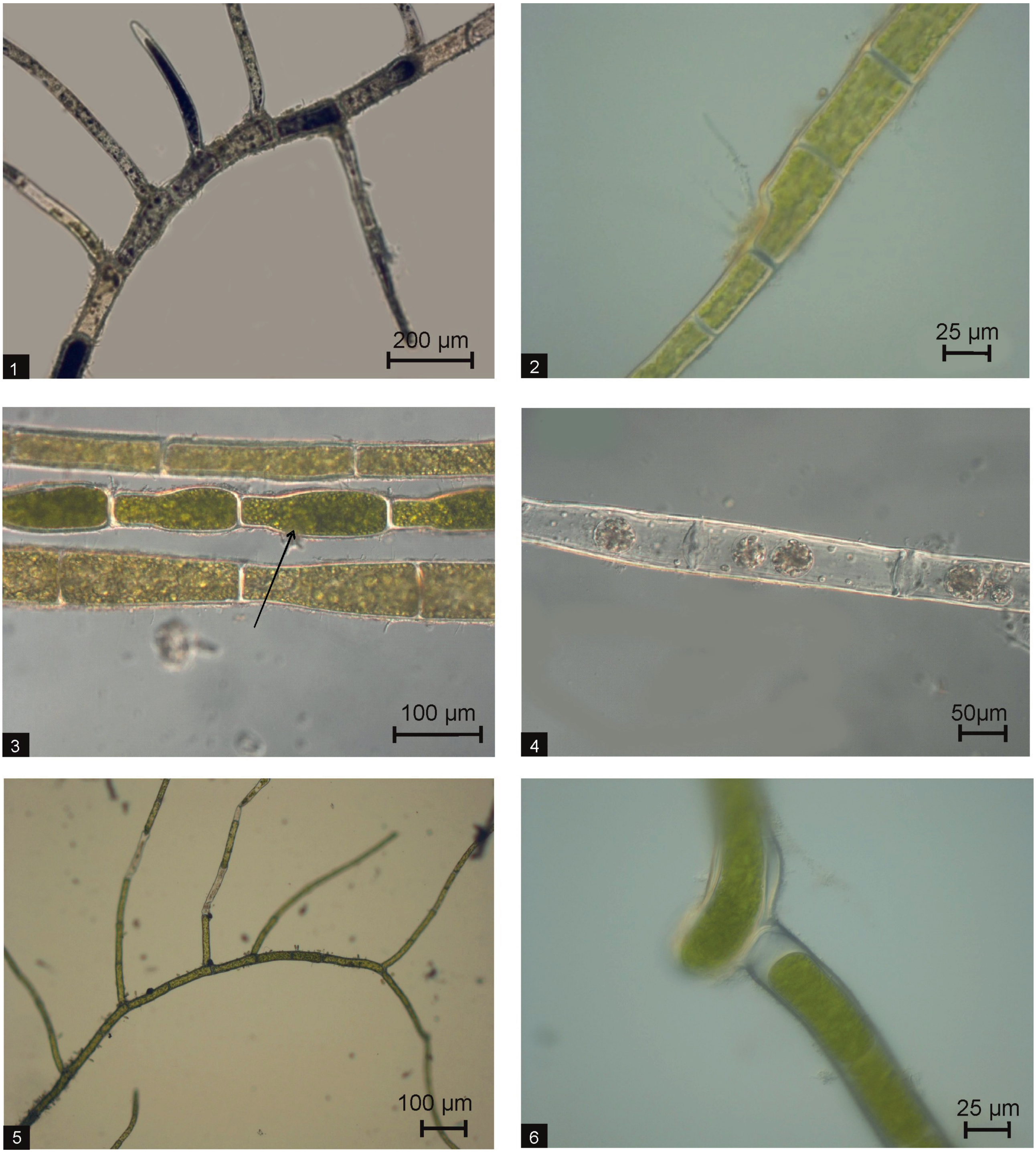

Figure 5

Photos of *Cladophora rivularis* (1-4): 1 – branches diverge at right angles; 2 – morphometric variability; 3 – akinete; 4 – zoospores; and *Cladophora fracta* (5-6): 5 – slender filaments with branches at an obtuse angle; 6 – fragmentation of the thallus

the water at the studied sites reflect high levels of fertility (Table 2). The highest content of NH_4^+ was determined in the Konojad pond and in the Nielba river, $N\text{-}NO_3^-$ – in the Mogilnica and Nielba rivers, and the content of $P\text{-}PO_4^{3-}$ above 1 mg l^{-1} was recorded in the Mogilnica river. At the other sites, the amount of orthophosphate was at a similar level. The lowest value of $N\text{-}NO_3^-$ was determined in the

Table 2

Mean values of physicochemical factors of water for the surveyed sites (L.O. – Lake Oporzyńskie, M.R. – Malta Reservoir, P.P. – pond in Poznań, P.K. – pond in Konojad, N.R. – Nielba river, S.S.R. – Samica Stęszewska river, M.R. – Mogilnica river

Parameters	Unit	L.O. n=46	M.Res. n=12	P.P. n=17	P.K. n=59	N.R. n=10	S.S.R. n=10	M.R. n=33
Temp.	°C	19.3	23.7	22.1	21.4	21.0	18.9	20.4
pH		8.4	8.6	8.3	8.8	7.9	7.5	7.9
Depth	cm	120	41.5	35	51	94	44	43
Color	PtCo	74	21	12.8	18.8	22	28	38
Turb.	FAU	3.5	4.2	3.3	5.2	4.5	0.3	5.4
EC	µS cm^{-1}	551	658	387	946	779	532	838
TDS	mg l^{-1}	259	442	198	532	538	516	491
$N\text{-}NO_3$		0.50	0.20	0.36	0.26	0.82	0.16	0.85
NH_4		0.57	0.25	0.59	0.81	0.82	0.28	0.73
SO_4^{2-}		69	81	46	109	140	67	63
NaCl		114	121	59	309	101	86	116
Cl^-		63	73	36	105	61	52	70
PO_4^{3-}		0.23	0.22	0.27	0.27	0.23	0.24	1.13
DO	%	111	93	99	100	87	91	73
Chl *a*	µg l^{-1}	25.2	7.2	4.95	1.86	3.2	6.4	8.25

Samica Stęszewska river (0.16 mg l^{-1}). Filamentous algae were observed in a wide range of electrolytic conductivity (EC) and the Total Dissolved Solids (TDS) – from 387 to 946 (µS cm^{-1}) and 198-538 (mg l^{-1}), respectively. The pH of water in all ecosystems was alkaline (9>pH≥7.5).

The relationships between 16 environmental factors and the filamentous algae distribution in water ecosystems were investigated. The Monte Carlo permutation test was used with 999 permutations to reduce the number of ecological variables and revealed that the water depth and concentration of chlorides, orthophosphates, nitrates, total dissolved solids and chlorophyll *a* are independent environmental gradients, significantly related to the composition of filamentous algae assemblages (p<0.05, Table 3). The content of chlorophyll *a*, nitrates, orthophosphates, sulfates and water pH, dissolved oxygen, color and water turbidity were also correlated with the first CCA axis, while the second CCA axis was associated with the water depth, electrolytic conductivity, total dissolved solids and concentration of chlorides and sulfates (Table 4).

Table 3

Results of the forward selection of environmental parameters (Monte Carlo permutation test in CCA, P<0.005 are statistically significant)

Parameter	λ	P	F
Cl^-	0.67	0.001	18.41
$P\text{-}PO_4$	0.36	0.001	10.41
TDS	0.25	0.001	7.71
$N\text{-}NO_3$	0.17	0.001	5.28
Chl *a*	0.15	0.001	5.09
Depth	0.15	0.001	4.98

Table 4

Pearson's correlation coefficients between CCA ordination scores (the first three axes) for filamentous algae and environmental factors (n = 187; p<0.05 are statistically significant and given in bold)

	CCA AXIS 1 Eigenvalue: 0.79	CCA AXIS 2 Eigenvalue: 0.66	CCA AXIS 3 Eigenvalue: 0.23
AXIS 1	-	0.03	**-0.51**
AXIS 2	0.03	-	0.04
AXIS 3	**-0.51**	0.04	-
Depth	-0.10	**-0.49**	0.00
Chl *a*	**0.61**	0.20	**-0.44**
Temp.	-0.01	0.21	0.18
pH	**-0.50**	-0.19	**0.57**
DO	**-0.30**	-0.27	**0.38**
EC	-0.11	**-0.78**	-0.01
TDS	0.20	**-0.74**	-0.20
$N\text{-}NO_3$	**0.33**	0.14	**-0.33**
$P\text{-}PO_4$	**0.54**	0.04	**-0.66**
SO_4^{2-}	**-0.36**	**-0.85**	0.19
Color	**0.40**	-0.14	**-0.54**
Turb.	**0.39**	-0.13	-0.25
Cl^-	-0.25	**-0.86**	0.05

The occurrence of *Cladophora glomerata*, which was the most common species of all filamentous algae, and the accompanying taxa (*Rhizoclonium* sp., *Vaucheria* sp. and *Stigeoclonium nanun*) was strongly correlated with water fertility (high values of chlorophyll *a*, nitrates and orthophosphate). The occurrence of *C. rivularis*, *Oedogonium capillare* and *Cladophora* sp. was correlated with high concentrations of chlorides and sulfates in shallow water ecosystems. At the same time, the occurrence of *Cladophora fracta* and Zygmenataceae was associated with inconsiderable TDS and electrolytic conductivity (Fig. 6).

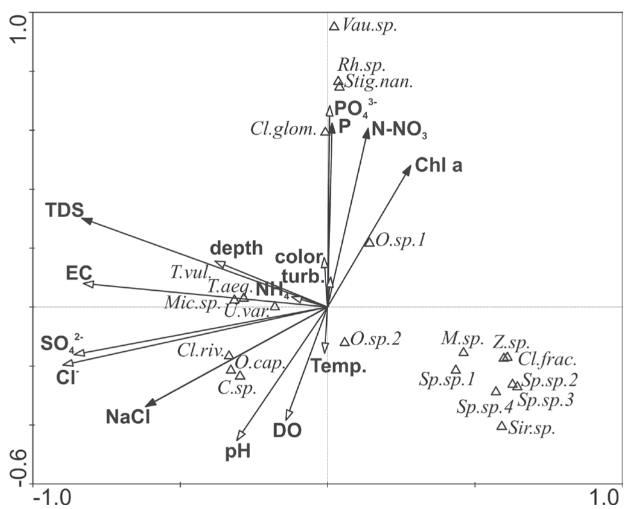

Figure 6

Canonical correspondence analysis (CCA) diagram showing the correlation between species distribution and environmental variables. All axes were found to be highly significant (p<0.005; Monte Carlo Simulation). Vau. sp. – *Vaucheria* sp., Rh. sp. – *Rhizoclonium* sp., Stig. nan. – *Stigeoclonium nanum*, Cl. glom. – *Cladophora glomerata*, O. sp.1 – *Oedogonium* sp. 1, Cl. glob. – *Cladophora globulina*, O. sp. 2 – *Oedogonium* sp. 2, M. sp. – *Mougeotia* sp., Z. sp. – *Zygnema* sp., Cl. frac. – *Cladophora fracta*, Sp.sp.1. *Spirogyra* sp. 1, Sp.sp.2 – *Spirogyra* sp. 2, Sp.sp.3. – *Spirogyra* sp. 3, Sp.sp.4. – *Spirogyra* sp. 4, Sir. sp. – *Sirogonium* sp., C. sp. – *Cladophora* sp., O.cap. – *Oedogonium capillare*, Cl.riv. – *Cladophora rivularis*, Mic. sp. – *Microspora* sp., U. var. – *Ulothrix variabilis*, T. vul. – *Tribonema vulgare*, T. aeg. – *Tribonema aequale*

Discussion

Floristic diversity of filamentous algae

Our study and the review of the literature data relate to *Cladophora* species and the accompanying filamentous algae in Poland. According to Whitton (1970), *Cladophora glomerata*, *C. rivularis* and *C. fracta* are the most common species of the genus *Cladophora* occurring in eutrophic freshwater ecosystems. Our research confirms this finding, because we found all three species within a short distance between the studied sites in the Wielkopolska Province. Most of the aquatic ecosystems in Poland are characterized by moderate or highly trophic conditions (Gołdyn et al. 2013; Messyasz et al. 2015b) and therefore, they are potential habitats of filamentous algae. Additionally, small lakes (1-5 ha) dominate in Poland and account for 44% of the total number of lakes (Choiński 1991), where filamentous algae, i.e. Oedogoniales and Zygnematales occur and may form dense mats. As reported in the literature, however, the largest numbers of the taxon *Oedogonium* were observed in small water bodies, such as small ponds, pools, roadside ditches, marshes, oxbow lakes, lakes, reservoirs, rivers (Mrozińska-Weeb 1976; Burchardt 1977; Sieminiak 1979; Kuczyńska- Kippen 2009; Pikosz & Messyasz 2015). The large-scale occurrence of *Cladophora* was previously observed in the Great Lakes of North America (Erie, Michigan, Ontario) in the 1950s and 1980s (Higgins et al. 2008). The extensive development of *C. glomerata* was also observed in the lake surveyed during our research (Oporzyńskie Lake) – the species densely covered the water column (Messyasz et al. 2015c). The maximum development of *Cladophora glomerata* in the Skawa river was determined by a few factors, such as the type of substrate, temperature (optimum growth in 15-20°C) and in pH of water (optimum 8.8) (Chudyba 1968). We also noticed that *Stigeoclonium nanum* occurred in small numbers in the Mogilnica river – only a few filaments entangled with *Cladophora glomerata*. Similar observations were made in the Jalala river in spring, where *S. nanum* was found attached to other algae growing in slow flowing waters (Akhtar & Rehman 2009). Species belonging to the genus *Stigeoclonium* show a wide range of ecological tolerance and high morphological plasticity, and may be found in different ecosystems, e.g. rivers, lakes, canals and ponds (Francke 1982). Only free-floating forms of *Spirogyra* species were observed during our research, which confirms the previous studies that the genus is represented mostly by free-floating (rarely attached) filamentous algae (Chalotra et al. 2013).

Our study demonstrates that representatives of filamentous algae may occur in all types of water ecosystems, such as lakes or rivers, despite the fact that these habitats are significantly different in term of their physicochemical parameters. Their occurrence is, among others, a result of a high tolerance to changes in temperature and light conditions.

Characteristics of filamentous algae

Numerous floristic data confirm the occurrence of filamentous algae in lowland lakes and rivers, but the studies usually do not take the structure of species and ecological characteristics into account (South & Whittick 1987; Pieczyńska 2008). Knowledge of filamentous algae from Poland, particularly of the genera *Oedogonium*, *Spirogyra* and *Cladophora* (most commonly recorded), comes from a few sources. The filamentous algae are an important component of the littoral communities in aquatic ecosystems, because they are one of the main primary oxygen producers. Nonetheless, studies of the vegetation in the littoral zone generally relate to macrophytes (Cambra & Aboal 1992). In Spain, the most common filamentous algae belonged to 7 genera, including the most frequent *Oedogonium*, *Spirogyra* and *Mougeotia* (Cambra & Aboal 1992). In Poland, Chudyba (1968) divided *Cladophora glomerata* from the Skawa river into two groups based on the morphological variation. Samples collected from the fast flowing water were referred to as *C. glomerata rheobenthicum* and from the slow flowing water – as *C. glomerata limnobenthicum*. We also observed intraspecific variability between *C. glomerata* from the surveyed rivers and from the lake. Thalli of *C. glomerata* in the lentic waters were fruticose and relatively short (up to 20 cm), while in the river waters – long and characterized by a small number of branches. Significant changes at the cellular level (length, width, the number of pyrenoids and cell nuclei) were observed in the filaments of *C. glomerata* collected from the lowland rivers (Nielba, Mogilnica, Samica Stęszewska). These changes could result mainly from hydrodynamic (diverse water flow) and thermal differences in the surveyed habitats. Morphological plasticity is characteristic of filamentous algae, which frequently causes problems during taxonomic identification (van den Hoek 1963; Starmach 1972). Even the degree of branching in each individual plant can affect the cell size (Ross 2006). Some information on the cell structure, morphological variation and biology of *Cladophora* genera are provided by van den Hoek (1963) and Whitton (1970).

Environmental gradients

According to van den Hoek (1963) and Robinson & Hawkes (1986), physiological requirements of most freshwater filamentous algal species restrict their distribution to eutrophic conditions (high nutrient concentrations and alkaline conditions). In addition, *Cladophora* species grow well at temperatures ranging from 15 and 25°C, in hard and alkaline waters (Wong et al. 1978, Whitton 1970). A similar trend was observed in the case of other filamentous green algae, i.e. *Cladophora glomerata*, *C. rivularis* and *C. fracta* – relatively high values of nutrients were determined in our study when analyzing the chemical composition of their habitats. Although all these species occurred in shallow waters, the optimum for *Cladophora glomerata* development was in the conditions of high concentrations of nitrate and orthophosphate and *Cladophora rivularis* requires a high content of chlorides and sulfates. There are other macroscopic green algae species such as representatives of *Ulva*, which occur mostly in eutrophic waters with high concentration of NaCl of anthropogenic origin (Messyasz & Rybak 2011; Messyasz et al. 2015a).

On the other hand, small values of TDS and electrolytic conductivity characteristic of slightly eutrophic waters (e.g. the pond in Poznań) were clearly favored by *Cladophora fracta*. Moreover, the accompanying Zygnemataceae taxa occur mainly in waters rich in dissolved oxygen and often form a filamentous mass overgrowing aquatic plants (Worobiec & Worobiec 2008). From environmental factors, both nitrogen depletion and light intensity have been regarded as key factors inducing the conjugation of *Spirogyra* (Zwirn et al. 2013). Additionally, the low level of nutrients determines the development and growth of *Spirogyra* filaments, rather than water temperature (Wongsawad & Peerapornpisal 2015). The obtained data show that individual species of filamentous algae occurred in specific environmental conditions.

Conclusions

1. Despite the common occurrence of filamentous

algae in Poland, they have been studied very superficially.
2. Large-scale development of filamentous algae corresponds to eutrophic water conditions.
3. The following environmental factors (Cl^-, TDS, water depth, $N\text{-}NO_3^-$, PO_4^{3-}, Chl *a*) were statistically significant for the occurrence of filamentous algae.
4. Species from *Cladophora*, *Oedogonium* and *Spirogyra* are most frequent in water ecosystems in Poland.
5. The results also demonstrated that more data are required on the growth of filamentous algae species in small water bodies, lakes and rivers to more accurately assess their role in the entire littoral community.

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