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New data on distribution, morphology and ecology of *Oedogonium capillare* Kützing ex Hirn (Oedogoniales, Chlorophyta) in Poland

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Abstract: Algological investigations were focused on taxonomy, chorology and ecology of threatened filamentous green alga species in Poland. Studies on *Oedogonium capillare* Kützing ex Hirn growing in large quantities in association with *Cladophora rivularis* (Linnaeus) Hoek in pond were conducted. The aim of these studies was to describe the distribution, ecology and morphology of *O. capillare* as part of a more comprehensive study of this filamentous green alga. It is the eighth record in Poland for *O. capillare*. Filaments of *O. capillare* were grown over a wide pH range (7.3-9.6) and in high variability of nutrients. Vegetative cells, oogonia and antheridia were observed, which allowed taxonomic identification. *O. capillare* occurs in eutrophic waters which requires protection of its habitat.

Key words: *Oedogonium capillare*, Poland, pond, filamentous green algae

1. Introduction

Macroscopic filamentous algae, including Chlorophyta, may form patches (mats) on the water surface (free-floating thalli) and in the benthos (thalli attached to the bottom or macrophytes) in lakes and rivers. These algae play an important role in functioning of aquatic ecosystems. *Oedogonium* species belong to Chlorophyta, include 534 species (Mahato 1999) and are classified as filamentous green algae. These species are cosmopolitan in freshwater ecosystems and prefer stagnant waters, such as small ponds, pools, roadside ditches, marshes, oxbows, lakes, reservoirs, rivers (Mrozińska-Weeb 1976; Burchardt 1977; Sieminiak 1979; Kuczyńska-Kippen 2009; Pikosz & Messyasz 2015). However, most *Oedogonium* taxa were found in small water bodies (Szymańska *et al.* 2015). *Oedogonium* species may grow throughout the year, but maximum reproductive development in the lowlands was observed in June and less in August (Mrozińska-Webb 1976). Young thalli are attached to macrophytes (mainly on the *Glyceria maxima* (Hartm.) Holmh., *Equisetum fluviatile* L. and *Phragmites australis* (Cov.) Trin. ex Steud.) by a basal holdfast and, as mature organisms, may form mats on the surface of water. *Oedogonium* mostly form multispecies mats and might be associated with *Spirogyra*, *Rhizoclonium, Cladophora* (Khanum 1982; Messyasz *et al.* 2015).

The first records of *Oedogonium* species in freshwater habitats from Poland were reported in the late 19th century by Hilse (1860), Gołowin (1964), Kirchner (1878), Kozłowski (1895) and Gutwiński (1897). Mrozińska was the first Polish phycologist examining this group in details (in terms of morphology, phenology, ecology and distribution) and described more than 400 species (including varieties and forms), mainly from southern Poland (Mrozińska 1958, 1981, 1984). According to Mrozińska (1991), there are 20 groups of *Oedogonium* based on phylogenetic analysis. Szymańska *et al.* (2015) presented species of Oedogoniales from north-eastern Poland and described two species of *Oedogonium*, namely *Oedogonium fremyi* and *Oedogonium irregular,* new for the algal flora of Poland. The first and detailed information of rare *Oedogonium capillare* was produced by Mrozińska (1984) and Sieminiak (1979), who described two forms of this

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species: *O. capillare* f. *stagnale* Hirn and *O. capillare* f. *capillare* Kützing ex Hirn.

The main aim of the study was to review distribution and morphology of the *O. capillare,* mainly in Poland and to provide new information about this taxon. In our research, *O. capillare* is characterized by a slightly oval oogonium (not visible typical, cylindrical shape) and grows in ponds. *O. capillare* was found only in a few places in Poland, so the information on its distribution and ecological requirements is important. Because of its rarity, this species is considered as threatened in Poland and is placed in the Red List of Algae in the category: vulnerable (VU) (Siemińska *et al.* 2006).

2. Material and methods

Studies on *O. capillare* were carried out during summer (July-August) in 2014 in a small (area 29.48 a; length 81.86 m; width 47.29 m), shallow (depth 1 m), agricultural pond in Konojad in Wielkopolska Voivodeship, Poland (N52˚10'14.17'', E16˚31'24.51''). During the study period, water depth ranged from 50 up to 70 cm. Based on literature data and our own research, sites of the *O. capillare* occurrence in Poland were marked on the map (Fig. 1). Terminology of recorded macrophytes follows Mirek *et al.* (2002).

Filaments appeared concentrated, tightly covering a significant surface of water, which reached up to 70% of the pond. The filaments of free-floating green algae (like mats) were taken from the surface by hand, placed in a plastic container and transported to the laboratory. Next, the filaments were rinsed repeatedly with distilled water in order to remove any biotic and abiotic particles attached to them. The specimens were examined with the LM and the ProCap program. The length, width and shape of cells, and number of pyrenoids were measured. Distinctive features were compared with morphometric data for *O. capillare* recorded in Poland and Europe, included in the Mrozińska key (1984), Sieminiak (1979), Tiffany (1937), Novis (2003) and Venkataraman & Natarajan (1959).

Physico-chemical parameters of water: temperature (˚C), electrolytic conductivity ($\mu S \cdot cm^{-1}$), oxygen saturation ($mg \cdot L^{-1}$), TDS ($mg \cdot L^{-1}$) and pH at the examined sites were measured by YSI Professional Plus handheld multiparameter gauge. Water samples were also taken for detailed laboratory analyses to measure the content of nitrogen, phosphorus and sulphates with HACH DR 2800 spectrophotometer (Hach Lange 2006).

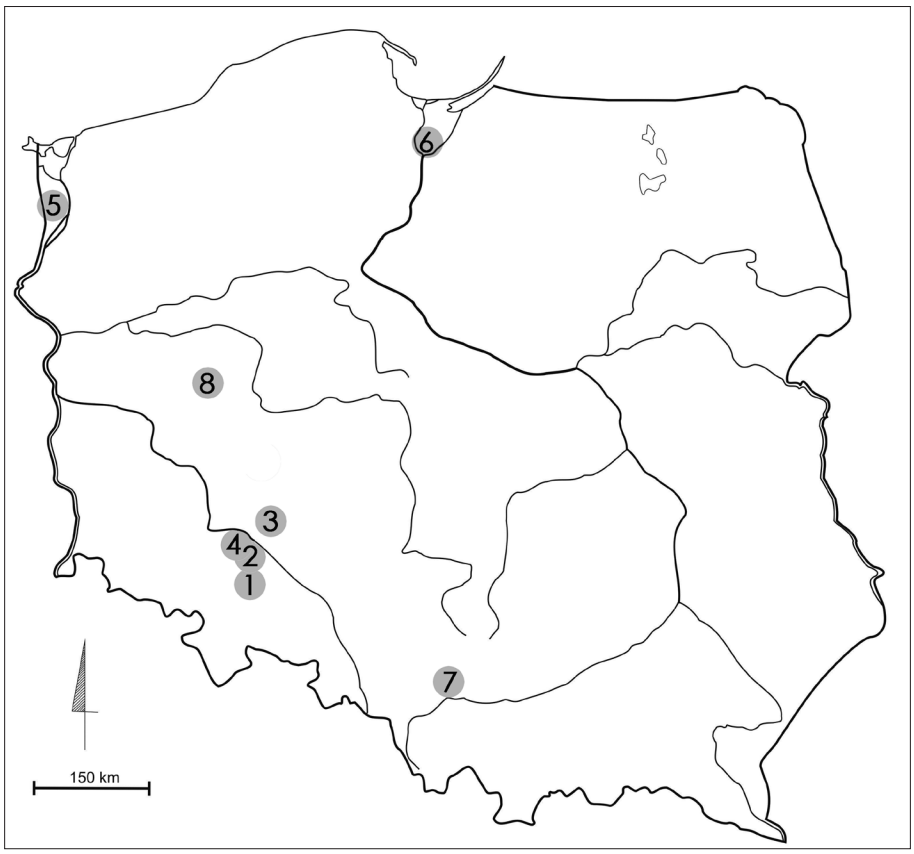

Fig. 1. The location of *Oedogonium capillare* in Poland
Explanations: 1 – Strzelin, 2 – Ołtaszyn, 3 – Domaszczyn, 4 – Sołtysowice, 5 – Szczecin, 6 – Koniecwałd, 7 – Przeczyce, 8 – Konojad

Table 1. Physical and chemical parameters of water for *Oedogonium capillare* in midfield pond in 2014 (n=5)

Parameter	Unit	Minimum	Maximum	Mean	SD
Temperature	°C	20.1	22.3	21.5	0.86
EC	$\mu S \cdot cm^{-1}$	875	963	925	37.70
pH	-	7.3	9.6	8.3	1.00
OS	$mg \cdot L^{-1}$	9.6	22.5	16.3	6.10
TDS	$mg \cdot L^{-1}$	532	642	600	43.50
NO_3^-	$mg \cdot L^{-1}$	0.1	0.4	0.26	0.11
NH_3	$mg \cdot L^{-1}$	0.05	0.2	0.14	0.06
NH_4	$mg \cdot L^{-1}$	0.06	0.23	0.17	0.07
PO_4	$mg \cdot L^{-1}$	0.07	0.25	0.11	0.08
SO_4	$mg \cdot L^{-1}$	90	115	101	11.26
Cl^-	$mg \cdot L^{-1}$	86	122	101	16.03

Explanations: SD – Standard Deviation, EC – Electrolytic Conductivity, OS – Oxygen Saturation, TDS – Total Dissolved Substance

3. Results

The polyalgal mats in the pond in Konojad were formed by representatives of green algae: *O. capillare* Kützing ex Hirn and *Cladophora rivularis* (Linnaeus) Hoek. It was the eighth described site of occurrence of *O. capillare* in Poland (Fig. 1). *Oedogonium* filaments appeared at the end of June, and in July-August were found dominant in a macroalgal mat. *O. capillare* grew over a broad pH range (7.3-9.6) and presented wide tolerance to the content of nutrients in water (Table 1). Significant changes were observed in the content of nitrates, ammonia nitrogen, phosphates and rather stable values of sulphates and chlorides were also recorded. Other values of physicochemical habitat parameters (electrolytic conductivity, total dissolved substance, water temperature, oxygen saturation) also achieved large values and amounted to 875-963 $\mu S \cdot cm^{-1}$, 600 $mg \cdot L^{-1}$, 20-22˚C, 9.6-22.5 $mg \cdot L^{-1}$ respectively (Table 1).

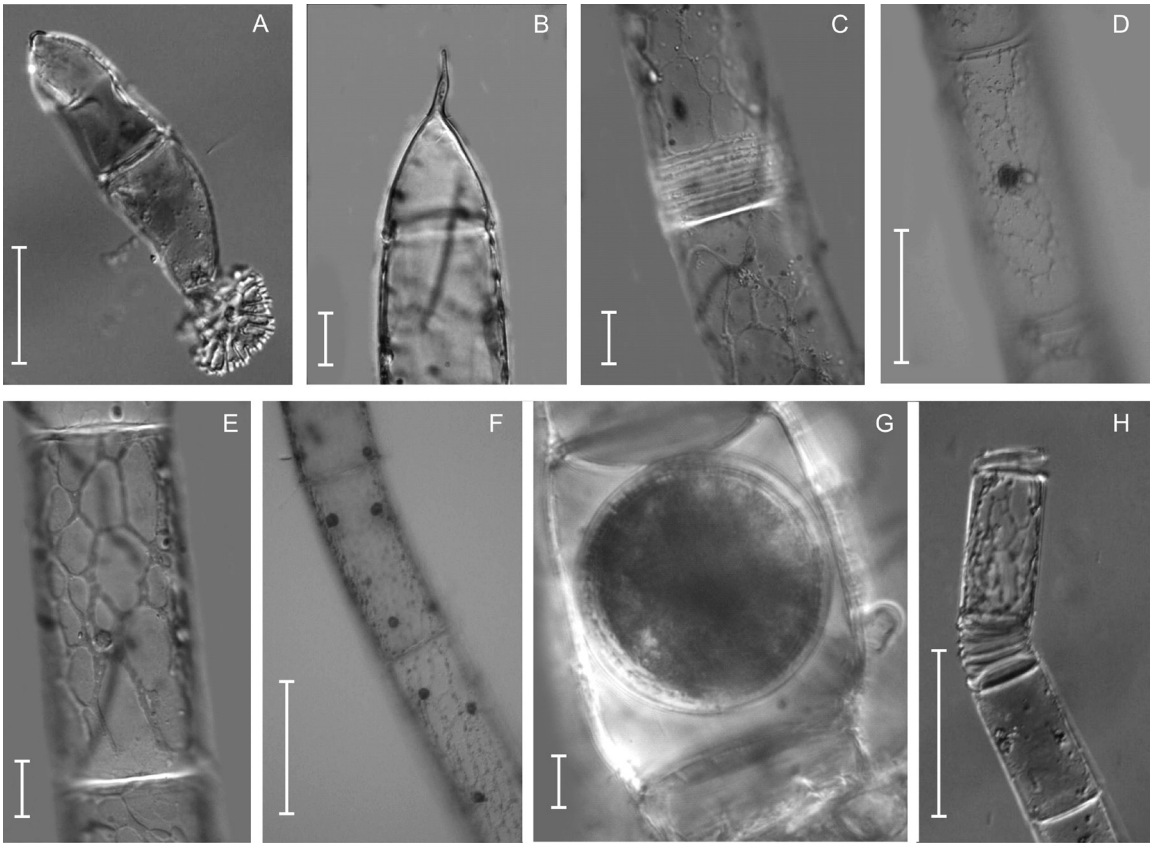

Fig. 2. *Oedogonium capillare* from the pond in Konojad (photograph by M. Pikosz, 2014)
Explanations: A – young thalli, B – apical cell, C – apical cap, D – nucleus, E – vegetative cell with reticulate chloroplast, F – pyrenoids in the cell, G – oogonium – generative cell, H – antheridial cells; scale, A, D, F – 50 µm, B, E – 15 µm, C, G – 10 µm; H – 100 µm

Table 2. Comparison of morphometric features (minimum-maximum) of *Oedogonium capillare* from different site in USA, New Zeland, India and Poland

Features	Unit	Lake Erie USA[1]	Chatham Island New Zeland[2]	Kerala India[3]	Przemsza Poland[4]	Konojad Poland[5]
width of veg. cells	[µm]	35-56	33-40	34-46	35-60	37-56
length of veg. cells	[µm]	36-120	31-55	46-76	35-120	30-102
width of oogonium	[µm]	40-60	45-55	42-46	35-65	30-52
length of oogonium	[µm]	35-75	39-54	34-57	45-75	30-55
width of oospory	[µm]	30-50	43-49	36	30-52	n.d.
length of oospory	[µm]	35-65	32-48	30-38	35-65	n.d.
width of internal antheridium	[µm]	30-48	22-26	34-38	30-48	28-38
width of external antheridium	[µm]	5-10	4-6	7-11	5-10	n.d.
number of pyrenoids	No.	n.d.	5-12	n.d.	n.d.	6-10
diameter of pyrenoids	[µm]	n.d.	n.d.	n.d.	n.d.	3-5
shape of pyrenoids	-	n.d.	n.d.	n.d.	n.d.	discoid

Explanations: veg. cells – vegetative cells, n.d. – no data; [1] – Tiffany (1937), [2] – Novis (2003), [3] – Venkataraman & Natarajan (1959), [4] – Sieminiak (1979), [5] – own research

O. capillare filaments and their cells were subjected to morphometric analysis. Filaments of *O. capillare* were multicellular, unbranched and composed of basal, tapered apical and vegetative cells (Fig. 2A-B). Vegetative cells had characteristic cap cells with rings (Fig. 2C), one nucleus (Fig. 2D) and reticulate multipyrenoid chloroplasts (Fig. 2E-F). Cylindrical cells of *O. capillare* were 37-56 µm wide and 30-102 µm long with 6, 8 or 10 discoid pyrenoids, 3-5µm in diameter and one nucleus in the central part of the cell (6-10 µm). Young organisms were attached to substrata such as macrophytes or stones by a holdfast – a specially adapted cell. In the later stage of development, free floating filaments were observed. Only single individuals of this species formed generative cells during research and, on this basis, it was possible to classify them to species as *O. capillare*. August was a reproductive season for solitary, spherical oogonia with ~30 µm in diameter to be attached to *female filaments* (Fig. 2G). Antheridia 28-38 µm wide, intercalary, 4-6 in series were noted in male filaments (Fig. 2H).

4. Discussion

The genus *Oedogonium* (Oedogoniaceae, Chlorophyta) consists of species, which are present only in freshwater ecosystems. *Oedogonium* grows in different types of ecosystems from reservoirs, lakes, ponds to rivers and drainage ditches. More than 100 species occur in Poland (Central Europe), of which *O. intermedium* Wittrock and *O. undulatum* (Brébisson) Al. Braun are the most widespread (Mrozińska 1984). *O. capillare* is a cosmopolitan species in freshwater habitats. It was found in Europe, North America, Africa, Asia and New Zealand (Venkalaraman & Natarajan 1959; Day *et al.* 1995; Baba *et al.* 2011; Broady *et al.* 2012). Untill 2015, *O. capillare* was found in freshwaters of Europe taking into consideration sites in Britain (Whitton *et al.* 1998; Huxley & Pentecost 2002), 6 records in Romania (Caraus 2012), 16 locations (14 for *O. capillare* and 2 for *O. capillare* f. *stagnale*) in Spain (Alvárez & Gallardo 1986; Cambra *et al*. 1998), 4 in Sweden, 1 (for *O. capillare* var. *fluitans*) in Germany and in such other countries as Denmark, Finland, France, Germany, Italy, Spain, Sweden (Venkalaraman & Natarajan 1959). In Poland, this taxon was recorded in 1860 (Hilse 1860) in a pool and a ditch in Strzelin (near Wrocław) where it appeared from June till October and in Domaszczyn (Hilse 1860) (Fig. 2). Mrozińska-Webb (unpublished) observed this taxon in a reservoir in Koniecwałd (Malbork) and in Upper Silesia in the Przemsza River in February 1978 in alkaline (8 pH) water at 6˚C (Sieminiak 1979). A location of the *O. capillare* in Wielkopolska Voivodeship was recorded for the first time in 2012, in Konojad village (Pikosz 2012) where it also appeared in the following years forming mats, which occupied large area.

The occurrence of *Oedogonium* species in any particular location seems to be governed mainly by biotic and abiotic factors. Abundance of *Oedogonium* species depends on temperature, light intensity and type of habitats. Sieminiak (1979) observed a community of *O. capillare* at 6˚C on a muddy river bottom . Sampling sites characterized by near neutral pH values were similar to measurements from lake Erie (Tiffany 1937), stream in New Zealand (Novis 2003) and from the Przemsza River (Sieminiak 1979), where *O. capillare* were also noted. However, it should be noted that *Oedogonium* rarely reproduces in flowing waters (Mrozińska 1984). Ponds, where water heats

up quickly, is a type of ecosystem, which is mostly inhabited by *Oedogonium* species (Mrozińska 1984). In the Konojad pond, abiotic parameters allowed large development of filaments, which later formed considerable floating mats on the pond surface. The obtained results showed that *O. capillare* occurred in water at 20°C and high nutrient and sulphate concentrations played an important factor in algae growth. In previous studies, sulphate content was not measured in waters where *O. capillare* developed. However, our studies indicate that filaments of this species were growing in the presence of high concentrations of this compound. *O. capillare* occurred with *C. rivularis* corroborating the assumption of Khanum (1982), that *Oedogonium* generally never formed independent mats, but coexisted with other species, such as *Spirogyra* and *Rhizoclonium*.

The specimens were slightly similar to those described previously (Table 2). Maximum vegetative cell lengths (more than 100 μm) were most similar to those of *O. capillare* from Lake Erie (Tiffany 1937) and from Poland (Mrozińska 1984). Oogonia, in these specimens, were spherical and more rounded than in the illustrations of Novis (2003) and Mrozińska (1984). In most specimens in our research, we observed mainly oval oogonia.

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