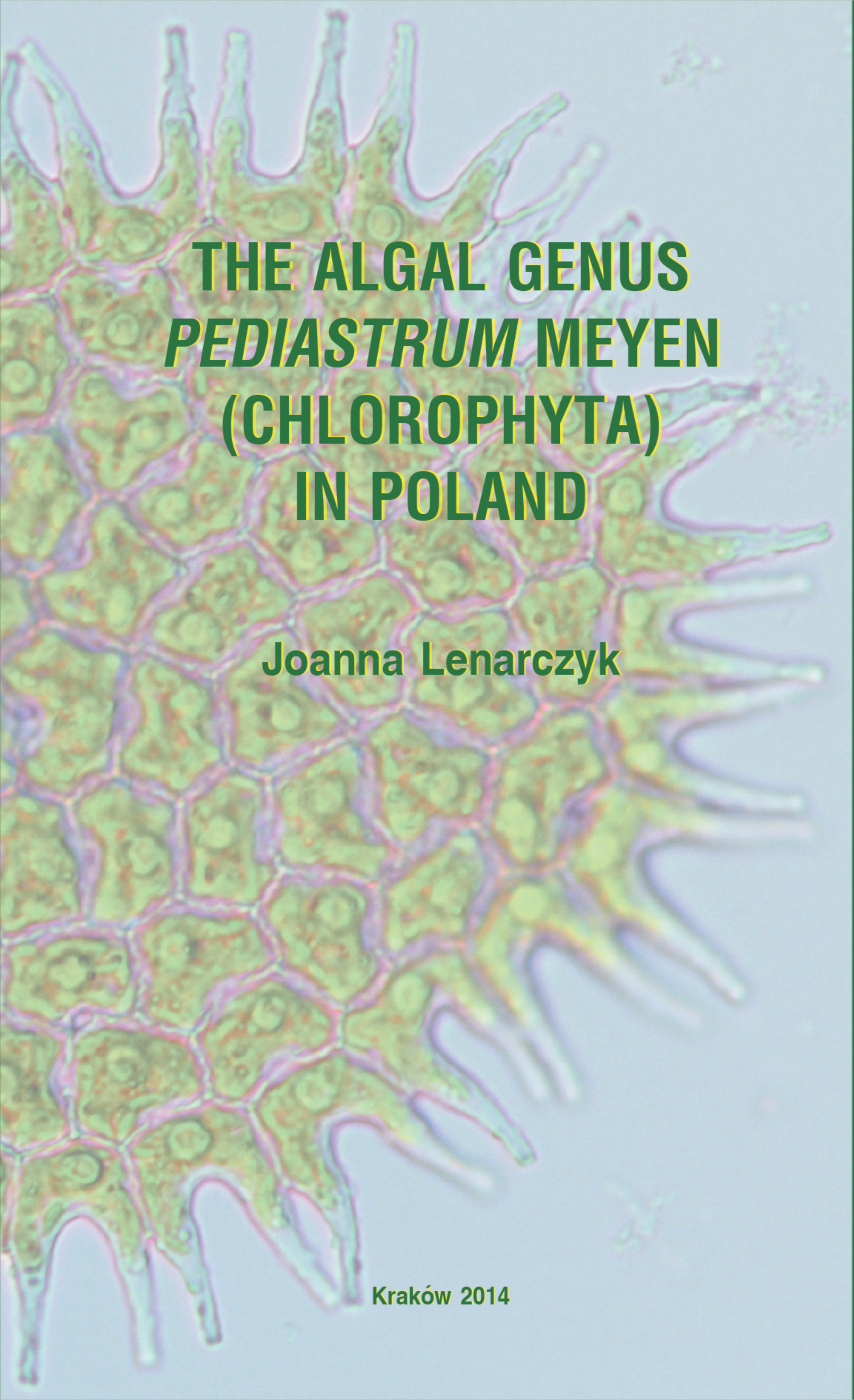

THE ALGAL GENUS *PEDIASTRUM* MEYEN (CHLOROPHYTA) IN POLAND

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For my dear mother,
who was with me
when I started my research.
Now I can only trust
that she is still close to me.

Contents

Abstract. Three years of taxonomic and environmental studies (2008–2010) on the green algal genus *Pediastrum* Meyen confirmed its occurrence at 50 of 71 localities situated in northern, central and southern regions of Poland. The genus commonly occurs in the littoral of eutrophic water bodies, especially coastal lakes and fish ponds. *Pediastrum* co-exists mainly with other taxa of Chlorophyceae and its share in algal communities is low. All together, 32 *Pediastrum* taxa belonging to 19 species occur in Poland, 23 of which were found in the field studies described here: *P. simplex* Meyen var. *simplex*, *P. simplex* var. *echinulatum* Wittrock, *P. musteri* Tell et Mataloni, *P. patagonicum* Tell et Mataloni, *P. kawraiskyi* Schmidle, *P. orientale* (Skuja) Jankovská et Komárek, *P. integrum* Nägeli var. *integrum*, *P. boryanum* (Turpin) Meneghini var. *boryanum*, *P. boryanum* var. *pseudoglabrum* Parra, *P. boryanum* var. *cornutum* (Raciborski) Sulek, *P. boryanum* var. *perforatum* (Raciborski) Nitardy, *P. boryanum* var. *longicorne* Reinsch, *P. boryanum* var. *brevicorne* A. Braun, *P. boryanum* var. *forcipatum* (Corda) Chodat, *P. duplex* Meyen var. *duplex*, *P. duplex* var. *gracillimum* W. West et G.S. West, *P. duplex* var. *rugulosum* Raciborski, *P. duplex* var. *asperum* (A. Braun) Hansgirg, *P. alternans* Nygaard, *P. angulosum* (Ehrenberg) Meneghini var. *angulosum*, *P. privum* (Printz) Hegewald, *P. tetras* (Ehrenberg) Ralfs and *P. biradiatum* Meyen var. *biradiatum*. Eight of these taxa are rare on the world scale: *P. musteri*, *P. patagonicum*, *P. privum*, *P. alternans*, *P. duplex* var. *asperum*, *P. integrum* var. *integrum*, *P. kawraiskyi* and *P. orientale*. Nine other taxa previously recorded in the Polish literature were not confirmed in the present study: *P. simplex* var. *clathratum* (Schröter) Chodat, *P. simplex* var. *sturmii* (Reinsch) Wolle, *P. subgranulatum* (Raciborski) Komárek et Jankovská, *P. argentinense* Bourrelly et Tell, *P. obtusum* Lucks, *P. longecornutum* (Gutwiński) Comas, *P. biradiatum* var. *glabrum* (Raciborski) Parra, *P. braunii* Wartmann and *P. taylori* Siemińska. Study of a newly created culture collection composed of 12 isolates representing 9 *Pediastrum* taxa, together with observations of field material, suggest that *P. simplex*, *P. boryanum*, *P. duplex*, *P. orientale* and *P. tetras* are the most variable Polish *Pediastrum* species. The morphological variability of *Pediastrum* creates problems in determining its varieties. For correct identification of taxa, morphological analyses of field and cultured material should be supplemented by molecular studies. The present study is offered as a contribution to world ecological and biogeographic studies on *Pediastrum*.

Introduction

Both the Latin name (*Pediastrum*, from the Greek root *astron* – star; Meyen 1829) and the Polish name (*gwiazdoszek*) for organisms of this genus accurately describe the typical form of this microscopic green alga (Chlorophyceae, Sphaeropleales, Hydrodictyaceae; Deason *et al.* 1991): the star-shaped representatives of the genus *Pediastrum* occur in the form of a flat round coenobium with radially oriented marginal cells having processes of various length and shape. A coenobium is a special grouping of cells originating from a single maternal cell. All cells are the same age and their number does not change after the coenobium forms (Komárek & Fott 1983). The processes have tiny apical pores through which tufts of bristles are released from organisms living in plankton (Petersen 1912) or drops of gelatinous substance are released from benthic organisms (Wołoszyńska 1924, 1925). The inner cells of *Pediastrum* are connected to each other either by convex elements, that is, by lobes, forming perforated coenobia, or by their sides, forming full coenobia. Besides the shape of coenobia and their cells, and the number and manner of composition of the cells, another important diagnostic character is the cell wall surface, which can be smooth or variously ornamented. More information about coenobium morphology is given by Sulek (1969), Parra (1979), Komárek & Fott (1983) and Komárek & Jankovská (2001).

More than 350 names of *Pediastrum* species, varieties and forms have been published since the German botanist and physicist Franz J.F. Meyen described the genus in 1829 (Parra 1979). Among the first to make taxonomic studies of the genus were Kützing (1845), Ralfs (1848), Nägeli (1849), A. Braun (1855), Raciborski (1889) and Nitardy (1914). As early as the end of the 19th century Raciborski noted that many of the names of *Pediastrum* taxa were synonyms. Later studies of morphological variability revealed high plasticity of *Pediastrum* taxa (e.g. Troickaja 1927; Bigeard 1933; Goriaczew 1960, 1961, 1963, 1966; Sulek 1969; Parra 1979, 1984; Neustupa & Hodač 2005). As scanning electron microscopy came into wider use in the mid 20th century, *Pediastrum* cell wall ultrastructure drew the attention of researchers. Such studies were done mainly by Parra (1979, 1984), and also by Couté & Tell (1979), Millington *et al.* (1981), Tell & Mataloni (1990), Hegewald & Yamagishi (1994), Krienitz *et al.* (1998), Hegewald & Jeon (2000), Nielsen (2000) and others. There are taxa whose cell wall ultrastructure has not yet been adequately described (Komárek & Jankovská 2001). Maintenance of *Pediastrum* in culture and the use of advanced microscopy techniques have enabled many studies on the cytomorphology of the genus, describing the formation of its coenobium (Moner & Chapman 1963; Davis 1967; Gawlik & Millington 1969; Millington & Gawlik 1970; Marchant 1974, 1979; Ueda & Nonaka 1992), and also experimental work on the impact of environmental factors on coenobium development (Richardson *et al.* 1975; Rands & Davis 1979; Schraudolf & Frauenkron 1979; Chang & Chang-Schneider 1980; Rojo *et al.* 2009). Recent years have seen the first publications presenting the results of phylogenetic studies on *Pediastrum*, focused on the position of this genus in the systematics of green algae (Krienitz *et al.* 2003) and the relationships between selected species and varieties (Buchheim *et al.* 2005; McManus & Lewis 2005, 2011; McManus *et al.* 2011; Jena *et al.* 2014).

Attempts to make a proper classification of *Pediastrum* have led to the publication of many taxonomic systems that rely on particular morphological characteristics observed in field and cultured material, as well as on genetic characteristics. Komárek & Jankovská (2001) listed 43 taxa belonging to 24 species in the most recent monograph concerning *Pediastrum* taxa worldwide. Since then, additional new taxa have been published, including the fossil *P. leonensis* (Tell & Zamaloa 2004), *P. aniae* found recently in Cuba (Comas 2005) and *P. willei* recorded from Spain (Comas *et al.* 2006).

The genus *Pediastrum* occurs commonly around the world (van den Hoek *et al.* 1995) and has been recorded very often from Europe (Nygaard 1949; Uherkovich 1973; Komárek & Fott 1983; John *et al.* 2002; Schmidt *et al.* 2003; Hindák & Hindáková 2008; Weckström *et al.* 2009), Africa (Schmidle 1901, 1903; Borge 1928; Krienitz *et al.* 1998), North America (Wolle 1884; Smith 1950; Prescott 1962; Dillard 1989), Central America (Comas 1989), South America (Bohlin 1897; Schmidt & Uherkovich 1973; Tell 2004), Asia (Lemmermann 1908; Yamagishi 1992; An *et al.* 1999; Tsarenko *et al.* 2000) and Australia (Ling & Tyler 2000). Only a few species are cosmopolitan, however. The geographical distribution of the other species is restricted; they occur rarely, sometimes at only a few localities very distant from each other (Komárek & Jankovská 2001). *Pediastrum* lives mainly in eutrophic water. It has been observed in plankton, the benthos and the periphyton. Some taxa are associated with waters having lower trophy or even dystrophic waters. Some have been observed in coastal lakes, in sea water, in rivers and on wet rocks (Parra 1979; Komárek & Jankovská 2001). Some taxa are widely distributed in various habitats. Other require specific environmental conditions (Parra 1979). Common *Pediastrum* species are treated as indicators of oligo- and ß-mesosaprobic waters (Sládeček & Sládečková 1996).

The genus *Pediastrum* has not been sufficiently studied in Poland. Siemińska & Wołowski (2003) listed about 160 Latin names of taxa given in Poland by various authors up to 1990. Only 24 names of *Pediastrum* taxa, including 10 names of species, can be found on the valid list of taxa given by Komárek & Jankovská (2001). This means that about 140 other names need to be verified.

Only a few works, including three monographs, are devoted exclusively to *Pediastrum* taxa in Poland. Raciborski (1889) wrote about taxa occurring in water bodies near Cracow, Lucks (1906/1907) studied them in lakes of western Pomerania, and Sitkowska (1992) identified taxa from ponds near Łódź. Two other works described taxa occurring in the Pojezierze Łęczyńsko-Włodawskie lakeland (Malicki 1972; Pasztaleniec & Poniewozik 2004). The most recent papers of Kowalska & Wołowski (2010a, b) are dovoted to *Pediastrum* taxa occurring in northern Poland. All of those works contain iconographic documentation in the form of line drawings or photos. They each relate to rather small areas of Poland and similar habitats.

Information on the occurrence and ecology of *Pediastrum* taxa in Poland is scattered in about 400 publications (Siemińska 1990; Siemińska & Pająk 1992), usually in lists of taxa in studies of other algal groups, often without any iconographic documentation, making it impossible to verify the taxonomic determination. A few papers give line drawings of *Pediastrum*, and occasionally light microscopy (LM) or scanning electron microscopy (SEM) images. Documented information can be found in publications concerning various habitats, including ponds (e.g. Sosnowska 1956; Kadłubowska 1961; Bednarz & Nowak 1972; Kowalski 1975; Sitkowska 1992; Wołowski & Kowalska 2009), lakes having different trophy (e.g. Wołoszyńska 1925; Siemińska 1967; Wojciechowski 1971; Kowalski 1975; Kotlińska 1976; Burchardt 1977; Koczorowska & Wetula 1984; Socha 1993; Kowalska & Luścińska 2006), peat bogs (Wasylik 1961), dam reservoirs (e.g. Bucka & Wilk-Woźniak 2002; Wołowski & Grabowska 2007) and coastal lagoons (e.g. Kowalski 1975; Luścińska 2005). There are some data on *Pediastrum* occurring in fossil material from Poland (e.g. Milecka 1997; A.M. Noryśkiewicz 1999; Bogaczewicz-Adamczak *et al.* 2002; Wołowski *et al.* 2002; Wacnik 2009) and other regions (e.g. Fjerdingstad 1954; Sebestyén 1968; Alhonen & Ristiluoma 1973; Jankovská & Komárek 1982, 2000; Nielsen & Sørensen 1992; Sarmaja-Korjonen *et al.* 2006).

In the literature there is no comprehensive work on Polish *Pediastrum* taxa presenting the genus in various types of habitat for the whole country; hence the need for a monograph describing their diversity and ecological requirements. In the present work their morphological variability (e.g. shape of coenobia and cells, cell wall ornamentation) was examined by LM and SEM in field and cultured material, described, and documented with micrographs. A current list of Polish *Pediastrum* taxa was elaborated, including their synonyms. Their distribution in Polish water bodies, frequency of occurrence and some data on the ecology of *Pediastrum* are given.

Study area

The study covers nine Polish physiographic units called subprovinces. They are presented briefly below, mainly following Kondracki (1994, 2002) and also Choiński (1995a), Raj (2001), Skała (2005) and Górniak (2006a).

I. Southern Baltic Coast – It forms a wide belt along the southern Baltic Sea, and includes maritime landscape with estuaries and moraine lowland with scattered hills.

II. Eastern Baltic Lakelands – They stretch across northern Poland from Olsztyn to the east. The lakes, moraine terrain and extensive lowland are characteristic for early post-glacial landscape. The subprovince forms a separate geobotanical and climatic region.

III. Southern Baltic Lakelands – They are situated in northern and central Poland, south of the Southern Baltic Coast. The early post-glacial landscape is composed of many depressions and lakes without outflow, as well as moraine hills and sandy plains divided by river valleys.

IV. Central Polish Lowlands – They extend south from the border of the last Vistulian glaciation (Southern Baltic Lakelands). These are mainly lowlands without lakes but with some moraine hills of previous glaciations, depressions and river valleys.

V. Polesie – This subprovince is situated in eastern Poland and extends beyond the national border. It is mainly a plain, with many swamps and lakes.

VI. Sudety Mountains and Foothills – They extend across south-western Poland. The highest Sudety mountain range (1200–1450 m a.s.l.) is formed by the Giant Mountains of Poland and the Czech Republic, called Karkonosze in Polish and Krkonoše in Czech. Five climatic zones, including subalpine and alpine, are distinguished in the

Giant Mountains. The most characteristic elements of their landscape are vast plateaus and monadnocks.

VII. Wyżyna Śląsko-Krakowska upland – Situated in southern Poland between Częstochowa and Cracow, it is a tectonic uplift built of a Palaeozoic formation covered by Mesozoic rock.

VIII. Northern Sub-Carpathia – This is a tectonic trench in the foreland of the Carpathians. The area divides the Polish uplands to the north from the Western Carpathians to the south.

IX. Central Western Carpathians – These mountains extend along the southern fringe of Poland. They are composed of mountain ranges on igneous and metamorphic bedrock sometimes overlain by sedimentary rock, as well as valleys.

Several sampling stations were established in each of those subprovinces (Fig. 1):

I.1 – north-western shore of Jezioro Jamno lake in Unieście, sample taken near sewage outflow, around *Phragmites* sp., sandy bottom;

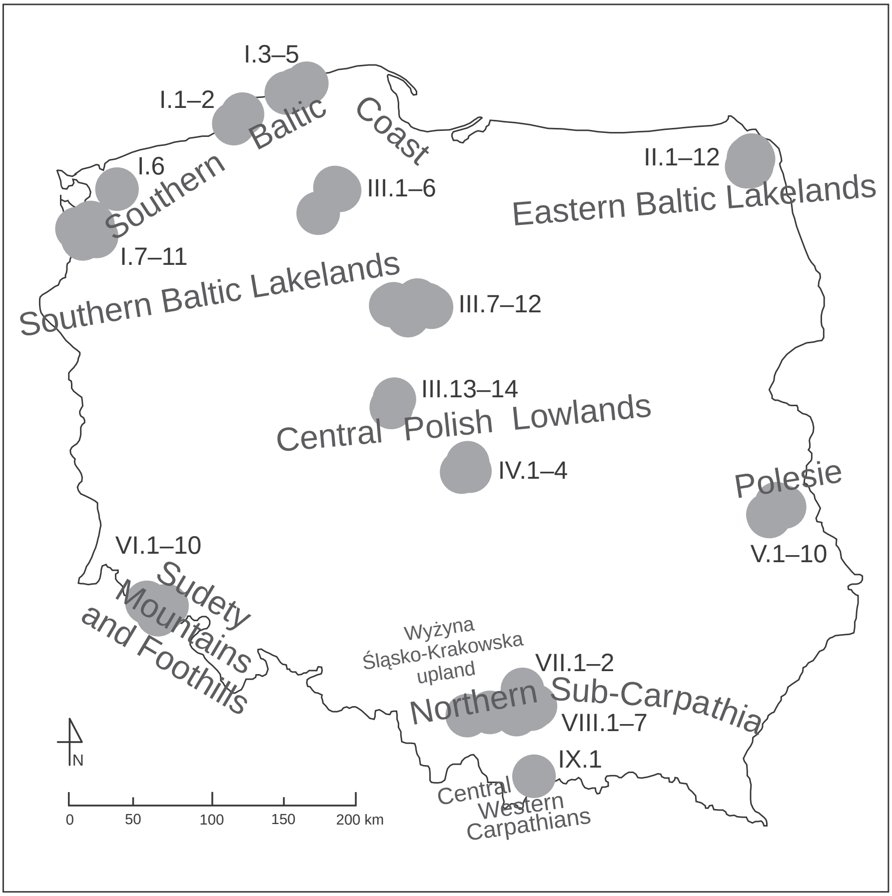

Fig. 1. Location of sampling stations in Poland and area bordering the Czech Republic, shown on map of physiographic units (subprovinces).

I.2 – north-western shore of Jezioro Bukowo lake in Dąbkowice, opposite a restaurant, sample taken from shore, around *Carex* sp., *Phragmites* sp., filamentous algae on bottom;

I.3 – south-eastern shore of Jezioro Gardno lake in Gardna Wielka, sample taken near sandy beach;

I.4 – south-western shore of Jezioro Łebsko lake, near viewpoint in Kluki, sample taken from pier, around macrophytes;

I.5 – south-western shore of Jezioro Sarbsko lake in Nowęcin, sample taken from pier;

I.6 – large pond on Zwycięstwa Street in Golczewo near a historic tower;

I.7 – pond ca. 1 km north-east of Święta;

I.8 – pond ca. 1.5 km east of Święta;

I.9 – eastern shore of Jezioro Bartoszewo lake near Bartoszewo, sample taken near beach;

I.10 – eastern shore of Jezioro Dąbie lake in Czarna Łąka, sample taken near beach;

I.11 – southern shore of Jezioro Rusałka lake in Szczecin, sample taken from shore;

II.1 – Jezioro Gałęziste lake, sample taken from shore near beach and hiking trail;

II.2 – south-western shore of Jezioro Pierty lake, sample taken from pier in private area, around macrophytes;

II.3 – south-eastern shore of Jezioro Czarne lake, ca. 500 m east of Krzywe, sample taken from pier where depth is ca. 70 cm;

II.4 – peatbog near shore of Jezioro Suchar IV lake;

II.5 – Jezioro Suchar II lake, near hiking trail, sample taken from shore, close to *Carex* sp.;

II.6 – Zatoka Zadworze bay of Jezioro Wigry lake, near road in Stary Folwark, sample taken from small pier;

II.7 – Jezioro Leszczewek lake, sample taken in Stary Folwark from private pier, near macrophytes;

II.8 – Jezioro Muliczne lake, near hiking trail and beach, close to *Phragmites* sp.;

II.9 – peatbog near south-eastern shore of Jezioro Suchar Wielki lake;

II.10 – western shore of Jezioro Czarne lake in Gawrych Ruda, muddy bottom, sample taken from boat near shore;

II.11 – south-eastern shore of Jezioro Okrągłe lake;

II.12 – Zatoka Słupiańska bay of Jezioro Wigry lake, sample taken near beach and road;

III.1 – eastern shore of Jezioro Kły lake, sample taken near shore, close to *Lobelia* sp.;

III.2 – western shore of Jezioro Zmarłe lake, sample taken from pier, close to *Lobelia* sp.;

III.3 – peatbog between Jezioro Małe Zmarłe lake and road from Lubnia to Wiele;

III.4 – northern shore of Jezioro Małe Zmarłe lake, sample taken from shore, close to *Carex* sp. and macrophytes;

III.5 – Jezioro Wielewskie lake, sample taken in Wiele from pier where depth is ca. 1 m;

III.6 – western shore of pond in Karolewo, sample taken from shore;

III.7 – pond ca. 400 m north of Błotka, sample taken from pier where depth is ca. 40 cm, bottom overgrown;

III.8 – pond in Barbarka, Toruń, sample taken from shore near forest, around *Cyperaceae*, *Poaceae* and *Lemna* sp. on water surface;

III.9 – pond ca. 1.3 km north-east of Młyniec Pierwszy, sample taken near forest;

III.10 – pond in Ciechocin Parcele, at right side of road from Ciechocin, near farm;

III.11 – pond in Rudaw, sample taken from shore;

III.12 – oxbow lake of Vistula river, ca. 500 m west of Grabowiec, sample taken from shore, close to *Schoenoplectus* sp., *Lemna* sp., *Stratiotes aloides* and *Salvinia natans*;

III.13 – southern shore of Jezioro Ślesińskie lake in Ślesin, sample taken from pier where depth is ca. 70 cm, close to *Phragmites* sp.;

III.14 – south-western shore of Jezioro Pątnowskie lake near Pątnów, sample taken from pier where depth is ca. 70 cm, in area of sport centre, close to macrophytes;

IV.1 – pond in Kotowice, sample taken from shore (horses are kept on the other side of the pond);

IV.2 – pond on Ciosenka river in Ciosny, sample taken from shore;

IV.3 – pond on Ciosenka river in Dzierżązna, sample taken from shore;

IV.4 – pond on Czerniawka river near Biała, sample taken from shore, around *Poaceae*, *Typha* sp., *Ceratophyllum* sp. and *Myriophyllum* sp.;

V.1 – southern shore of Plany pond near Białka, around *Phragmites* sp.;

V.2 – eastern shore of Jezioro Bialskie lake, sample taken from pier;

V.3 – northern shore of Kościuszko pond near hiking trail and Libiszów, sample taken near water gate, around *Phragmites* sp.;

V.4 – pond ca. 300 m west of Libiszów, near hiking trail, bottom muddy;

V.5 – north-western shore of pond near Giewont pond near hiking trail and Libiszów, sample taken from shore;

V.6 – southern shore of Hetman pond near Sosnowica, sample taken from pier;

V.7 – Anielski pond, near road and Sosnowica, around *Phragmites* sp.;

V.8 – Jezioro Głębokie lake, sample taken from pier in Głębokie where depth is ca. 90 cm;

V.9 – south-eastern shore of Jezioro Uścimowiec lake, sample taken from private pier in Uścimów, among *Phragmites* sp.;

V.10 – south-western shore of Jezioro Maśluchowskie lake, sample taken from shore near beach, among *Phragmites* sp.;

VI.1 – Śnieżny Stawek I pond in Giant Mountains, north of station VI.2, sample taken from bottom where depth is ca. 50 cm;

VI.2 – Śnieżny Stawek II pond in Giant Mountains, south of station VI.1, sample taken from bottom where depth is ca. 40 cm;

VI.3 – north-eastern shore of Wielki Staw lake in Giant Mountains, near outflow of Biały Potok brook;

VI.4 – mountain peat pool ca. 150 m north-east of Wielki Staw lake in Giant Mountains, near Biały Potok brook, depth of pool is 2–5 cm;

VI.5 – another mountain peat pool a few metres south of station VI.4, near Biały Potok brook, pool more than 10 cm deep;

VI.6 – northern shore of Mały Staw lake in Giant Mountains;

VI.7 – mountain peat pool at Równia pod Śnieżką in Giant Mountains, along footbridge, north side of blue hiking trail, sample taken from ca. 10 cm depth, pool without *Sphagnum* sp. or other plants;

VI.8 – mountain peat pool at Równia pod Śnieżką, west of sampling station VI.7, along the same footbridge, north side of blue hiking trail, sample taken from ca. 5 cm depth, pool without *Sphagnum* sp. or other plants;

VI.9 – peat bog sampling station at Równia pod Śnieżką, west of sampling station VI.8, along the same footbridge, north side of blue hiking trail, near pool, on bottom sparse *Sphagnum* sp.;

VI.10 – mountain peat pool at Równia pod Śnieżką, along the same footbridge, south side of blue hiking trail, in water was *Carex* sp. or *Juncus* sp.;

VII.1 – pond in Czajowice, north side of road, near bicycle path, sample taken from shore;

VII.2 – pond in centre of Zelków, sample taken from concrete stairs;

VIII.1 – western bank of mine effluent settling pond at Brzeszcze coal mine west of the town of Brzeszcze, sample taken from shore, near outlet to Vistula river, around *Phragmites* sp.;

VIII.2 – Nowińczyk pond, one of the Przeręb group of ponds near Zator;

VIII.3 – pond near road in Wołowice;

VIII.4 – oxbow lake of Vistula river, next to highway between Cracow and Tyniec, sample taken from pier in sport centre, around *Poaceae*;

VIII.5 – eastern bank of flooded quarry in Zakrzówek, sample taken next to diving centre;

VIII.6 – main pond (with island having *Taxodium distichum*) in Botanic Garden of Jagiellonian University, Cracow, sample taken from shore, around *Phragmites* sp., *Typha* sp., *Nymphaea* sp.;

VIII.7 – concrete-lined pond in Jagiellonian University Botanic Garden;

IX.1 – south-western shore of Zalew Czorsztyński reservoir, sample taken near Niedzica castle.

The above-described sampling stations varied with respect to origin, morphometry, catchment, usage, trophy, selected physical and chemical parameters of the water (Table 1), and the qualitative and quantitative composition of phytoplankton (Table 2). The sampling stations were in water bodies including coastal (5 sampling stations) and delta (1) lakes, lowland lakes with manmade (3), forest (7) and mixed (11) catchments, oxbow lakes (2), mountain lakes (2), ponds (2), peat pools (5), lowland and upland ponds including field (1), fish (10), through-flow (2), park (3), suburban (1) and village (4) ponds, clay (1) and peat (3) pits, a flooded quarry (1), a mine effluent settling pond (1), a dam reservoir (1), and lowland (3) and mountain (1) peat bogs. Their water parameters fell within the

Table 1. Characterization of sampling stations. Types of water bodies and peat bogs: CoLa – coastal lake, DeLa – delta lake, LaMa – lowland lake with manmade catchment, LaFo – lowland lake with forest catchment, LaMi – lowland lake with mixed catchment, OxLa – oxbow lake, MoLa – mountain lake, MoPd – mountain pond, MoPl – mountain peat pool, FdPo – field pond, FhPo – fish pond, FwPo – through-flow pond, PaPo – park pond, SuPo – suburban pond, ViPo – village pond, ClPi – clay pit, PePi – peat pit, FlQu – flooded quarry, MiEf – mine effluent settling pond, DaRe – dam reservoir, LoPb – lowland peat bog, MoPb – mountain peat bog. Trophy: e – eutrophy, m/e – meso/eutrophy, m – mesotrophy, o/m – oligo/mesotrophy, o – oligotrophy, d – dystrophy, he – humoeutrophy, a – alkalitrophy, l – low. Types of samples: li – littoral, be – benthos, me – metaphyton. Morphometry measured in Graham program, ver. 0.3.1 (author M. Lenarczyk, unpubl.) or after [1] – Bucka & Wilk-Woźniak 2002, [2] – Choiński 1991a, [3] – Choiński 1991b, [4] – Choiński 1995a, [5] – Filipiak & Raczyński 2000, [6] – Górniak & Krzysztofiak 2006, [7] – Komarzewska, unpubl., [8] – Kowalska & Wołowski 2010b; '–' – no data.

Subprovince	Sampling station	Type of water basin/ peat bog	Latitude (N)/ Longitude (E)	Morphometry: area (ha), maximum depth (m)	Trophy	Date of sampling	Type of sample	Water temperature (°C)	pH	Conductivity (µS/cm)	Total hardness (°n)	Carbonate hardness (°n)	Nitrates (mg/l)	Orthophosphates (mg/l)
Southern Baltic Coast	I.1	CoLa	54°16′/ 16°06′	2240, 3.9 [8]	e	06.07.2008	li	24.6	9.6	425	12.0	9.2	<5.0	0.75
	I.2	CoLa	54°21′/ 16°15′	1750, 2.8 [8]	e	06.07.2008	li	23.6	9.3	1540	23.8	7.0	<5.0	<0.15
	I.3	CoLa	54°38′/ 17°10′	2470, 2.6 [8]	e	11.07.2008	li	19.8	8.9	560	11.6	6.4	<5.0	<0.15
	I.4	CoLa	54°41′/ 17°21′	7140, 6.3 [8]	e	11.07.2008	li	19.5	9.3	1740	27.8	7.8	<5.0	<0.15
	I.5	CoLa	54°45′/ 17°35′	650, 3.2 [8]	e	05.07.2008	li	25.0	9.4	152	9.0	5.6	<5.0	<0.15
	I.6	FhPo	53°49′/ 14°58′	2.13, –	e	27.07.2009	li	23.9	9.1	233	–	–	–	–
	I.7	PePi	53°34′/ 14°38′	25.00, 1.5 [7]	e	27.07.2009	li	22.4	9.1	551	–	–	–	–
	I.8	PePi	53°33′/ 14°39′	11.89, 0.8 [7]	e	27.07.2009	li	21.6	9.2	388	–	–	–	–
	I.9	LaMi	53°31′/ 14°27′	3.6, 2.5 [5]	e	28.07.2009	li	21.6	8.3	293	–	–	–	–
	I.10	DeLa	53°27′/ 14°42′	5600, 8.0 [5]	e	28.07.2009	li	22.0	8.3	614	–	–	–	–
	I.11	LaMi	53°27′/ 14°32′	3.4, – [5]	e	29.07.2009	li	21.5	8.8	624	–	–	–	–
Eastern Baltic Lakelands	II.1	LaFo	54°07′/ 23°04′	3.9, 14 [6]	m	01.07.2008	li	20.7	8.8	186	9.4	9.0	<5.0	<0.15
	II.2	LaMi	54°06′/ 23°05′	228.2, 38 [6]	e	01.07.2008	li	21.4	8.5	358	14.4	13.0	<5.0	0.25
	II.3	LaFo	54°05′/ 23°01′	20.5, 8.8 [3]	m	02.07.2008	li	22.4	8.7	230	9.8	8.0	<5.0	<0.15
	II.4	LoPb	54°05′/ 23°01′	–	o	02.07.2008	me	18.4	4.1	97	–	–	–	–
	II.5	LaFo	54°05′/ 23°01′	2.6, 10 [6]	d	02.07.2008	li	21.4	5.5	17	0.4	0.6	<5.0	<0.15
	II.6	LaMi	54°05′/ 23°05′	2118.3, 73 [6]	e	04.07.2008	li	21.2	8.5	295	11.6	10.6	<5.0	0.25
	II.7	LaMi	54°05′/ 23°04′	21.0, 6.5 [6]	e	02.07.2008	li	21.5	8.4	344	15.8	14.4	<5.0	<0.15
	II.8	LaFo	54°02′/ 23°02′	25.7, 11.3 [6]	m	03.07.2008	li	22.5	8.5	242	11.6	9.6	<5.0	<0.15
	II.9	LoPb	54°02′/ 23°04′	–	o	03.07.2008	me	25.1	4.2	58	–	–	–	–
	II.10	LaMi	54°01′/ 22°59′	6.4, 10 [6]	e	03.07.2008	li	18.3	8.5	325	15.0	13.0	10.0	<0.15
	II.11	LaMi	54°01′/ 23°01′	12.2, 13 [6]	e	03.07.2008	li	22.6	8.6	290	12.8	10.2	<5.0	<0.15
	II.12	LaMi	54°01′/ 23°03′	2118.3, 73 [6]	m	03.07.2008	li	22.6	8.9	292	10.0	8.4	<5.0	<0.15

Table 1. *Continued.*

Subprovince	Sampling station	Type of water basin/ peat bog	Latitude (N)/ Longitude (E)	Morphometry: area (ha), maximum depth (m)	Trophy	Date of sampling	Type of sample	Water temperature (°C)	pH	Conductivity (µS/cm)	Total hardness (°n)	Carbonate hardness (°n)	Nitrates (mg/l)	Orthophosphates (mg/l)
Southern Baltic Lakelands	III.1	LaFo	53°57′/ 17°47′	20.0, 7.8 [2]	o/m	09.06.2008	li	22.5	7.9	62	2.4	1.8	<5.0	0.25
	III.2	LaFo	53°57′/ 17°48′	6.6, – [2]	o/m	09.06.2008	li	23.6	7.4	46	1.8	1.2	<5.0	<0.15
	III.3	LoPb	53°56′/ 17°49′	–, –	m/e	09.06.2008	me	20.8	4.5	270	–	–	–	–
	III.4	LaFo	53°56′/ 17°49′	2.5, – [2]	he	09.06.2008	li	24.7	8.2	148	5.0	4.0	<5.0	0.25
	III.5	LaMi	53°55′/ 17°51′	152.5, 40.5 [2]	e	09.06.2008	li	22.8	9.1	156	5.6	4.8	<5.0	0.25
	III.6	SuPo	53°43′/ 17°32′	1.9, –	e	10.06.2008	li	22.8	8.5	314	11.0	8.2	<5.0	0.25
	III.7	PePi	53°02′/ 18°30′	1.3, –	e	07.06.2008	li	22.6	8.2	476	14.6	10.0	<5.0	0.50
	III.8	PaPo	53°03′/ 18°33′	0.4, –	e	07.06.2008	li	15.7	8.6	537	13.0	9.0	20.0	0.15
	III.9	FhPo	53°05′/ 18°49′	2.5, –	e	17.08.2008	li	18.4	8.2	541	14.4	12.0	5.0	<0.15
	III.10	ViPo	53°03′/ 18°56′	0.02, –	e	17.08.2008	li	16.9	8.5	667	–	–	–	–
	III.11	FdPo	53°02′/ 19°00′	0.3, –	e	16.06.2008	li	18.7	7.9	549	20.6	15.6	<5.0	0.50
	III.12	OxLa	52°58′/ 18°43′	0.2, –	e	17.06.2008	be	19.6	7.5	550	19.4	19.0	<5.0	0.50
	III.13	LaMi	52°18′/ 18°16′	148.1, 25.7 [4]	e	09.07.2008	li	22.0	8.6	398	17.2	13.6	<5.0	0.50
	III.14	LaMi	52°22′/ 18°19′	307.1, 5.4 [4]	e	09.07.2008	li	22.1	8.6	294	14.8	11.6	<5.0	<0.15
Central Polish Lowlands	IV.1	ViPo	51°58′/ 19°26′	0.2, –	e	24.07.2008	li	20.8	9.2	267	15.2	12.2	<5.0	1.50
	IV.2	FhPo	51°55′/ 19°23′	1.6, –	m/e	24.07.2008	li	17.0	8.5	183	10.0	7.2	5.0	<0.15
	IV.3	FwPo	51°56′/ 19°26′	1.6, –	m/e	24.07.2008	li	18.1	8.5	199	–	–	–	–
	IV.4	FwPo	51°56′/ 19°28′	3.2, –	e	24.07.2008	li	18.8	8.8	181	–	–	–	–
Polesie	V.1	FhPo	51°33′/ 23°01′	15, –	e	21.08.2008	li	25.2	8.6	412	–	–	–	–
	V.2	LaMi	51°32′/ 23°01′	31.7, 18.2 [4]	m	21.08.2008	li	23.9	8.6	280	–	–	–	–
	V.3	FhPo	51°32′/ 23°02′	25, –	e	21.08.2008	li	24.6	9.2	307	–	–	–	–
	V.4	FhPo	51°32′/ 23°02′	1.7, –	e	21.08.2008	li	24.8	8.0	398	10.6	10.0	5.0	<0.15
	V.5	FhPo	51°32′/ 23°03′	15, –	e	21.08.2008	li	23.8	8.5	330	8.6	8.0	10.0	<0.15
	V.6	FhPo	51°32′/ 23°05′	77, –	e	20.08.2008	li	24.3	8.6	404	–	–	–	–
	V.7	FhPo	51°32′/ 23°06′	54, –	e	20.08.2008	li	26.3	8.3	332	–	–	–	–
	V.8	LaAn	51°29′/ 22°55′	20.5, 7.1 [4]	m/e	22.08.2008	li	25.2	9.2	231	–	–	–	–
	V.9	LaAn	51°28′/ 22°56′	66.7, 4.4 [4]	e	22.08.2008	li	25.0	9.0	401	–	–	–	–
	V.10	LaAn	51°28′/ 22°57′	26.7, 9.4 [4]	m/e	22.08.2008	li	23.3	8.4	141	–	–	–	–

Sudety Mountains and Foothills	VI.1	MoPd	50°47′/ 15°34′	0.24, –	o	28.07.2008	be	13.6	5.3	10	–	–	–	–
	VI.2	MoPd	50°47′/ 15°34′	0.16, –	o	28.07.2008	be	11.1	5.4	2	–	–	–	–
	VI.3	MoLa	50°45′/ 15°42′	8.3, 24.4 [4]	o	29.07.2008	li	18.3	5.8	11	–	–	–	–
	VI.4	MoPl	50°46′/ 15°42′	–	l	29.07.2008	be	32.5	4.9	14	–	–	–	–
	VI.5	MoPl	50°46′/ 15°42′	–	l	29.07.2008	be	14.3	4.7	16	–	–	–	–
	VI.6	MoLa	50°45′/ 15°42′	2.9, 7.3 [4]	o	29.07.2008	be	17.2	6.7	13	–	–	–	–
	VI.7	MoPl	50°44′/ 15°42′	–	d	28.07.2008	be	21.0	5.5	25	–	–	–	–
	VI.8	MoPl	50°44′/ 15°43′	–	d	28.07.2008	be	23.5	4.3	34	–	–	–	–
	VI.9	MoPb	50°44′/ 15°43′	–	o	28.07.2008	me	24.2	4.0	35	–	–	–	–
	VI.10	MoPl	50°44′/ 15°43′	–	d	28.07.2008	be	22.3	4.4	21	–	–	–	–
Wyżyna Śląsko-Krakowska upland	VII.1	ViPo	50°12′/ 19°48′	0.13, –	e	01.09.2008	li	20.2	8.2	308	5.6	4.8	10.0	<0.15
	VII.2	ViPo	50°10′/ 19°48′	0.2, –	e	01.09.2008	li	18.0	9.4	740	–	–	–	–
Northern Sub-Carpathia	VIII.1	SeTa	49°59′/ 19°07′	25, –	e	31.08.2009	li	23.2	8.7	19200	–	–	–	–
	VIII.2	FhPo	50°01′/ 19°24′	25, –	e	29.08.2008	li	22.1	8.7	249	–	–	–	–
	VIII.3	ClPi	50°00′/ 19°44′	0.5, –	e	22.07.2008	li	22.2	8.7	122	–	–	–	–
	VIII.4	OxLa	50°02′/ 19°50′	5.7, –	e	11.08.2008	li	23.3	7.9	1588	20.0	10.8	10.0	0.25
	VIII.5	DrWo	50°02′/ 19°55′	17, –	a	05.08.2009	li	22.9	8.2	1181	–	–	–	–
	VIII.6	PaPo	50°04′/ 19°57′	0.08, –	e	03.06.2008	li	24.5	7.5	438	14.6	11.6	<5.0	0.25
	VIII.7	PaPo	50°04′/ 19°58′	0.01, –	e	27.06.2008	li	24.3	8.0	480	12.8	9.2	5.0	0.25
Central Western Carpathians	IX.1	DaRe	49°25′/ 20°19′	1300, 46 [1]	m/e	22.06.2009	li	17.1	9.0	184	–	–	–	–

following ranges: temperature 11.1–32.5°C, pH 4.0–9.6, conductivity 2–19200 μS/cm, total hardness 0.4–27.8°n, carbonate hardness 0.6–19.0°n, nitrates <5.0–20.0 mg/dm^3 and orthophosphates <0.15–1.50 mg/dm^3. The sampling stations ranged from oligotrophic to eutrophic; some were humoeutrophic and dystrophic. Trophy was determined on the basis of the catchment, physicochemical parameters and phytoplankton communities, and on data from Filipiak & Raczyński (2000) and Kowalska & Wołowski (2010b) for the lakes in the Southern Baltic coastal region, Górniak (2006b) for the lakes in the Eastern Baltic Lakelands, and Wojciechowska & Solis (2009) for the lakes in Polesie.

Material and methods

Field studies and analyses of the collected material

Material was collected in the summers of 2008 (3rd June – 1st September) and 2009 (22nd June – 31st August). Samples were taken from one station (in a single case two stations) of the water bodies or peat bogs. The samples were of the following types: littoral samples taken with a no. 25 plankton net from deeper water bodies; benthic samples taken with a pipette from shallower water bodies or places where a plankton net could not be used; and metaphyton samples of water from peat bogs, squeezed from *Sphagnum* sp. A total of 71 littoral, benthos and metaphyton samples representing 70 water bodies and peat bogs were collected and analyzed (Table 1). Some of the material was preserved, usually with 2–4% formaldehyde; only additional samples at stations no. I.3, 4 and 8 collected in 2009 were preserved with 1–2% glutaraldehyde in cacodylate buffer. Other material was maintained alive for *Pediastrum* culturing. The preserved material is deposited in the Department of Phycology, W. Szafer Institute of Botany, Polish Academy of Sciences (IB PAS), Cracow.

Water temperature, pH and conductivity were measured at each sampling station with an Elmetron CPC-401 pH/conductivity meter fitted with an EPS-1 electrode, Elmetron conductivity sensor (its cell constant is K=0.95 but the meter was set at 1.00) and Nakamichi temperature sensor. Other chemical parameters of the water, including total and carbonate hardness, nitrates and orthophosphates (Table 1), were measured using an Aquamerck Compact Laboratory (Merck) at 31 selected sampling stations. The first two tests are based on titrimetric methods, the rest on colorimetric methods described in the manufacturer's instructions.

As density varied between the collected samples, for each sampling station the composition and quantitative relationships of the *Pediastrum* taxa were assessed from fixed subsamples of ca. 5000 algal specimens, using an original method based on LM observation and calculation of the number of rows (x) required to reach ca. 5000 specimens on a 24 × 24 mm glass slide under 200× magnification. The number of slide rows (x) was calculated as:

$$x = \frac{12 \cdot 5000}{37.5y}$$

where:

y – number of specimens in 12 fields on a 24 × 24 mm slide under 200× magnification

12 – number of fields on a 24 × 24 mm slide under 200× magnification where *y* specimens occur

5000 – number of specimens estimated to occur in a fixed subsample

37.5 – number of fields in one row on a 24 × 24 mm slide under 200× magnification

For each subsample, the shares of the genus *Pediastrum* as a whole and of its species, as well as accompanying taxa of other algal groups having at least a moderate share (11–25%) in the algal communities, were estimated on a 7-degree scale (Wojciechowski 1971, modified) as follows: + – very low (≤0.2%), 1 – low (0.3–3%), 2 – somewhat low (4–10%), 3 – moderate (11–25%), 4 – somewhat high (26–50%), 5 – high (51–75%), and 6 – very high (76–100%). Percentages that fell between categories were rounded downward to the nearest category. For determination of diatoms (Bacillariophyceae) accompanying the *Pediastrum* taxa, permanent slides with diatoms were prepared: the material was boiled in 30% perhydrol on glass cover slips and allowed to evaporate before being mounted with Naphrax on glass slides. For these estimates I treated the following as single specimens: coenobia of *Pediastrum* and other green alga (Chlorophyta) of the order Chlorococcales, all one-celled algal organisms, cells in colonies of diatoms (Bacillariophyceae), chrysophytes (Chrysophyceae) and desmids (Desmidiales), colonies of green algae from the orders Chlorococcales and Volvocales, and colonies of most cyanophyte (Cyanophyta) representatives of the order Chroococcales. Also treated as single specimens was 100 μm diameter of a colony of the chroococcalean genus *Microcystis*, and also 100 μm length of a trichome for trichomes of cyanophytes and green algae (according to Picińska-Fałtynowicz *et al.* 2006, modified). Because of difficulties in determining some specimens belonging to *Pediastrum biradiatum*, *P. boryanum*, *P. duplex* and *P. simplex* in LM, the abundance of their varieties was not estimated but their occurrence was indicated with an asterisk (*). A detailed list of *Pediastrum* and their accompanying taxa at each sampling station is given in Table 2.

The material was examined by LM and SEM. LM studies employed Nikon OPTIPHOT-2, Jenaval (Carl Zeiss Jena) and Nikon Eclipse 600 microscopes. LM micrographs were taken with PixeLINK PL-A661, Nikon DS-Fi1 and Nikon H-III cameras. For SEM the material was prepared and analyzed in two ways. Samples preserved with formaldehyde were rinsed with distilled water, placed on cover glasses and air-dried at 30–40°C. The cover glasses were then affixed to aluminium stubs with double-sided carbon tape. The samples preserved with glutaraldehyde were rinsed with 10% ethanol (3 × 20 min.) and dehydrated in an ethanol series (20–30 min. each: 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%) and then in 100% acetone (2 × 30 min.). They were placed in micropore capsules (30 μm pore diameter), critical-point dried with CO_2 in an Anderson apparatus and then mounted on aluminium stubs with double-sided carbon tape. The material was sputter-coated with carbon or gold and observed using Hitachi S-4700 or JEOL JSM 5410 microscopes. SEM micrographs were taken in laboratories of the Jagiellonian University, Cracow: the Laboratory of Field Emission, Scanning Electron Microscopy and Microanalysis at the Institute of Geological Sciences, and the Laboratory of Scanning Electron Microscopy of Biological and Geological Sciences at the Institute of Zoology.

The classification system for *Pediastrum* follows Komárek & Jankovská (2001), the most recent identification key for world taxa of this genus. For identification of most *Pediastrum* taxa I used their original descriptions in papers by Nägeli (1849), A. Braun (1855), Reinsch (1867), Wolle (1884), Hansgirg (1888), Raciborski (1889), W. West & G.S. West (1895), Lucks (1906/1907), Nitardy (1914), Nygaard (1949), Siemińska (1965), Sulek (1969), Hegewald & Schnepf (1979), Comas (1989), Tell & Mataloni (1990), Jankovská & Komárek (1995) and Komárek & Jankovská (2001). For other algal phyla and classes the classification follows van den Hoek *et al.* (1995).

The frequency of occurrence of *Pediastrum* taxa at the sampling stations was determined on a 4-degree scale (Piątek 2007, modified): infrequent (1–5 sampling stations), somewhat frequent (6–15 sampling stations), frequent (16–35 sampling stations) and very frequent (>35 sampling stations).

Cultured material

Material for culturing was collected from selected sampling stations (Table 1) and from Jezioro Warnowskie lake and Jezioro Zatorek lake, Wolin National Park, Poland (phytoplankton samples obtained from Prof. Lubomira Burchardt, Adam Mickiewicz University, Poznań, Poland). Cultures were started and maintained in the laboratory of the Department of Phycology, IB PAS, Cracow. The culture collection contained 12 *Pediastrum* strains (Table 3). They were used for analysis of the taxonomic characteristics of rare and not well known taxa (*P. alternans*, *P. integrum* var. *integrum*, *P. orientale*) and common species reflecting a wide range of morphological variability (*P. boryanum*, *P. biradiatum*, *P. duplex*). Each axenic strain was started with a single coenobium transferred with a Narishige MM 188 micromanipulator (under a Jenaval microscope) into a test tube containing ca. 5 ml sterile liquid medium. Three kinds of medium were used:

Table 3. List of cultured *Pediastrum* strains.

No.	*Pediastrum* taxon	Strain no.	Medium	Water body, sampling station
1.	*P. alternans*	01.160708	CK	Jezioro Gardno lake, I.3
2.	*P. biradiatum* var. *biradiatum*	02.040908	C	Hetman pond, V.6
3.	*P. biradiatum* var. *biradiatum*	05.040908	C	Hetman pond, V.6
4.	*P. boryanum* var. *brevicorne*	06.030608	CK	Concrete-lined pond in Jagiellonian University Botanic Garden, VIII.7
5.	*P. boryanum* var. *cornutum*	19.090508	C	Jezioro Zatorek lake
6.	*P. boryanum* var. *longicorne*	13.280608	CK	Concrete-lined pond in Jagiellonian University Botanic Garden, VIII.7
7.	*P. boryanum* var. *longicorne*	22.280608	CK	Concrete-lined pond in Jagiellonian University Botanic Garden, VIII.7
8.	*P. duplex* cf. var. *duplex*	16.160708	CK	Jezioro Jamno lake, I.1
9.	*P. duplex* var. *rugulosum*	10.090508	C	Jezioro Zatorek lake
10.	*P. duplex* var. *rugulosum*	13.090508	CK	Jezioro Zatorek lake
11.	*P. integrum* var. *integrum*	09.170408	CK	Jezioro Warnowskie lake
12.	*P. orientale*	12.160708	CK	Jezioro Łebsko lake, I.4

"C" – Chu's medium (Chu 1942 in Parra 1979) composed of 0.04 g $Ca(NO_3)_2$, 0.01 g K_2HPO_4, 0.025 g $MgSO_4 \times 7 H_2O$, 0.02 g Na_2CO_3, 0.025 g Na_2SiO_3, 0.0008 g $FeCl_3$, and distilled H_2O to 1000 ml; "K" – modified Knop's medium (Starmach 1963) composed of 0.25 g $Ca(NO_3)_2$, 0.06 g $MgSO_4 \times 7 H_2O$, 0.06 g K_2HPO_4, 0.03 g KCl or KNO_3, 1 drop of 1% solution of Fe_2Cl_6, and distilled H_2O to 1000 ml; or "CK" – medium composed of equal amounts of "C" and "K". The strains were cultured in a Bolarus G-18-2 phytotron at ca. 20°C under fluorescent light alternating in intensity at 15 W/2 × 15 W in a 5/19-h cycle. Some strains became contaminated with other coccoid green algae.

Herbarium material

Some material was borrowed from the following European herbaria:

B – Botanic Garden and Botanical Museum Berlin-Dahlem, Berlin, Germany

BM – Natural History Museum, London, England

M – National Botanical Collection, Munich, Germany

Z – Institute of Systematic Botany, University of Zurich, Zurich, Switzerland.

Those abbreviations, taken from Index Herbariorum (http://sweetgum.nybg.org/ih/), are used in the text below.

Literature data

I analyzed the literature data in order to develop a comprehensive picture of the distribution of *Pediastrum* in Poland, giving the previously reported frequency of occurrence of *Pediastrum* taxa and verifying their determination on the basis of iconography. Frequency of occurrence was estimated on a 4-degree scale (Piątek 2007, modified) depending on the number of records, except for fossil records, in *Catalogue of Prokaryotic and Eukaryotic Algae Noted in Poland* (Siemińska & Wołowski 2003), *The Polish Phycological Bibliography* (Siemińska 1990; Siemińska & Pająk 1992) and the available literature up to 2013, as follows: infrequent ("few records" in Literature data – 1–10), somewhat frequent ("some records" – 11–30), frequent ("many records" – 31–70), very frequent ("very many records" – >70). Misapplied names and synonyms were found during analysis of the Polish literature data. Records that were unclear and impossible to assign to any name given by Komárek & Jankovská (2001) were excluded from this analysis. For wrong spellings the invalid names of *Pediastrum* were corrected before inclusion.

Results

Thirty-two *Pediastrum* taxa belonging to 19 species occur in Poland. Of these, 23 taxa (asterisked) representing 13 species were found in my recent field and laboratory studies. Analysis of the literature data yielded 9 more names of taxa for the current Polish *Pediastrum* list. Besides the valid *Pediastrum* names, 93 other names are given here as synonyms (including 14 basionyms).

A description of the genus *Pediastrum* from the studied material is provided below.

Pediastrum Meyen 1829, p. 772

TYPE SPECIES: *Pediastrum duplex* Meyen 1829, p. 772, pl. XLIII, fig. 16.

Coenobia 12–223 µm in diameter, round, oval or irregular in outline, single-layered, with or without perforations, 4-, 8-, 16-, 32-, 64-, 128-celled. Cells 4–37 µm long, 5–39 µm wide, triangular, tetragonal, polygonal, almost round or oval, with concave, straight or convex sides, arranged concentrically, spirally or irregularly in the coenobium. Marginal cells with 1–4 lobes or without lobes. Lobes conical or cylindrical, sometimes divided into secondary lobes situated on outer cell margin, on or off plane of coenobium (Fig. 2). Between two lobes of the same cell is a V-shaped, U-shaped or no incision. Each lobe terminating in hyaline cylindrical process or processes situated directly on cell body, sometimes processes reduced or absent. Cell wall surface smooth (Lat. *membrana laevigata*), without concave or convex elements (type 1), or variously ornamented (Table 4; Figs 3 & 4); nomenclature according to Parra 1979, Ziembińska-Tworzydło & Kohlman-Adamska (2003):

– scabrate (*m. scabrata*) – composed of tiny verrucas (*verrucae*; elements irregular in outline, not pointed) and punctae (*puncta*; tiny pores of different shapes) (type 2),

– granulate (*m. granulata*) – composed of granules (*granula*; elements round in outline, not pointed) disposed in regular rows or granules and punctae (type 3),

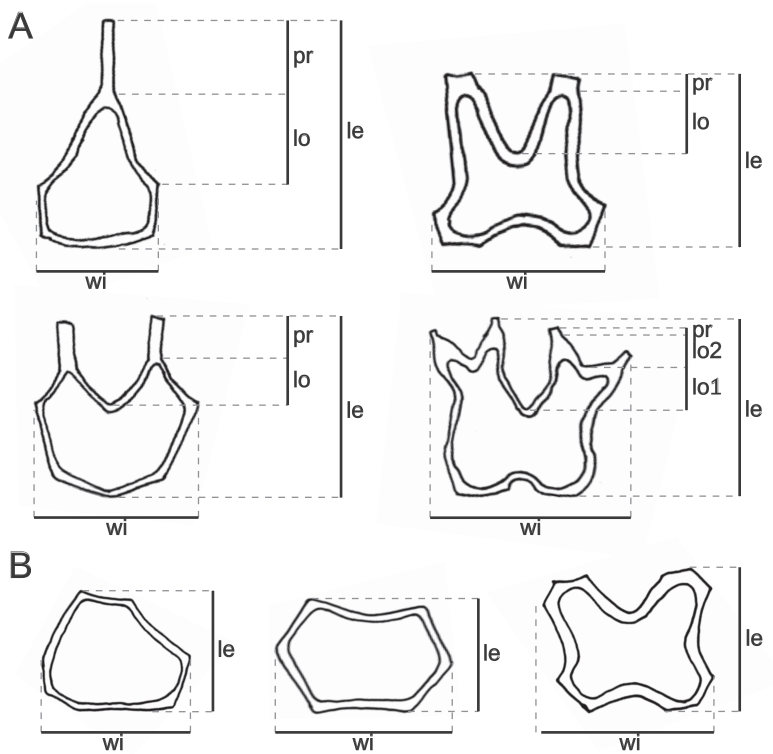

Fig. 2. Examples of marginal (A) and inner (B) cells in *Pediastrum* (le – length, wi – width, pr – process, lo – lobe, lo1 – main lobe, lo2 – secondary lobe).

Table 4. Types of cell wall surface in *Pediastrum* (abbreviations: Psisim – *P. simplex* var. *simplex*, Psicla – *P. simplex* var. *clathratum*, Psistu – *P. simplex* var. *sturmii*, Psiech – *P. simplex* var. *echinulatum*, Pmu – *P. musteri*, Ppa – *P. patagonicum*, Pka – *P. kawraiskyi*, Por – *P. orientale*, Pinint – *P. integrum* var. *integrum*, Pbobor – *P. boryanum* var. *boryanum*, Pbopse – *P. boryanum* var. *pseudoglabrum*, Pbocor – *P. boryanum* var. *cornutum*, Pboper – *P. boryanum* var. *perforatum*, Pbolon – *P. boryanum* var. *longicorne*, Pbobre – *P. boryanum* var. *brevicorne*, Pbofor – *P. boryanum* var. *forcipatum*, Psu – *P. subgranulatum*, Pdudup – *P. duplex* var. *duplex*, Pdugra – *P. duplex* var. *gracillimum*, Pdurug – *P. duplex* var. *rugulosum*, Pduasp – *P. duplex* var. *asperum*, Pal – *P. alternans*, Panang – *P. angulosum* var. *angulosum*, Par – *P. argentinense*, Ppr – *P. privum*, Pob – *P. obtusum*, Pte – *P. tetras*, Plo – *P. longecornutum*, Pbibir – *P. biradiatum* var. *biradiatum*, Pbigla – *P. biradiatum* var. *glabrum*, Pbr – *P. braunii*, Pta – *P. taylori*; * – taxa noted in this study).

Types of cell wall surface	1	2	3	4	5	6		7		
	smooth	scabrate	granulate	verrucate	araneose	a. rugulate with granules	b. rugulate with verrucas	a. reticulate with granules on polygonal mesh	b. reticulate with spines on trigonal or tetragonal mesh	c. reticulate with granules on trigonal mesh
*Psisim								+		+
Psicla			+?							
Psistu			+?							
*Psiech									+	
*Pmu								+		
*Ppa								+?		
*Pka		+		+						
*Por						+				
*Pinint								+		+
*Pbobor										+
*Pbopse		+								
*Pbocor										+
*Pboper										+
*Pbolon										+
*Pbobre										+
*Pbofor			+							
Psu										+
*Pdudup	+									
*Pdugra	+									
*Pdurug								+		
*Pduasp					+					
*Pal							+			
*Panang					+					
Par						+				
*Ppr						+?	+?	+?		
Pob				+						
*Pte	+									
Plo	+									
*Pbibir						+				
Pbigla	+									
Pbr						+		+		
Pta			+?							

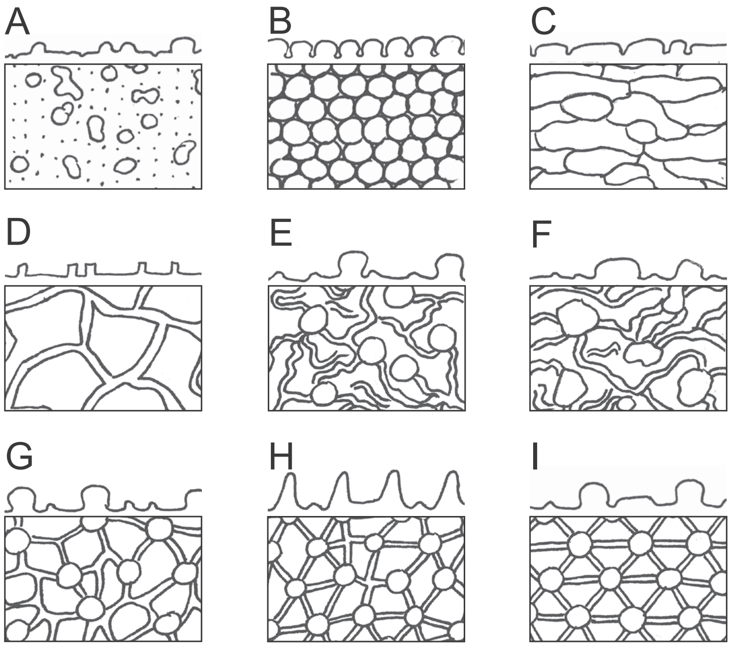

Fig. 3. Types of cell wall ornamentation in *Pediastrum*. A – scabrate (type 2). B – granulate (type 3). C – verrucate (type 4). D – araneose (type 5). E – rugulate with granules (type 6a). F – rugulate with verrucas (type 6b). G – reticulate with granules on polygonal mesh (type 7a). H – reticulate with spines on trigonal or tetragonal mesh (type 7b). I – reticulate with granules on trigonal mesh (type 7c).

– verrucate (*m. verrucosa*) – composed of verrucas or verrucas and punctae (type 4),

– araneose (*m. araneosa*) – composed of ridges (*jugae*; wider, elongated, straight or broken elements, sometimes connected or crossed) (type 5),

– rugulate (*m. rugulata*) – composed of wrinkles (*rugae*; narrow, elongated, serpentine twisted elements, forming an irregular pattern), on which granules (type 6a) or verrucas (type 6b) occur,

– reticulate (*m. reticulata*) – composed of a mesh (*reticulum*; elongated elements connected by their ends, forming a regular or irregular pattern); three subtypes were distinguished: with granules on a polygonal mesh (type 7a), spines (*echina*; pointed elements narrowing to top) on a trigonal or tetragonal mesh (type 7b), or granules on a trigonal mesh (type 7c).

Identification key

The identification key for Polish *Pediastrum* taxa is based on coenobium morphology observed by both LM and SEM in the field material. Their characteristics, including the shape of the marginal and inner cells and the type of cell wall surface, are presented in Figures 4–29 (taxa found in my studies; asterisked) and 30 & 31 (remaining taxa).

1a. Each marginal cell in coenobium with a single process. . . . . 2. **P. simplex*
1b. Marginal cells having different morphology 5

2a. Marginal cells broadly oval to almost round, immediately narrowing in coarse process half of cell length . . . . *P. simplex* var. *sturmii*
2b. Marginal cells having different morphology 3

3a. Perforations between inner cells always larger than cell diameter, cell wall surface having a delicate, regular arrangement of granules (type 3?) . . . . *P. simplex* var. *clathratum*
3b. Perforations between inner cells of different sizes and shapes 4

4a. Cell wall surface reticulate with granules (types 7a, 7c) . . . . *P. simplex* var. *simplex*
4b. Cell wall surface reticulate with irregularly disposed spines (type 7b). . . . . *P. simplex* var. *echinulatum*

5a. Each marginal cell having maximally two processes or lobes. 6
5b. Each marginal cell having more than two processes or lobes 26

6a. Marginal cells having one or two processes, or processes absent 7
6b. Marginal cells having two processes or warts 8

7a. Marginal cells without lobes and incision (outer margin straight), usually with one or two short processes, or processes absent; cell wall surface reticulate with granules (type 7c). . . . . *P. integrum* var. *integrum*
7b. Marginal cells usually without lobes and incision, with outer margin convex or conically extended, processes of different length situated off plane of coenobium, sometimes processes absent; cell wall surface rugulate with granules (type 6a). . . . . *P. orientale*

8a. Coenobia usually 4-celled, rarely 8-celled; margin of marginal cells straight or slightly concave, sometimes forming two very small lobes; processes short, reduced, visible only in some cells as small warts at corners of coenobium . . . . *P. privum*
8b. Coenobia usually having more cells, each marginal cell having one or two lobes. 9

9a. Each marginal cell elongated in one broad massive lobe, usually divided into two secondary lobes oriented obliquely to plane of coenobium, processes long, cell wall surface verrucate (type 4) or scabrate (type 2) . . . . *P. kawraiskyi*
9b. Each marginal cell having two lobes 10

10a. Coenobia with perforations, marginal and inner cells in form of an H, processes or warts short and broad. 11
10b. Coenobia with or without perforations, cells of various shapes. 16

11a. Cell wall surface reticulate with granules (type 7c) . . . . *P. subgranulatum*
11b. Cell wall surface different 12

12a. Marginal cells with widely spaced short and broad lobes terminating in warts often connecting adjacent cells, cell wall surface rugulate with granules (type 6a) . . . . *P. argentinense*
12b. Marginal cells with distinctly longer lobes and U-shaped or V-shaped incision between them; lobes terminating in processes, cell wall surface smooth (type 1), araneose (type 5) or reticulate with granules (type 7a) . . . . 13. *P. duplex*

13a. Cell wall surface smooth 14
13b. Cell wall surface ornamented 15

14a. Coenobia usually having small perforations; incision in marginal cells running less than half of cell length; inner cells with concave or straight sides . . . . *P. duplex* var. *duplex*
14b. Perforations usually larger and cells narrower than in *P. duplex* var. *duplex*; incision running more than half of cell length; inner cells with concave sides . . *P. duplex* var. *gracillimum*

15a. Cell wall surface reticulate with granules (type 7a) . . . . *P. duplex* var. *rugulosum*
15b. Cell wall surface araneose (type 5). . . . . *P. duplex* var. *asperum*

16a. Coenobia always with perforations, lobes of marginal cells situated both on and off plane of coenobium 17
16b. Coenobia with or without perforations, lobes usually situated on, only occasionally off plane of coenobium 19

17a. Incision between lobes of the same cell usually deeper than incision between lobes of two adjacent cells; walls of adjacent cells and lobe margins undulate; cell wall surface rugulate with verrucas (type 6b). . . . . **P. alternans*
17b. Incision between lobes of the same cell shallower than incision between lobes of two adjacent cells 18
18a. Base of marginal cells concave, straight or slightly convex, inner cells tetragonal, with concave or straight sides connected with their lobes . . . . **P. musteri*
18b. Base of marginal cells straight or slightly convex, inner cells polygonal, with straight or slightly concave sides connected by their sides . . . . **P. patagonicum*

19a. Coenobia with very small perforations, cell wall surface araneose (type 5) . . . . **P. angulosum* var. *angulosum*
19b. Coenobia with or without perforations, cell wall surface different . . . . 20. **P. boryanum*
20a. Cell wall surface reticulate with granules (type 7c) 21
20b. Cell wall surface not reticulate 25

21a. Coenobia without perforations; marginal cells with very short lobes, between them a broad and shallow incision, V-shaped or U-shaped, maximally running ca. one third of cell length; processes short, from one fifth to one fourth cell length; cell surface with 10–14 granules in cell width . . . . **P. boryanum* var. *brevicorne*
21b. Coenobia with or without perforations, having different morphology 22
22a. Coenobia always with perforations 23
22b. Coenobia having no or very small perforations 24

23a. Coenobia with regularly disposed perforations; between marginal cells a U-shaped or V-shaped incision running ca. half of cell length; processes from one fifth to one fourth of cell length; granulation delicate, 12–14 granules in cell width . . . . **P. boryanum* var. *cornutum*
23b. Coenobia with regularly or irregularly disposed perforations; between marginal cells a U-shaped or V-shaped incision running from half to two thirds of cell length; processes from one sixth to one third of cell length; granulation rather coarse, 7–11 granules in cell width . . . . **P. boryanum* var. *perforatum*
24a. Marginal cells with U-shaped incision, narrow or wide, almost flat in older cells, running from half to two thirds of cell length; processes usually long, from one third to half of cell length, sometimes shorter, from one fifth to one fourth of cell length; granulation coarse, 7–10 granules in cell width . . . . **P. boryanum* var. *longicorne*
24b. Marginal cells with U-shaped or V-shaped incision running from one third to half of cell length, occasionally to two thirds of cell length; processes from less than one third to almost half of cell length, granulation coarse or delicate, 6–20 granules in cell width . . . . **P. boryanum* var. *boryanum*

25a. Incision in marginal cells running ca. half of cell length, processes quite short, less than one third of cell length, cell wall surface scabrate (type 2). . . . . **P. boryanum* var. *pseudoglabrum*
25b. Incision in marginal cells running from half to two thirds of cell length, processes to ca. one third of cell length, cell wall surface granulate (type 3) . . . . **P. boryanum* var. *forcipatum*
26a. Marginal cells with four lobes or processes, or with additional smaller lobes 27
26b. Marginal cells with more than four distinct lobes and processes. . . . . *P. taylori*

27a. Inner cells connected by their lobes 28
27b. Inner cells connected by their sides 30
28a. Each marginal cell having two radiate, sometimes longer inner lobes and two outer lobes, adjacent inner and outer lobes ± perpendicular to each other . . . . *P. longecornutum*
28b. Each marginal cell having four lobes of ± equal length, V-shaped or U-shaped incision between adjacent inner and outer lobes . . . . 29. **P. biradiatum*

29a. Cell wall surface smooth (type 1) . . . . *P. biradiatum* var. *glabrum*
29b. Cell wall surface rugulate with granules (type 6a). . . . . **P. biradiatum* var. *biradiatum*

30a. Every lobe and process of marginal cells on plane of coenobium 31
30b. Lobes and processes of marginal cells on and off plane of coenobium, additional lobes can be present . . . . *P. braunii*
31a. Between main lobes of marginal cells a narrow incision terminating in a round widening in middle of cell, secondary lobes of marginal cells of the same shape and size . . . . *P. obtusum*
31b. Between main lobes of marginal cells a narrow U-shaped or V-shaped incision, inner secondary lobes of marginal cells slightly longer, remaining two slightly shorter. . . . . **P. tetras*

Polish *Pediastrum* taxa

The 23 taxa found in my recent studies and the other 9 previously recorded in the Polish literature are presented below in systematic order according to Komárek & Jankovská (2001). For each taxon the following information is included: figure(s), basionym and synonym(s) from the Polish literature, morphological description on the basis of the collected field material (asterisked) or according to Komárek & Jankovská (2001), taxonomic notes, frequency of occurrence in previous studies in Poland, and documented and undocumented localities from the Polish literature (Literature data). For the taxa noted in my study additional information is given, including morphological descriptions of selected strains, the shares of the *Pediastrum* species in algal communities, their frequency of occurrence, and sampling stations (Current records). Synonyms and misapplied names given directly under a species name do not fit any of its varieties. Descriptions, notes and records given directly under a species name refer to the species as a whole.

****Pediastrum simplex*** Meyen 1829, p. 772, pl. XLIII, figs 1–5 Figs 4I, 5A–F, 6A–F

Synonyms:

P. simplex var. *duodenarium* (Bailey) Rabenhorst 1868, p. 72;
P. simplex var. *radians* Lemmermann 1897, p. 180;
P. clathratum (Schröter) Lemmermann 1897, p. 179, figs 1–4;
P. clathratum var. *duodenarium* (Bailey) Lemmermann 1897, p. 182;
P. clathratum var. *microporum* Lemmermann 1899, p. 115, pl. II, fig. 29–31;
P. clathratum var. *punctatum* Lemmermann 1897, p. 182, fig. 5;
P. ovatum (Ehrenberg) A. Braun 1855, p. 81;
P. triangulum (Ehrenberg) A. Braun var. *angustatum* Nitardy 1914, p. 177, pl. IV, fig. 4, pl. VIII, fig. 3, pl. X, figs 14 & 15;
P. triangulum var. *latum* Nitardy 1914, p. 177, pl. IV, figs 7 & 8, pl. VI, figs 1–10, pl. VII, fig. 5, pl. VIII, fig. 5, pl. X, fig. 2.

Coenobia 51–137 µm in diameter, round, oval or irregular in outline, with or without perforations, 4-, 8-, 16-, 32-celled; cells arranged concentrically, spirally or irregularly. Marginal cells 15–37 µm long, 7–20 µm wide, triangular or trapezoidal in outline, each having one conical lobe situated in the middle of the cell margin, occasionally without a lobe. Lobe terminating in a hyaline cylindrical process; sometimes tufts of proteinous bristles attached to the ends of processes. Inner cells 6–21 µm long, 8–22 µm wide, triangular or polygonal in outline; sometimes without inner cells, then the marginal cells form a circle. Cell wall surface reticulate with spines (type 7b) or granules (types 7a, 7c).

Notes. The species is quite variable morphologically. Komárek & Jankovská (2001) recognized six varieties of *P. simplex*, including *simplex*, *clathratum* (Schröter) Chodat, *pseudoglabrum* Parra, *biwaense* Fukushima, *sturmii* (Reinsch) Wolle, *echinulatum* Wittrock and *mirabile* Wołoszyńska. They differ in cell shape and arrangement, perforation size and type of cell wall surface. The intraspecific taxonomic system of *P. simplex* has been variously treated by different authors. According to Bigeard (1933), *P. sturmii* (synonym of *P. simplex* var. *sturmii* in this monograph) having rounded cells is a senile form of *P. simplex*, and *P. clathratum* is a plankton form of this species. Even earlier, Troitzkaja (1927) noted that coenobia without perforations placed in new culture medium give rise to perforated coenobia. This suggests that the perforations occur under particular environmental conditions. Parra (1979) treated the varieties *clathratum*, *echinulatum* and *sturmii* as synonyms of the variety *simplex*, and stated that neither the occurrence and size of perforations nor cell shape and reticulate wall ornamentation are stable features. He recognized only two varieties, *simplex* and *pseudoglabrum*, the latter having not reticulate but granulate or fossulate cell walls. Detailed molecular studies of all the varieties should help solve the taxonomic problems with *P. simplex*. Such studies have been done for some strains of the varieties (Buchheim *et al.* 2005; McManus & Lewis 2005, 2011; Jena *et al.* 2014).

Current records. *P. simplex* occurred at 18 of 71 stations, located on the Southern Baltic Coast and Lakelands and in the Central Polish Lowlands, Polesie and Northern Sub-Carpathia, including fish ponds (stations I.6, III.9, V.1, 3–7), through-flow ponds (IV.3, 4), a village pond (IV.1), peat pits (I.7–8, III.7), lowland lakes with mixed catchments (III.13–14, V.2) and an oxbow lake (VIII.4). The species had shares of ≤0.2% (13 sampling stations), sometimes 0.3–3% (4) or 11–25% (1) in the algal communities. The water bodies ranged from meso- to eutrophic, but most (16) were eutrophic; water temperature 18.1–26.3°C, pH 7.9–9.2, conductivity 181–1588 µS/cm, total hardness 8.6–20.0°n, carbonate hardness 8.0–13.6°n, nitrates <5.0–10.0 mg/dm^3 and orthophosphates <0.15–1.50 mg/dm^3.

Literature data. Very many records were given for *P. simplex*. Localities include lakes (e.g. Krause 1906, fig. 4b; Lucks 1906/1907, p. 43, fig. 3 – as synonym *P. clathratum*, fig. 4; Schröder 1918, pl. XII, figs 3–6 – as synonym *P. triangulum* var. *latum*; Malicki 1972, pl. I, figs a–c), eutrophic lakes (e.g. Kotlińska 1976, pl. XV, fig. 243 – as synonym *P. simplex* var. *radians*, fig. 244 – as misapplied name *P. simplex* var. *granulatum*, fig. 245 – as synonym *P. clathratum*, fig. 246 – as synonym *P. clathratum* var. *microporum*, fig. 247 – as synonym *P. clathratum* var. *punctatum*, pl. XVI, fig. 248 – as synonym *P. clathratum* var. *duodenarium*; Burchardt 1977, pl. XIII, fig. 2 – as synonym *P. clathratum*; Pasztaleniec & Poniewozik 2004, p. 44, figs 12 & 13 – as misapplied name *P. simplex* var. *clathratum*), ponds (e.g. Kadłubowska 1961, p. 88, pl. XI, figs 1 & 2), fish ponds (e.g. Bucka *et al.* 1968, p. 420, fig. 15 – as synonym *P. simplex* var. *radians*; Sitkowska 1992, p. 66, pl. XXVI, figs 1–3 & 6, pl. XXVII, figs 1–5, pl. XXVIII, figs 1–3 & 5, pl. XXIX, figs 1 & 3 – as misapplied name *P. simplex* var. *simplex*, p. 67, pl. XXVI, figs 4 & 5, pl. XXVII, fig. 6, pl. XXIX, fig. 6 – as misapplied name *P. simplex* var. *sturmii*, pl. XXVIII, fig. 6 – as misapplied name *Pediastrum* sp.), as well as dam reservoirs (e.g. Bucka & Wilk-Woźniak 2002, p. 169, fig. 185), peaty water bodies (Kowalski 1975, p. 360, fig. 22), a settling pond (Humblet-Pawłowska 1939, pl. V, fig. 119 – as synonym *P. simplex* var. *radians*, fig. 120 – as synonym *P. clathratum* var. *microporum*), a lagoon (Luścińska 2005, pl. VIII, fig. 17 – as misapplied name *P. simplex* var. *simplex*) and a river (Luer-Jeziorańska 1939, pl. XI, fig. 195 – as synonym *P. simplex* var. *radians*).

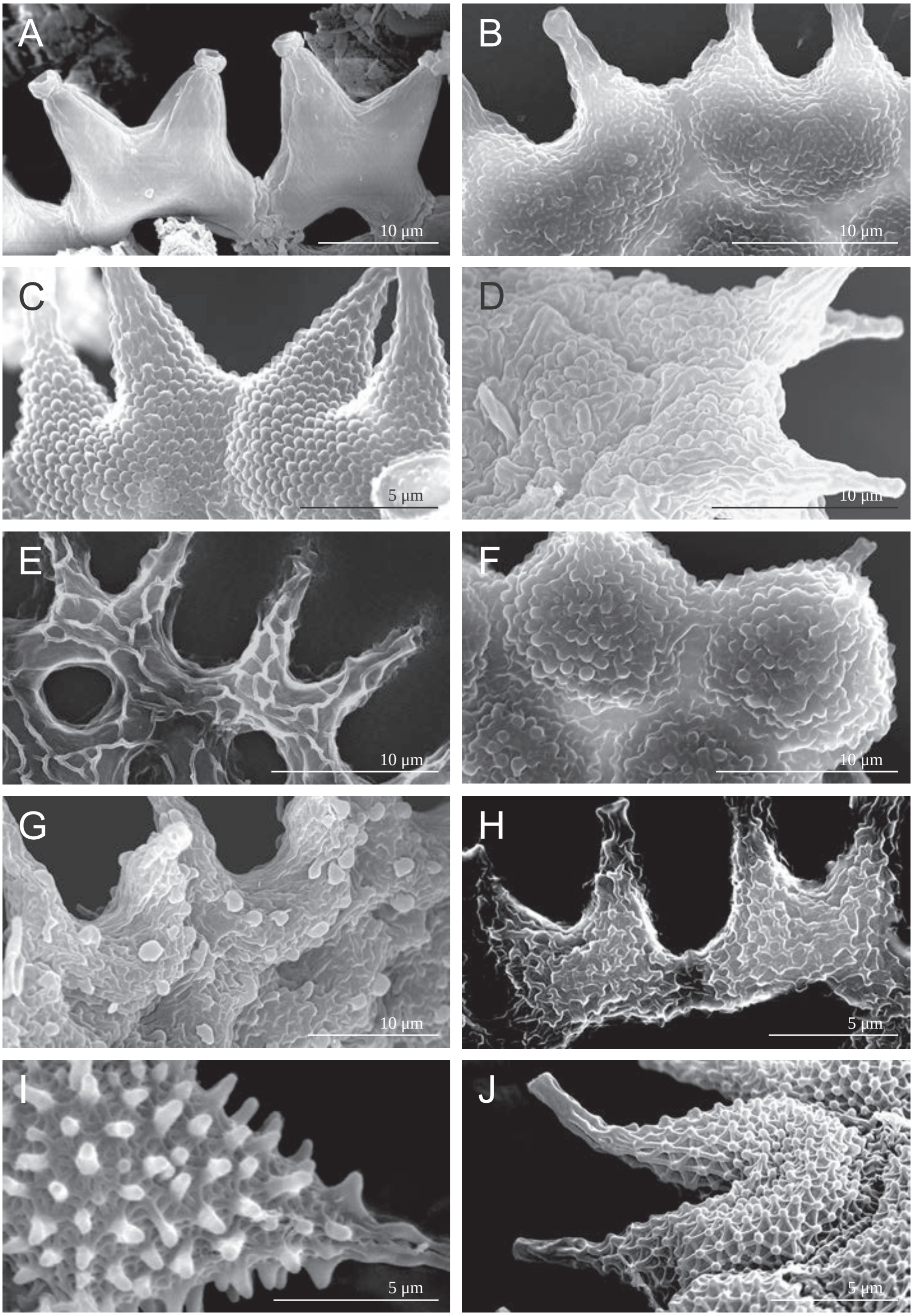

Fig. 4. Examples of cell wall surface in *Pediastrum* (SEM). A – smooth in *P. duplex* Meyen var. *duplex*. B – scabrate in *P. boryanum* (Turpin) Meneghini var. *pseudoglabrum* Parra. C – granulate in *P. boryanum* var. *forcipatum* (Corda) Chodat. D – verrucate in *P. kawraiskyi* Schmidle. E – araneose in *P. duplex* var. *asperum* (A. Braun) Hansgirg. F – rugulate with granules in *P. orientale* (Skuja) Jankovská et Komárek. G – rugulate with verrucas in *P. alternans* Nygaard. H – reticulate with granules on polygonal mesh in *P. duplex* var. *rugulosum* Raciborski. I – reticulate with spines on trigonal or tetragonal mesh in *P. simplex* Meyen var. *echinulatum* Wittrock. J – reticulate with granules on trigonal mesh in *P. boryanum* cf. var. *boryanum*.

*****Pediastrum simplex*** var. ***simplex*** Fig. 5A–F

Coenobia 51–137 µm in diameter, with regularly or irregularly disposed perforations of different sizes, sometimes without perforations or the cells form a circle with one central perforation, 8-, 16-celled. Marginal cells 15–37 µm long, 7–20 µm wide, with concave, straight or slightly convex sides, with or without lobe. Processes from one fourth to half of cell length, sometimes oblique to plane of coenobium. Inner cells 7–21 µm long, 8–22 µm wide, with concave, straight or convex sides. Cell wall surface reticulate with granules (types 7a, 7c).

Notes. There were difficulties in distinguishing *P. simplex* var. *simplex* from the other varieties of the species, including *clathratum*, *echinulatum* and *sturmii*.

Some coenobia of *P. simplex* recognized in this work as *P. simplex* var. *simplex* (Fig. 5A & B) also fitted the description of *P. simplex* var. *sturmii* (Reinsch) Wolle given by Komárek & Jankovská (2001, p. 34, fig. 12d). The coenobia had very small irregular perforations and marginal cells with concave or straight sides. According to the original description (Wolle 1884, p. 153, pl. LIII, fig. 18), the coenobium of *P. simplex* var. *sturmii* is composed of 6 cells forming a circle. However, such a coenobium can only be a teratological form, as a normally developed coenobium of *Pediastrum* is always composed of 2^n cells, (e.g. 2, 4, 8 or 16). The specimen has rather short and broad cells, the same as in some coenobia of *P. simpex* var. *sturmii* presented by Komárek & Jankovská (2001). Because the descriptions given by various authors contain inaccuracies, only specimens fitting the description of *P. sturmii* Reinsch (1867, p. 90, pl. VII, fig. Ia–d) are recognized as *P. simplex* var. *sturmii* in this work. *P. sturmii* is treated as a synonym of *P. simplex* var. *sturmii* by Komárek & Jankovská (2001). Reinsch (1867) noted that *P. sturmii* differs from *P. simplex* in the shape of the marginal cells, which are broadly oval to almost round and immediately narrowing toward a rough process as long as the cell in *P. sturmii*, whereas the cells gradually taper to a long process in *P. simplex*.

The *P. simplex* var. *simplex* specimens I observed possess a reticulate cell wall surface (Fig. 5F), differing from the rugulate one given by Komárek & Jankovská (2001). In some places the reticulate pattern probably was not fully developed, having a tetragonal mesh and sometimes no granules (type 7a) or flattened granules on a trigonal mesh. According to Parra (1979), the reticulate pattern in *P. simplex* var. *simplex* is only initially composed of a trigonal mesh, becoming irregular in older coenobia, including elements connected in a Y shape, which makes them resemble wrinkles.

Current records. *P. simplex* var. *simplex* occurred at 9 of 71 stations, located on the Southern Baltic Coast and Lakelands and in the Central Polish Lowlands, Polesie and Northern Sub-Carpathia, including fish ponds (sampling stations III.9, V.1, 5, 7), throughflow ponds (IV.3, 4), a village pond (IV.1), a peat pit (I.8) and an oxbow lake (VIII.4). The water bodies were eutrophic except for a meso/eutrophic one; water temperature 18.1–26.3°C, pH 7.9–9.2, conductivity 181–1588 µS/cm, total hardness 8.6–20.0°n, carbonate hardness 8.0–12.2°n, nitrates <5.0–10.0 mg/dm^3 and orthophosphates <0.15–1.50 mg/dm^3.

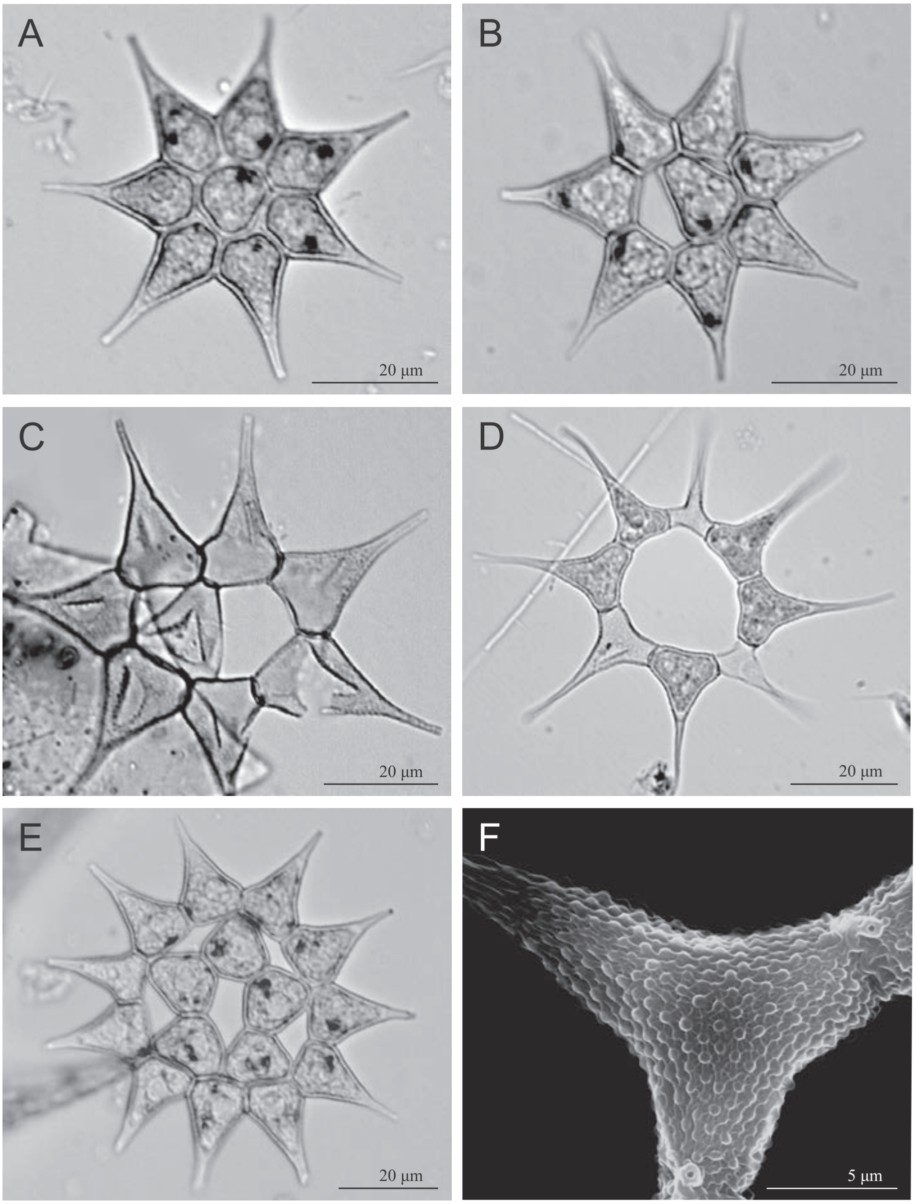

Fig. 5. A–F – *Pediastrum simplex* Meyen var. *simplex* from field material. A–E – coenobia (LM). F – details of cell wall ultrastructure (SEM).

Literature data. Few records were given for *P. simplex* var. *simplex*. Localities include a fish pond near Łódź (Sitkowska 1992, p. 66, pl. XXVIII, fig. 4, pl. XXIX, figs 2, 4 & 5), eutrophic Jezioro Rusałka lake (Kotlińska 1976, pl. XV, figs 242 – as misapplied name *P. simplex*) and eutrophic Jezioro Maltańskie lake (Stefko 1976, pl. XI, fig. 8 – as misapplied name *P. simplex*) in Poznań, and the Jeziorka river (Luer-Jeziorańska 1939, pl. XI, fig. 194 – as misapplied name *P. simplex*).

Pediastrum simplex var. ***clathratum*** (Schröter) Chodat 1902, p. 226, fig. 149a & d
Fig. 30A

BASIONYM:

P. simplex fo. *clathratum* Schröter 1883, p. 182.

Coenobia up to 248 µm in diameter, always with perforations larger than cell diameter, 4-, 8-, 16-, 32-(128-)celled. Marginal and inner cells 4–39 µm long, 4–35 µm wide. Cell wall surface having a delicate, regular arrangement of granules (type 3?).

NOTES. The specimens of *P. simplex* var. *clathratum* presented by the author of the variety (Chodat 1902, fig. 149a & d) have pentagonal cells with equal sides, very long processes and rather small perforations. According to Komárek & Jankovská (2001), var. *clathratum* has perforations larger than cell diameter, whereas *simplex* can have smaller or larger perforations. What is more confusing, in *clathratum* the cell wall granulation is fine and visible only with immersion, whereas in *simplex* it is distinct and visible on empty walls without immersion. Additionally, the granules of the latter are situated on wrinkles. It is unclear whether the granulation in *P. simplex* var. *simplex* should also be well visible in living cells and if the wrinkles on its surface should be visible without immersion.

LITERATURE DATA. *P. simplex* var. *clathratum* was recorded only once. That record given by Wołoszyńska (1923) from Jezioro Kunowskie lake in eastern Poland is doubtful because it has no description or iconographic documentation, and A. Braun is given as the author of the taxon, not Chodat.

Pediastrum simplex var. ***sturmii*** (Reinsch) Wolle 1884, p. 153, pl. LIII, fig. 18
Fig. 30B

BASIONYM:

P. sturmii Reinsch 1867, p. 90, pl. VII, fig. 1a–d.

SYNONYM:

P. simplex var. *granulatum* Lemmermann 1898, p. 151.

Coenobia up to 248 µm in diameter, with small, usually irregularly disposed perforations which usually are smaller than cell diameter, or completely without perforations, 4-, 8-, 16-, 32-(128-)celled. Marginal and inner cells 4–39 µm long, 4–35 µm wide. Marginal cells of all or only older coenobia broadly oval to almost round, immediately narrowing to a coarse process half of cell length, or only lateral sides of lobes in old coenobia distinctly convex. Cell wall surface having a delicate, regular arrangement of granules (type 3?).

NOTES. Cell wall ornamentation in *P. simplex* var. *sturmii* has not been recognized previously. Komárek & Jankovská (2001) raised doubts about whether the granules are situated on a reticulum, wrinkles or anything else. As mentioned above (in NOTES under *P. simplex* var. *simplex*), only coenobia of *P. simplex* having broadly oval to almost rounded cells immediately narrowing to a coarse long process, matching *P. sturmii* Reinsch (1867, p. 90, pl. VII, fig. Ia–d), are treated in this work as coenobia of *P. simplex* var. *sturmii* (Reinsch) Wolle.

Literature data. Few records were given for *P. simplex* var. *sturmii*. Localities include a pool in Łęg near Cracow (Raciborski 1888, without documentation – as synonym *P. sturmii*), a settling pond in Warsaw (Humblet-Pawłowska 1939, pl. V, fig. 118 – as synonym *P. sturmii*) and eutrophic Jezioro Gosławickie lake (Szyszka 1978, without documentation – as synonym *P. simplex* var. *granulatum*).

**Pediastrum simplex* var. *echinulatum* Wittrock in Wittrock et Nordstedt 1883, fasc. 5, no. 235 Figs 4I, 6A–F

Synonym:
P. clathratum (Schröter) Lemmermann var. *asperum* Lemmermann 1897, p. 182, fig. 6.

Coenobia 60–108 µm in diameter, with perforations of different sizes disposed regularly or irregularly, sometimes without perforations, or the cells form a circle with one central perforation, 4-, 8-, 16-celled. Marginal cells 23–32 µm long, 8–16 µm wide, with concave, straight or convex sides. Each marginal cell with one lobe. Processes from one third to half of cell length, sometimes off plane of coenobium. Inner cells 9–15 µm long, 10–18 µm wide, with concave, straight or convex sides. Cell wall surface reticulate with irregularly disposed spines (type 7b).

Herbarium material. Wittrock & Nordstedt, Algae aquae dulcis exsiccatae praecipue scandinavicae, no. 235, leg. G. Thuret comm. E. Bornet, August 1848 (B, BM, M).

Notes. Some specimens recognized as *P. simplex* var. *echinulatum* during my study were covered with shorter spines, making them resemble *P. simplex* var. *simplex* (Fig. 6E). There is no clear cutoff to distinguish spine length between the two varieties. This characteristic needs detailed study.

Current records. *P. simplex* var. *echinulatum* occurred at 10 of 71 stations, located on the Southern Baltic Coast and Lakelands and in Polesie and Northern Sub-Carpathia, including fish ponds (sampling stations V.3–7), peat pits (I.8, III.7), lowland lakes with mixed catchments (III.14, V.2) and an oxbow lake (VIII.4). All the water bodies were eutrophic except for a meso/eutrophic one; water temperature 21.6–26.3°C, pH 7.9–9.2, conductivity 280–1588 µS/cm, total hardness 8.6–20.0°n, carbonate hardness 8.0–11.6°n, nitrates <5.0–10.0 mg/dm^3 and orthophosphates <0.15–0.50 mg/dm^3.

Literature data. Few records were given for *P. simplex* var. *echinulatum*. Localities include Muttersee lake near Gdańsk (Schröder 1898b, without documentation; Schröder 1900, without documentation – as synonym *P. clathratum* var. *asperum*; Seligo 1900, without documentation – as synonym *P. clathratum* var. *asperum*), a pool in Łęg near Cracow (Raciborski 1889, p. 9, pl. II, fig. 10), several eutrophic lakes, including Jezioro Gosławickie (Socha 1993, p. 47, pl. XII, fig. 9 – as misapplied name *P. simplex*), Jezioro Licheńskie, Jezioro Pątnowskie and Jezioro Ślesińskie (Socha 1993, p. 47, pl. XII, fig. 9 – as misapplied name *P. simplex*) in central Poland, and eutrophic Jezioro Sumin lake in the Pojezierze Łęczyńsko-Włodawskie lakeland, eastern Poland (Pasztaleniec & Poniewozik 2004, p. 43, figs 10 & 11).

**Pediastrum musteri* Tell et Mataloni 1990, p. 168, pl. III, figs 1–4, pl. V, figs 1–4 Fig. 7A–C

Coenobia 35–54 µm in diameter, round in outline, with small perforations formed by connections of cell lobes, 16-celled. Cells arranged concentrically. Marginal cells 8–16 µm long, 7–12 µm wide, with two conical lobes oriented obliquely to plane of

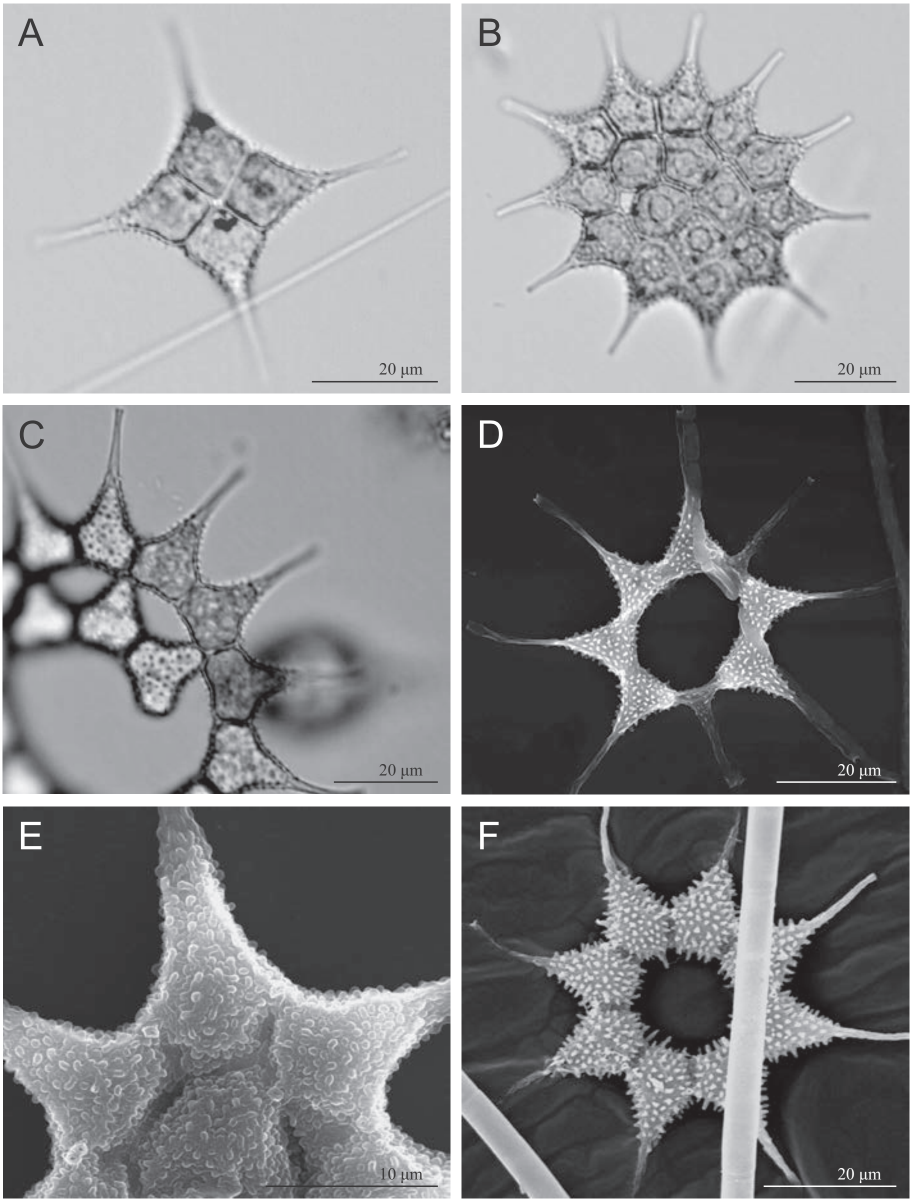

Fig. 6. A–F – *Pediastrum simplex* var. *echinulatum* Wittrock from field material. C – part of coenobium with well visible spines on surface of inner cells and margins of marginal cells. E – part of specimen with smaller spines, similar to var. *simplex*. A–C – LM. D–F – SEM.

coenobium, terminating in short processes. Incision ca. half of cell length. Base of marginal cells concave, straight or slightly convex. Inner cells 5–9 µm long, 7–13 µm wide, tetragonal, with concave or straight sides.

Notes. In younger coenobia (Fig. 7C) the base of marginal cells and the sides of inner cells are concave, so it is a typical *P. musteri* specimen. In older ones (Fig. 7A & B) the base of marginal cells is straight or slightly convex and the sides of inner cells are sometimes straight, making the older specimen closely resemble *P. patagonicum* Tell et Mataloni. Cell wall ultrastructure was not observed. According to Komárek & Jankovská (2001) it is reticulate with granules (type 7a).

Current record. *P. musteri* had a share of ≤0.2% in a eutrophic coastal lake (sampling station I.4), Southern Baltic Coast; water temperature 19.5°C, pH 9.3, conductivity 1740 μS/cm, total hardness 27.8°n, carbonate hardness 7.8°n, nitrates <5.0 mg/dm^3 and orthophosphates <0.15 mg/dm^3. The record was published as the first finding of *P. musteri* in Central Europe by Kowalska & Wołowski (2010b, p. 227, figs 2–4).

Literature data. There are no published Polish records of *P. musteri* except for the one mentioned above (Kowalska & Wołowski 2010b). It was observed also in the Zalew Wiślany lagoon (F. Hindák, oral information).

[*]***Pediastrum patagonicum*** Tell et Mataloni 1990, p. 169, pl. III, fig. 5, pl. V, figs 5 & 6 Fig. 7D

Coenobium 38 μm in diameter, round in outline, with several small perforations in cell corners, 16-celled. Cells arranged concentrically. Marginal cells 10 μm long, 7–8 μm wide, with two conical lobes oriented obliquely to plane of coenobium, terminating in long processes ca. one third of cell length. Incision ca. half of cell length. Base of marginal cells straight or slightly convex. Inner cells 5–6 μm long, 7–8 μm wide, polygonal, with straight or slightly concave sides, connected by their sides.

Notes. The only specimen found was smaller than given by Tell & Mataloni (1990) in the original species description. Cell wall ultrastructure in *P. patagonicum* was not observed in my study; probably it is similar to *P. musteri* (type 7a?).

Current record. *P. patagonicum* had a share of ≤0.2% in a eutrophic fish pond (sampling station V.5), Polesie; water temperature 23.8°C, pH 8.5, conductivity 330 μS/cm, total hardness 8.6°n, carbonate hardness 8.0°n, nitrates 10.0 mg/dm^3 and orthophosphates <0.15 mg/dm^3.

Literature data. *P. patagonicum* was not recorded from Poland previously.

[*]***Pediastrum kawraiskyi*** Schmidle 1897, p. 269 Figs 4D, 7E & F, 8A–C

Synonyms:

P. kawraiskyi var. *brevicorne* Lemmermann 1898, p. 151;
P. kawraiskyi var. *cornutum* Morozova-Wodianitzkaja 1925, p. 8, fig. 8.

Coenobia 50–108 μm in diameter, round, oval or irregular in outline, sometimes slightly curved, without perforations, 8-, 16-, 32-celled. Cells arranged irregularly, spirally or concentrically. Marginal cells 15–27 μm long, 10–18 μm wide, elongated in one broad massive lobe divided at approximately half its length into two secondary lobes oriented obliquely to plane of coenobium. Each secondary lobe terminating in a single long hyaline process from one fourth to one third of cell length; sometimes secondary lobes absent. Incision shallower than half of cell length. Inner cells 8–14 μm long,

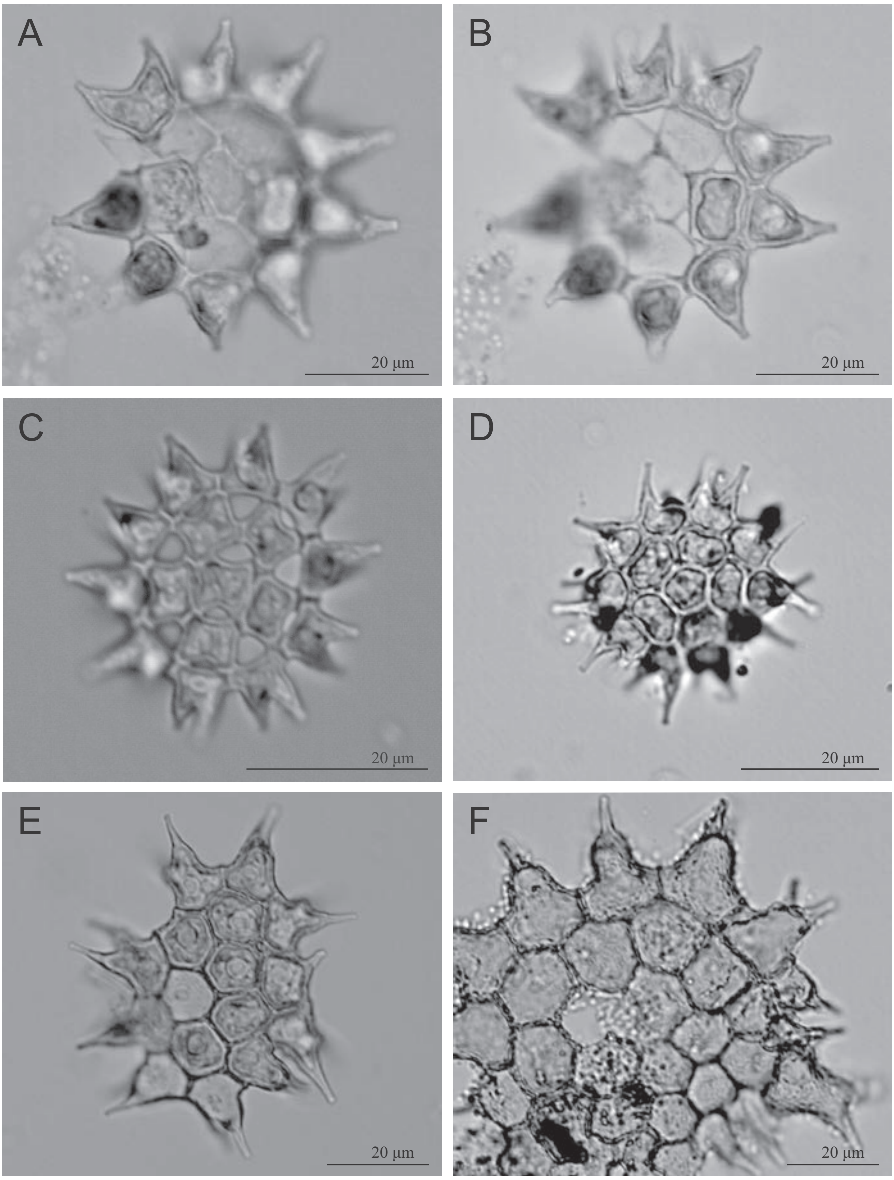

Fig. 7. A–C – *Pediastrum musteri* Tell et Mataloni from field material. A & B – older coenobium having an untypical cell shape (base of marginal cells straight or convex, sides of inner cells straight), similar to *P. patagonicum* Tell et Mataloni. D – *P. patagonicum* from field material. E & F – *P. kawraiskyi* Schmidle from field material. F – cell wall surface in empty cells. A–F – LM.

10–19 µm wide, polygonal, with straight sides, occasionally with processes off plane of coenobium. Cell wall surface verrucate (type 4) or scabrate (type 2).

NOTES. An older coenobium with unusually shaped marginal cells without any secondary lobes (Fig. 8A & B) and a teratological form having processes typical for marginal cells on an inner cell (Fig. 8C) were observed.

The cell wall surface of the old coenobium was not verrucate but scabrate as a result of wall stretching and flattening of verrucas during coenobium growth. A new feature – tiny punctae on both types of surfaces (Figs 4D, 8A & B) – was observed in the field material.

Current records. *P. kawraiskyi* occurred at 6 of 71 stations on the Southern Baltic Coast and in Polesie, including eutrophic coastal lakes (sampling stations I.1–5) and a lowland lake with a manmade catchment (V.9). The species had shares of ≤0.2% (3 sampling stations) or 0.3–3% (3) in the algal communities. Water temperature 19.5–25.0°C, pH 8.9–9.6, conductivity 152–1740 µS/cm, total hardness 9.0–27.8°n, carbonate hardness 5.6–9.2°n, nitrates <5.0 mg/dm^3 and orthophosphates <0.15–0.75 mg/dm^3. A recent finding in coastal lakes was published by Kowalska & Wołowski (2010b, fig. 16).

Literature data. Many records were given for *P. kawraiskyi*. Localities include Jezioro Głębokie lake near Tuchola, northern Poland (Lucks 1906/1907, p. 42, fig. 1a–c), Jezioro Gosławickie lake (Wołoszyńska 1913, p. 603, fig. 2; Rozmiarek 1975, pl. IX, fig. 5), polluted Jezioro Pątnowskie lake in the Pojezierze Kujawskie lakeland (Burchardt 1977, pl. XIII, fig. 7), paraoligotrophic Jezioro Czarne-Sosnowickie lake (Wojciechowski 1971, pl. XXIII, fig. 9), Jezioro Uściwierz lake (Malicki 1972, pl. II, fig. e) and eutrophic Jezioro Sumin lake (Pasztaleniec & Poniewozik 2004, p. 45, fig. 19) in the Pojezierze Łęczyńsko-Włodawskie lakeland, eutrophic coastal lakes including Jezioro Łebsko and Jezioro Gardno (Picińska-Fałtynowicz 1997, fig. 15), peat pits in Bolesławice, eutrophic Jezioro Myślibórz Wielki lake, the Nowe Warpno firth in Szczecin Pomerania, and Zalew Szczeciński lagoon (Kowalski 1975, p. 361, figs 19–21) including a hypertrophic sampling station in this lagoon (Luścińska 2005, pl. VIII, fig. 18), a fish pond near Łódź (Sitkowska 1992, p. 64, pl. XXIV, fig. 6) and a settling pond in Warsaw (Humblet-Pawłowska 1939, pl. V, fig. 128).

*__Pediastrum orientale__ (Skuja) Jankovská et Komárek 1995, p. 327, figs 2–6
Figs 4F, 8D–F, 9A–F

Basionym:

P. pearsonii var. *orientale* Skuja 1937, p. 47, pl. I, figs 23–27.

Coenobia 41–72 µm in diameter, round, oval or irregular in outline, without perforations, 16-, 32-celled. Cells arranged spirally, concentrically or irregularly. Marginal cells 7–17 µm long, 7–15 µm wide, approximately round, with convex or conically extended outer margin, sometimes with concave sides, without incision and lobes, or with very shallow incision and very short lobes. Each marginal cell with two processes oriented obliquely to plane of coenobium, or very rarely on plane of coenobium. Processes of different length, from less than one fourth to half of cell length. Sometimes processes absent. Inner cells 5–12 µm long, 6–15 µm wide, polygonal. Cell wall surface rugulate with granules (type 6a).

Notes. Coenobia of *P. orientale* from the cultured material (strain no. 12.160708; Fig. 9C–F) were similar to the field material in shape, number and composition of cells, and dimensions (coenobia 46–69 µm in diameter, marginal cells 9–20 µm long, 8–17 µm wide, inner cells 7–13 µm long, 8–16 µm wide). Some cells in the cultured material had small perforations and rather short processes. The marginal cells were sometimes conically elongated, with concave sides (Fig. 9C), very similar to the cells in *P. kawraiskyi*.

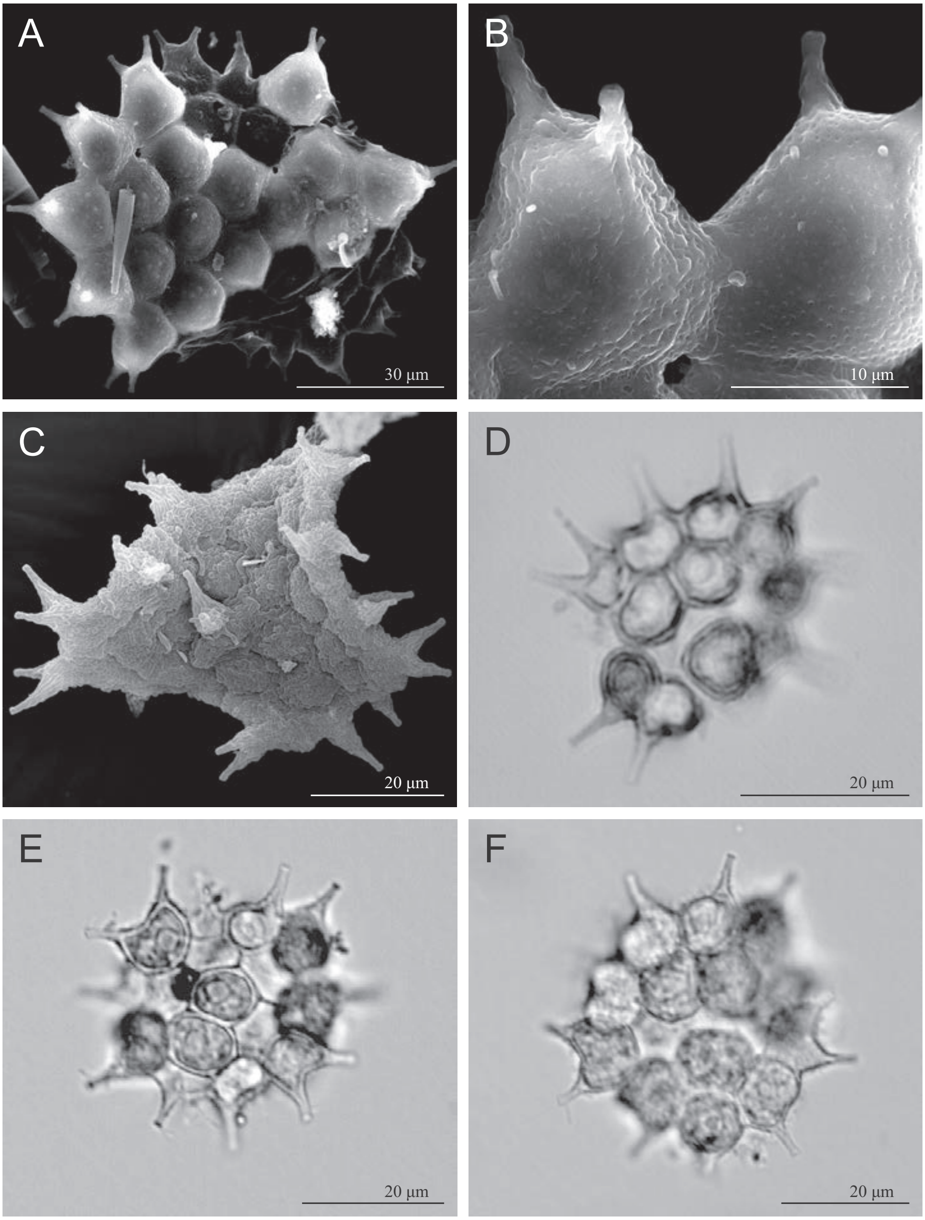

Fig 8. A–C – *Pediastrum kawraiskyi* Schmidle from field material. A & B – older coenobium having an untypical shape of marginal cells and a scabrate cell wall surface. C – teratological form having processes on an inner cell. D–F – *P. orientale* (Skuja) Jankovská et Komárek from field material – coenobia similar to *P. boryanum* (Turpin) Meneghini var. *brevicorne* A. Braun. A–C – SEM. D–F – LM.

Detailed microscopy revealed high intraspecific variability in *P. orientale*. Two morphotypes were distinguished. The coenobia of one type, found in fish ponds, a clay pit and a coastal lake (Fig. 8D–F), were similar to *P. boryanum* var. *brevicorne*, and the coenobia of the second type, from coastal lakes and the above-mentioned cultured

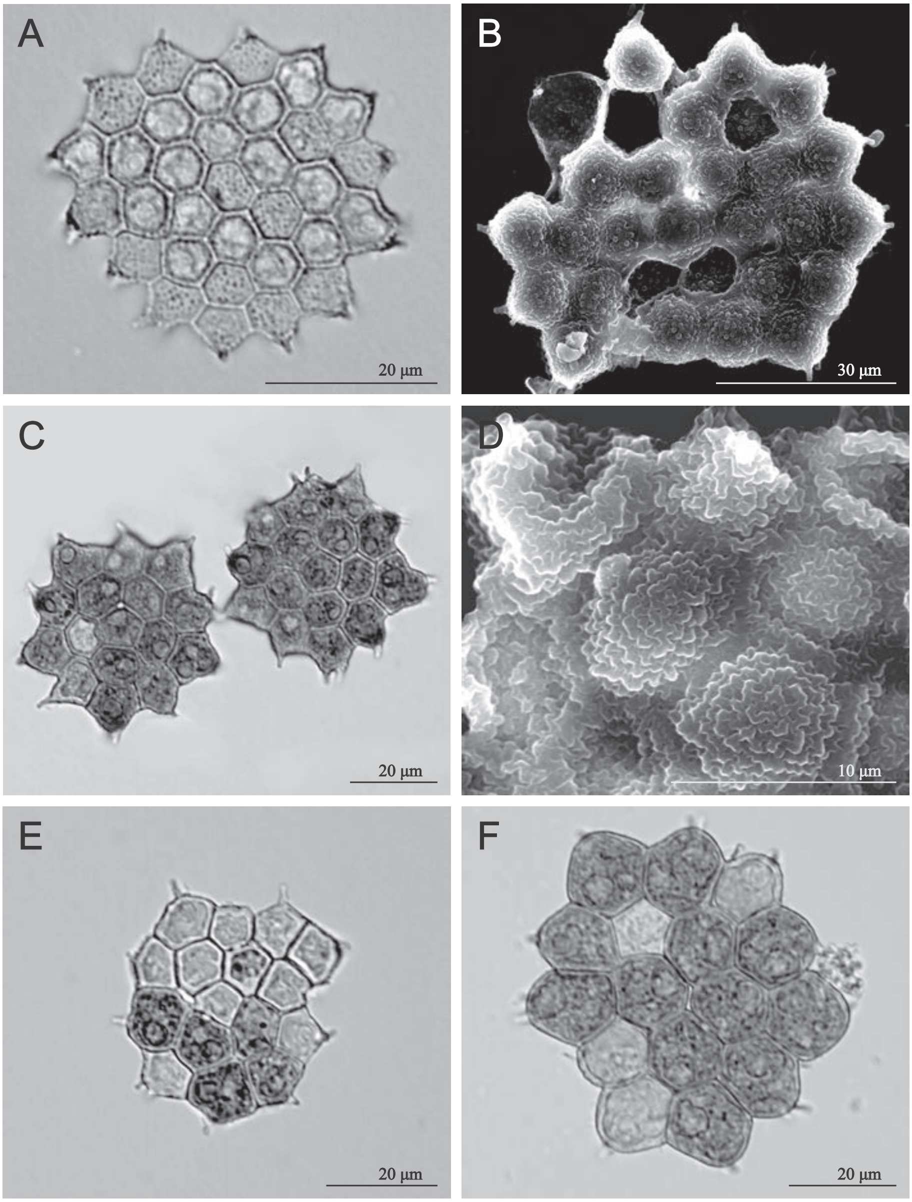

Fig. 9. A–F – *Pediastrum orientale* (Skuja) Jankovská et Komárek – coenobia similar to *P. kawraiskyi* Schmidle. A & B – field material. C–F – cultured material. A, C, E & F – LM. B & D – SEM.

material (Fig. 9A–F), resembled *P. kawraiskyi*. The first morphotype had long processes running from one third to half of cell length, and some round marginal cells with processes on the plane of the coenobium and a very shallow incision. Similar coenobia of *P. orientale* were also observed by Malicki (1972) and by Pasztaleniec & Poniewozik (2004). The second morphotype had short processes, maximally ca. one fourth of cell length, and some conically extended marginal cells with concave sides, processes on the plane of the coenobium, a very shallow incision and sometimes single tiny perforations. Similar coenobia were noted by Sitkowska (1992).

The cell wall ornamentation of field and cultured material (Figs 4F, 9B & D) differed from that originally described by Jankovská & Komárek (1995). Further notes on *P. orientale* cell wall ultrastructure from the above-mentioned material are given by Kowalska & Wołowski (2010b), who pointed to the need for more study of the morphological variability of the species.

CURRENT RECORDS. *P. orientale* occurred at 7 of 71 stations, located on the Southern Baltic Coast and in Polesie, including coastal lakes (sampling stations I.2–4), fish ponds (V.3, 5, 6) and a peat pit (I.8). The species always had a share of ≤0.2% in the algal communities. The water bodies were eutrophic; water temperature 19.5–24.6°C, pH 8.5–9.3, conductivity 307–1740 µS/cm, total hardness 8.6–27.8°n, carbonate hardness 6.4–8.0°n, nitrates <5.0–10.0 mg/dm^3 and orthophosphates <0.15 mg/dm^3. A recent finding in coastal lakes was published by Kowalska & Wołowski (2010b, p. 229, figs 5–8).

LITERATURE DATA. Few records were given for *P. orientale*. Localities include two lakes, Jezioro Rotcze lake (Malicki 1972, pl. II, fig. f, upper – as misapplied name *P. kawraiskyi*) and eutrophic Jezioro Sumin lake (Pasztaleniec & Poniewozik 2004, p. 45, figs 20–24) in the Pojezierze Łęczyńsko-Włodawskie lakeland, and ponds, one natural and one artificial, near Łódź (Sitkowska 1992, pl. XXIII, figs 2 & 4–6, pl. XXIV, figs 3–5 – as misapplied name *P. kawraiskyi*).

****Pediastrum integrum*** var. ***integrum*** Nägeli 1849, p. 96, pl. V, fig. 4 Fig. 10A–G

SYNONYMS:

P. integrum var. *braunianum* (Grunow) Nordstedt 1878, p. 8, pl. I, fig. 6;
P. integrum var. *braunianum* fo. *brevicorne* Raciborski 1889, p. 7, pl. II, fig. 4;
P. integrum var. *genuinum* Bleisch fo. *granulatum* Raciborski 1889, p. 3, pl. II, fig. 1;
P. integrum var. *scutum* Raciborski 1889, p. 5, pl. II, fig. 6;
P. muticum Kützing var. *brevicorne* Raciborski 1889, p. 11, pl. II, fig. 7.

Coenobium 105 µm in diameter, round in outline, without perforations, 32-celled, cells polygonal. Marginal cells 17–21 µm long, 15–20 µm wide, without incision and lobes, each with two processes one fourth the length of cells. Sometimes processes off plane of coenobium or absent. Outer cell margin between processes straight. Inner cells 7–12 µm long, 6–15 µm wide, with thick cell walls. Cell wall surface with regularly disposed granules (type 7c?).

NOTES. In strain no. 09.170408 (Fig. 10B–G), 16- and 32-celled coenobia were observed; they were 54–117 µm in diameter. Marginal cells were 8–30 µm long, 7–30 µm wide, inner cells 7–23 µm long, 8–27 µm wide. Smaller coenobia sometimes had very shallow incisions in the margins of polygonal marginal cells (Fig. 10C). Older cells were bigger and rounder, sometimes with slightly thickened cell walls (Fig. 10B). Similar differences connected with coenobium age were also observed by Sulek (1969) and Parra (1979).

Parts of older coenobia (Fig. 10E) and single cells (Fig. 10F & G) of *P. integrum* var. *integrum* were also observed in the strain. The cells were round and oval, 23–34 µm long, 21–32 µm wide, with thick (1–4 µm) walls and sometimes a rough surface. They

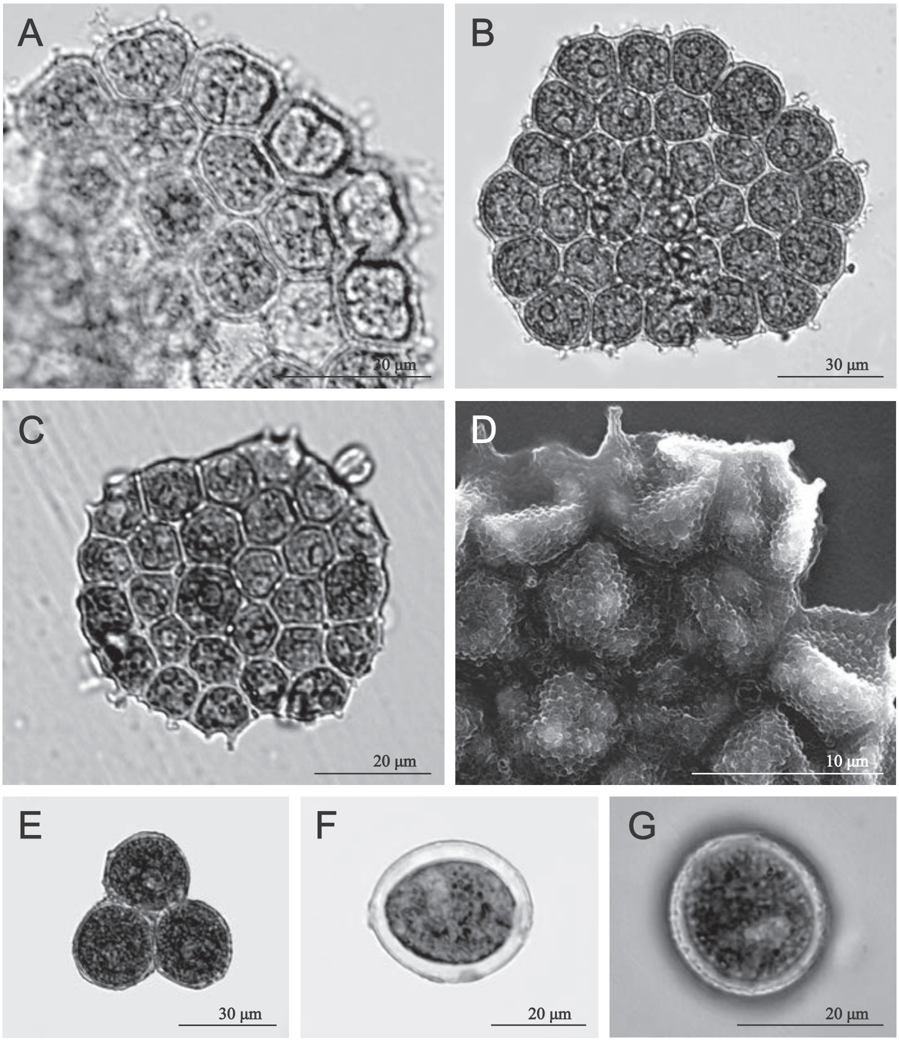

Fig. 10. A–G – *Pediastrum integrum* Nägeli var. *integrum*. A – part of coenobium from field material. B–G – cultured material. D – details of cell wall ultrastructure. E – part of an older coenobium. F & G – single cells having thicker cell walls and sometimes a rough surface. A–C & E–G – LM. D – SEM.

were morphologically similar to normally developed cells in coenobia. This suggests that they were resting cells, emerged as a result of coenobium disintegration. Such single cells of *Pediastrum* have not been noted previously in the literature. Chang & Chang-Schneider (1980) mentioned a cultured coenobium of *P. boryanum* var. *longicorne* having a group of thick-walled dark green cells in the middle. The group was surrounded by empty cells, perhaps representing a resting stage of the taxon. Komárek & Jankovská (2001) gave information on thick-walled hypnozygotes of *Pediastrum* which undergo dormancy after gamete fusion. Rojo *et al.* (2009) observed oval-shaped zygotes of *P. tetras* having thicker cell walls. The origin and fate of the single cells from the cultured material is not clear.

In LM only regularly disposed granules were visible on the surface of the only coenobium found in the field material (Fig. 10A). In SEM the reticulate cell wall surface with regularly disposed granules (type 7c) was observed in the cultured material only (Fig. 10D). Apart from this ornamentation, another type composed of polygonal mesh and irregularly disposed granules (type 7a) was sometimes noted. Such differently developed ornamentation may be a natural or teratological modification. Similar irregularities were observed by Parra (1979).

The analyzed strain was contaminated with tiny coccoid green algae *Didymocystis planctonica* Koršikov.

Current record. *P. integrum* var. *integrum* had a share of ≤0.2% in a humoeutrophic lowland lake with a forest catchment (sampling station III.4), Southern Baltic Lowlands; water temperature 24.7°C, pH 8.2, conductivity 148 µS/cm, total hardness 5.0°n, carbonate hardness 4.0°n, nitrates <5.0 mg/dm^3 and orthophosphates 0.25 mg/dm^3.

Literature data. All the previous Polish localities of *P. integrum* given by Siemińska & Wołowski (2003) are treated as localities of *P. integrum* var. *integrum*, because only the variety *integrum* has been noted from Central Europe. The second variety, *pearsonii* (G.S. West) Fritsch in Fritsch et Stephens, is known from Africa and probably occurs in areas surrounding the Mediterranean Sea (Komárek & Jankovská 2001). In previous studies there are many records of *P. integrum* var. *integrum* from e.g. a pond in the Botanic Garden of the Jagiellonian University in Cracow, from Modlniczka near Cracow, Chełmek and the Vistula river (Raciborski 1889, p. 3, pl. II, fig. 1 – as synonym *P. integrum* var. *genuinum* fo. *granulatum*, p. 7, pl. II, fig. 4 – as synonym *P. integrum* var. *braunianum* fo. *brevicorne*, p. 11, pl. II, fig. 7 – as synonym *P. muticum* var. *brevicorne*), from the southern part of the Baltic Sea (Namysłowski 1924, without documentation – as synonym *P. integrum*), from Jezioro Wigry lake in north-eastern Poland, (Wołoszyńska 1924, without documentation – as synonym *P. integrum* var. *braunianum*), and from several eutrophic lakes in various regions of Poland, including coastal Jezioro Gardno lake (Strzelecki & Półtorak 1971, without documentation – as synonym *P. integrum*), Jezioro Zmarłe lake in the Bory Tucholskie forest (Oleksowicz 1986, fig. 102 – as misapplied name *P. boryanum*) and Jezioro Sumin lake in the Pojezierze Łęczyńsko-Włodawskie lakeland (Pasztaleniec & Poniewozik 2004, p. 45, fig. 17).

Pediastrum boryanum* (Turpin) Meneghini 1840, p. 210

Figs 4B, C & J, 11A–F, 12A–F, 13A–F, 14A–F, 15A–G, 16A–F, 17A–G, 18A–F

Basionym:

Helierella boryana Turpin 1828, p. 319, fig. 22.

Synonyms:

P. boryanum ssp. *forcipatum* (Corda) Raciborski 1889, p. 15, pl. II, fig. 17;
P. boryanum var. *brevicorne* fo. *glabrum* Raciborski 1889, p. 13, pl. II, fig. 12;
P. boryanum var. *brevicorne* fo. *punctatum* Raciborski 1889, p. 13;
P. boryanum var. *selenaea* (Kützing) Nitardy 1914, p. 178, pl. V, fig. 6, pl. VIII, fig. 9;
P. bidentulum A. Braun 1855, p. 91;
P. bidentulum var. *ornatum* Nordstedt 1878, p. 8, pl. I, fig. 6;
P. duplex Meyen var. *genuinum* A. Braun fo. *gracilis* (A. Braun) Brunnthaler 1915, p. 95, fig. 57c;
P. selenaea Kützing 1845, p. 143.

Coenobia 30–161 µm in diameter, round or almost round, very rarely irregular, with or without perforations, 8-, 16-, 32-, 64-, 128-celled. Cells arranged concentrically, spirally or irregularly. Cells tetragonal or polygonal in outline. Marginal cells 6–36 µm long, 6–34 µm wide, each cell with two conical lobes on plane of coenobium. Incision between lobes maximally to two thirds of cell length, V- or U-shaped. Processes of different lengths, maximally to half of cell length. Inner cells 4–27 µm long, 5–39 µm wide. Cell wall surface scabrate (type 2), granulate (type 3) or reticulate with granules (type 7c).

Notes. The species is highly variable morphologically, causing many taxonomic problems. Some intermediate forms occur between its varieties, as described below. Sulek (1969) also mentioned intermediate forms in *P. boryanum*.

Among the *Pediastrum* species, *P. boryanum* has the highest number of varieties (9) (Komárek & Jankovská 2001). The main characters distinguishing single varieties are cell shape, the occurrence of perforations, and type of cell wall ornamentation. A reticulate surface with a trigonal mesh and regularly disposed granules (type 7c) was observed in most *P. boryanum* varieties, including *boryanum* (Figs 11A–F, 12A), *cornutum* (Figs 13A–F, 14A & B), *perforatum* (Figs 14C–F, 15A & B), *longicorne* (Figs 15C–G, 16A–F) and *brevicorne* (Fig. 17A–G). However, the five taxa differed in granule density. In the varieties *boryanum*, *longicorne* and *perforatum* the granules were sparsely disposed, 7–10 granules in cell width. The granules were most densely disposed in var. *boryanum* and var. *brevicorne*, 18–20 granules in cell width.

Granule density in the reticulate ornamentation of *P. boryanum* has been variously described in the literature. Sulek (1969) and Komárek & Jankovská (2001) used only simple terms such as "surface densely, delicately granulated", whereas Parra (1979) and Nielsen (2000) gave the number of granules in 10 µm cell length. Bearing in mind that the cells of *P. boryanum* enlarge and that the cell walls stretch with age, granule density in this work is taken as number of granules in cell width, as presented above.

The first molecular studies on the species have been carried out (Buchheim *et al.* 2005; McManus & Lewis 2005, 2011; Jena *et al.* 2014) but they need to be expanded and some morphometric analyses of selected varieties should be included, to produce reliable findings on the taxonomy and phylogeny of the species.

Current records. *P. boryanum* occurred at 47 of 71 stations, located on the Southern Baltic Coast, in the Eastern and Southern Baltic Lakelands, Central Polish Lowlands, Polesie, Wyżyna Śląsko-Krakowska upland, Northern Sub-Carpathia and Central Western Carpathians, including coastal lakes (sampling stations I.1–5), lowland lakes with mixed (I.9, II.2, 6, 7, 11, 12, III.5, 13, 14, V.2), forest (II.3, III.2, 4) and manmade (V.8–10) catchments, a delta lake (I.10), fish ponds (I.6, III.9, IV.2, V.1, 3–7), park ponds (III.8, VIII.6, 7), through-flow ponds (IV.3, 4), village ponds (IV.1, VII.1, 2), a suburban pond (III.6), a field pond (III.11), peat pits (I.7, 8, III.7), a clay pit (VIII.3), an oxbow lake (VIII.4) and a dam reservoir (IX.1). It usually had a share of ≤0.2% (25 sampling stations), 0.3–3% (21) or 4–10% (1) in the algal communities. The water bodies ranged from oligo/meso- to eutrophic, most were eutrophic (37) and one was humoeutrophic; water temperature 15.7–26.3°C, pH 7.4–9.6, conductivity 46–1740 µS/cm, total hardness 1.8–27.8°n, carbonate hardness 1.2–15.6°n, nitrates <5.0–20.0 mg/dm^3 and orthophosphates <0.15–1.50 mg/dm^3.

Literature data. Very many records were given for *P. boryanum*. Localities include lakes (e.g. Krause 1906, fig. 4a, except for left figure – as misapplied name *P. pertusum*, fig. 4c; Lucks 1906/1907, p. 46, fig. 19 – as misapplied name *P. boryanum* var. *genuinum*, p. 47, fig. 22 – as misapplied name *P. boryanum* var. *forcipatum*; Nitardy 1914, p. 178, pl. V, fig. 6 – as synonym *P. boryanum* var. *selenaea*; Malicki 1972, pl. III, fig. a – as misapplied name *P. boryanum* var. *cornutum*, figs b–d & f – as misapplied name *P. boryanum* var. *boryanum*), including eutrophic lakes (Kotlińska 1976, pl. XVI, fig. 250 – as misapplied name *P. duplex* var. *genuinum* fo. *convergens*, fig. 251 – as synonym *P. duplex* var. *genuinum* fo. *gracilis*, fig. 252 – as misapplied name *P. duplex* var. *recurvatum*, figs 255 & 256 – as misapplied name *P. boryanum* var. *brevicorne*, fig. 258 – as misapplied name *P. boryanum* var. *subuliferum*, fig. 261 – as misapplied name *P. tetras* var. *excisum*; Stefko 1976, pl. XI, figs 1 & 4 – as misapplied name *P. boryanum* var. *brevicorne*, fig. 2 – as misapplied name *P. boryanum* var. *undulatum*, fig. 6 – as misapplied name *P. tetras*; Burchardt 1977, pl. XIII, fig. 3; Koczorowska & Wetula 1984, pl. I, fig. 17; Socha 1993, p. 47, pl. XII, fig. 8; Pasztaleniec & Poniewozik 2004, p. 40, fig. 2 – as misapplied name *P. boryanum* var. *boryanum*; Kowalska & Luścińska 2006, p. 50, pl. XIII, fig. 2 – as misapplied name *P. boryanum* var. *boryanum*, fig. 3 – as misapplied name *P. boryanum* var. *longicorne*) and paraoligotrophic lakes (Wojciechowski 1971, pl. XXIII, figs 5 & 6 – as misapplied name *P. boryanum* var. *cornutum*), as well as various types of ponds (e.g. Raciborski 1889, p. 13, pl. II, fig. 12 – as synonym *P. boryanum* var. *brevicorne* fo. *glabrum*, p. 13 – as synonym *P. boryanum* var. *brevicorne* fo. *punctatum*, p. 15, pl. II, fig. 17 – as synonym *P. boryanum* ssp. *forcipatum*; Kadłubowska 1961, p. 98, pl. XI, fig. 6), including fish ponds (e.g. Kadłubowska *et al.* 1972, p. 57, figs 23–27, photos 6–9; Sitkowska 1992, p. 58, pl. V, figs 1–6, pl. VI, figs 1, 2 & 4–6, pl. VII, figs 1–6, pl. IX, figs 1–5, pl. X, figs 1–3 & 5 – as misapplied name *P. boryanum* var. *boryanum*, pl. XI, figs 1 & 2 – as misapplied name *P. boryanum* var. *brevicorne*, p. 63, pl. XXI, fig. 2, pl. XXII, fig. 2 – as misapplied name *P. integrum*), dam reservoirs (e.g. Bucka & Wilk-Woźniak 2002, p. 166, figs 183 & 184), retention reservoirs (Gołdyn 1989, photo V-1 – as misapplied name *P. boryanum* var. *boryanum*), a settling pond (Humblet-Pawłowska 1939, pl. V, fig. 121 – as misapplied name *P. duplex*, fig. 124 – as synonym *P. duplex* var. *genuinum* fo. *gracilis*, figs 126 & 127 – as misapplied name *P. boryanum* var. *genuinum*, fig. 129a), lagoon (Luścińska 2005, pl. VIII, fig. 14 – as misapplied name *P. boryanum* var. *boryanum*, fig. 19 – as misapplied name *P. tetras*), peat bogs (Piątek 2007, p. 54, fig. 313 – as misapplied name *P. boryanum* var. *brevicorne*) and a river (Luer-Jeziorańska, pl. XI, figs 201 & 202 – as misapplied name *P. boryanum* var. *brevicorne*, 203 – as misapplied name *P. boryanum* var. *longicorne*, 204 – as misapplied name *P. boryanum* var. *subuliferum*).

**Pediastrum boryanum* var. *boryanum* — Figs 11A–F, 12A

Synonyms:

P. boryanum fo. *typicum* Brunnthaler 1915, p. 100, fig. 61a;
P. boryanum var. *divergens* Lemmermann 1901, p. 92, pl. IV, fig. 6;
P. boryanum var. *genuinum* Kirchner 1878, p. 95;
P. boryanum var. *granulatum* (Kützing) Rabenhorst 1868, p. 75;
P. boryanum var. *subuliferum* (Kützing) Rabenhorst 1868, p. 75;
P. granulatum Kützing 1845, p. 143.

Coenobia 41–118 μm in diameter, without or with small sparse perforations, 8-, 16-, 32-, 64-celled. Cells polygonal in outline. Marginal cells 11–25 μm long, 9–22 μm wide. Incision U-shaped or V-shaped, from one third to half of cell length, occasionally to two thirds of cell length. Processes from less than one third to almost half of cell length. Inner cells 6–16 μm long, 9–23 μm wide. Cell wall surface reticulate with granules (6–20 granules in cell width) (type 7c).

Herbarium material. Wittrock & Nordstedt, Algae aquae dulcis exsiccatae praecipue scandinavicae, no. 235, leg. G. Thuret comm. E. Bornet, August 1848, ut *P. simplex* (BM).

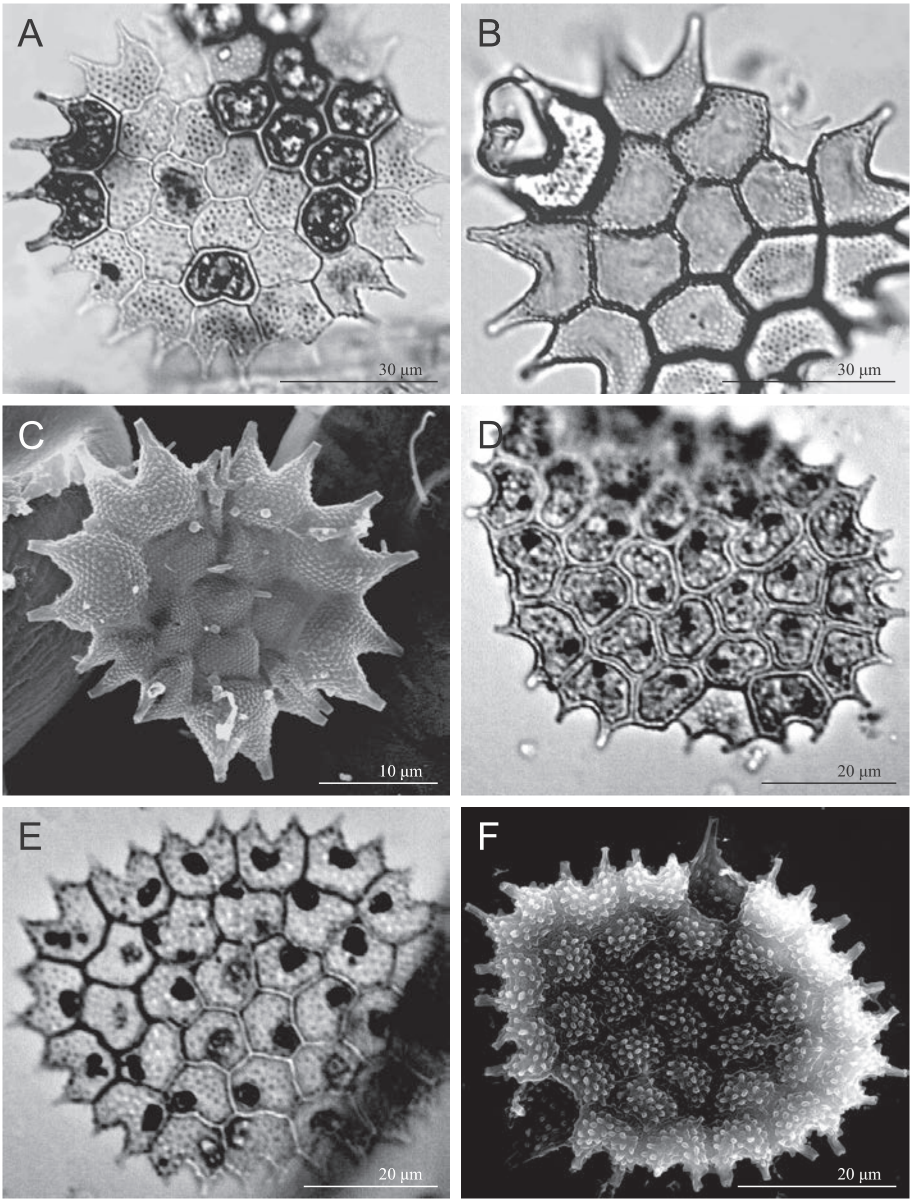

Fig. 11. A–F – *Pediastrum boryanum* (Turpin) Meneghini var. *boryanum* from field material – morphological variability within the variety. A – coenobium with full cells and empty cells with wall granulation. C – differences in cell shape and cell wall ornamentation between cells of various size. A, B, D & E – LM. C & F – SEM.

Notes. High variability of morphology, including cell shape and granule density, was observed in *P. boryanum* var. *boryanum* (Figs 11A–F, 12A). Among its coenobia, forms characteristic for the variety were observed (Fig. 11A), but also intermediate forms similar to other varieties of the species. There were forms similar to var. *forcipatum* in having longer lobes (Fig. 11B) and denser, delicate granulation (Fig. 11B & C), forms

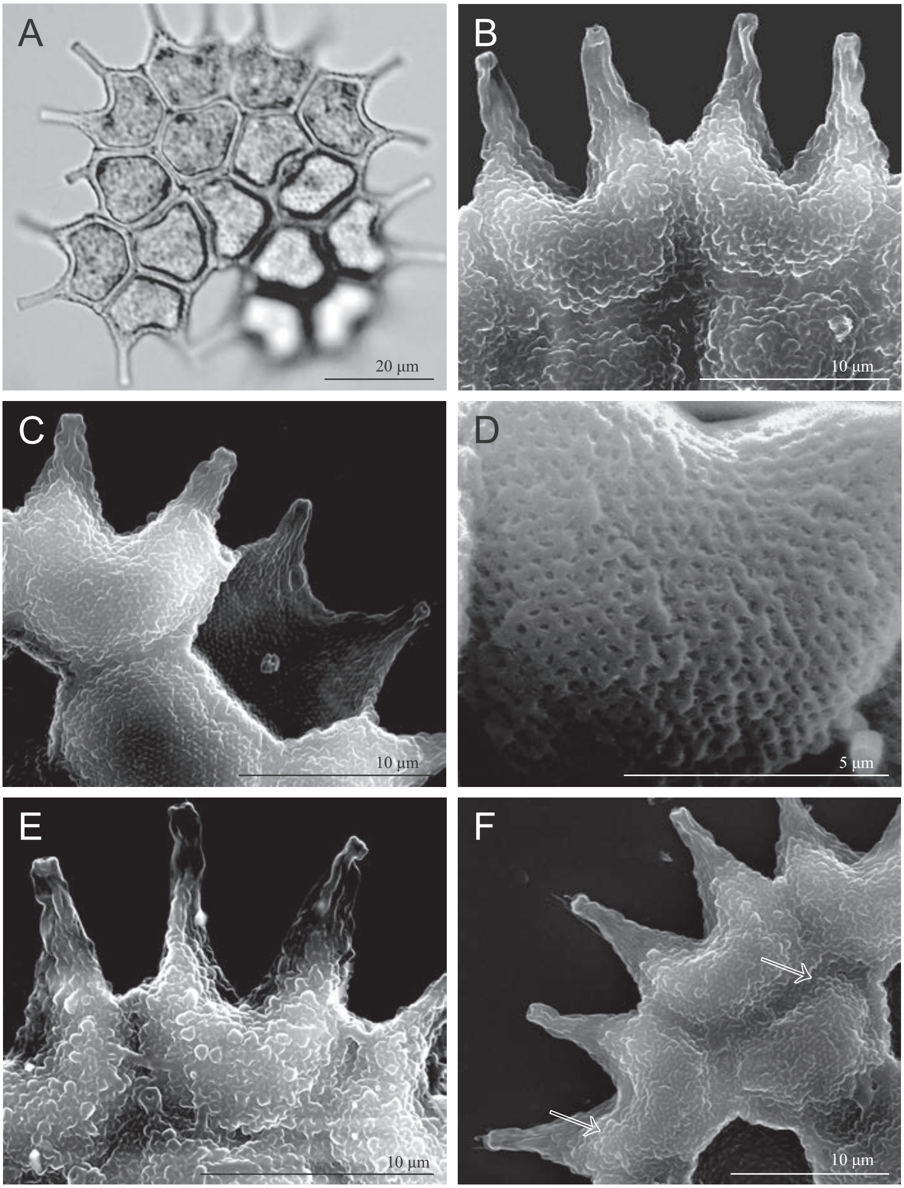

Fig. 12. A – *Pediastrum boryanum* (Turpin) Meneghini var. *boryanum* from field material – morphological variability within the variety. B–F – *P. boryanum* var. *pseudoglabrum* Parra from field material – variability of cell wall surface. F – scabrate ornamentation with granules arranged in rows (arrows), similar to the granulate ornamentation in *P. boryanum* var. *forcipatum* (Corda) Chodat. A – LM. B–F – SEM.

similar to var. *perforatum* in having very sparsely distributed large granules (Fig. 11E & F), forms similar to var. *brevicorne* in having short processes and a shallow incision (Fig. 11D), and forms similar to var. *longicorne* in having very sparsely distributed granules (Fig. 11E & F) and long processes (Fig. 12A). Parra (1979) also noted coenobia of *P. boryanum* var. *boryanum* resembling two other varieties of the species, *brevicorne* and *longicorne*. Chang and Chang-Schneider (1980) observed alteration of *P. boryanum* var. *boryanum* coenobia in cultured material under strong lighting. The coenobia were perforated and had rounded cells, without incisions and processes. McManus & Lewis (2005) mentioned a strain of *P. boryanum* var. *boryanum* that was genetically more similar to *P. duplex* than to other strains of *P. boryanum*, and pointed out that morphological features can be misleading.

The morphological variability of *P. boryanum* var. *boryanum* was connected with cell size (Fig. 11C). Bigger cells were rounder, had shallower incisions, and granules disposed more sparsely on the cell surface though their number remained the same.

These observations suggest that the taxon may be a complex of many different forms, requiring molecular studies and morphometric analyses of material cultured under various environmental conditions.

Current records. *P. boryanum* var. *boryanum* occurred at 32 of 71 stations, located on the Southern Baltic Coast, in the Eastern and Southern Baltic Lakelands, Central Polish Lowlands, Polesie, Wyżyna Śląsko-Krakowska upland and Northern Sub-Carpathia, including coastal lakes (sampling stations I.1–5), lowland lakes with mixed (I.9, II.7, III.14), forest (III.4) and manmade (V.8) catchments, a delta lake (I.10), fish ponds (III.9, IV.2, V.1, 3–7), park ponds (III.8, VIII.7), through-flow ponds (IV.3, 4), village ponds (IV.1, VII.2), a suburban pond (III.6), field pond (III.11), peat pits (I.7, 8, III.7), a clay pit (VIII.3) and an oxbow lake (VIII.4). The water bodies were mostly eutrophic, three were meso/eutrophic and one humoeutrophic; water temperature 15.7–26.3°C, pH 7.9–9.6, conductivity 122–1740 µS/cm, total hardness 5.0–27.8°n, carbonate hardness 4.0–15.6°n, nitrates <5.0–20.0 mg/dm^3 and orthophosphates <0.15–1.50 mg/dm^3. A recent finding in coastal lakes was published by Kowalska & Wołowski (2010b, fig. 17).

Literature data. Many records were given for *P. boryanum* var. *boryanum*. Localities include lakes in western Pomerania (Lucks 1906/1907, p. 43, fig. 2 – as misapplied name *P. integrum* var. *braunianum*, p. 46, fig. 21 – as misapplied name *P. boryanum* var. *longicorne* fo. *granulatum*), polluted Jezioro Pątnowskie lake in central Poland (Burchardt 1977, pl. XIII, fig. 4 – as synonym *P. boryanum* var. *divergens*), two eutrophic lakes, Jezioro Rusałka lake (Kotlińska 1976, pl. XVI, fig. 257 – as synonym *P. boryanum* var. *granulatum*, fig. 259 – as synonym *P. boryanum* var. *divergens*) and Jezioro Maltańskie lake (Stefko 1976, pl. XI, fig. 5 – as synonym *P. boryanum* var. *granulatum*) in Poznań, eutrophic Jezioro Sumin lake in the Pojezierze Łęczyńsko-Włodawskie lakeland (Pasztaleniec & Poniewozik 2004, p. 40, fig. 3 – as misapplied name *P. boryanum* var. *brevicorne*) and fish ponds, including organically and artificially fertilized ponds near Łódź (Sitkowska 1992, p. 58, pl. VI, fig. 3, pl. VIII, figs 1–6, pl. X, fig. 4, p. 59, pl. XI, figs 3 & 6, pl. XII, figs 5 & 6 – as misapplied name *P. boryanum* var. *longicorne*).

[*]***Pediastrum boryanum*** var. ***pseudoglabrum*** Parra 1979, p. 75, pl. XX, figs a–l
Figs 4B, 12B–F

Coenobia 45–108 µm in diameter, without perforations, 16-, 32-celled. Cells polygonal in outline. Marginal cells 11–20 µm long, 7–19 µm wide, each with a U-shaped or V-shaped incision ca. half of cell length. Processes quite short, less than one third of cell length. Inner cells 7–13 µm long, 8–17 µm wide. Cell wall surface scabrate (type 2).

NOTES. The scabrate ornamentation varied in the observed specimens. Verrucas were large and densely disposed (Fig. 12B & E) or delicate and sparsely disposed, with well visible punctae between them (Figs 4B, 12C, D & F). In photos taken by Parra (1979) the verrucas are disposed somewhat densely but the punctae are still well visible on the surface. In my study the surface of some cells of *P. boryanum* var. *pseudoglabrum* showed several granules or verrucas disposed quite regularly (Fig. 12F), resembling the granulate type of ornamentation occurring in *P. boryanum* var. *forcipatum* (Figs 4C, 18A–F). Nielsen (2000) also noted more regular granulation in *P. boryanum* var. *pseudoglabrum*. However, it is also possible that var. *pseudoglabrum* does not exist and that its coenobia belong to var. *forcipatum* but with granulate ornamentation not well developed. Tiny punctae (Figs 4B & C, 12B–F, 18E & F), a common feature in both taxa, are another feature possibly supporting this suggestion.

The iconographic documentation given by Sitkowska (1992), the only one who observed *P. boryanum* var. *pseudoglabrum* in Poland, is out of focus. She noted that in LM the cells were smooth but that in SEM tiny pores much smaller than the granules of *P. boryanum* var. *boryanum* were visible. She did not mention verrucas or granules. This description is ambiguous, suggesting that Sitkowska (1992) may have been observing coenobia belonging to *P. boryanum* var. *pseudoglabrum* with an almost flat surface having verrucas and punctae, or to *P. boryanum* var. *forcipatum* covered with flattened granules and punctae.

Further observation of cell wall ultrastructure in *P. boryanum* var. *pseudoglabrum* is needed. Separation of the taxon should be confirmed by genetic methods.

CURRENT RECORDS. *P. boryanum* var. *pseudoglabrum* occurred at 11 of 71 stations, located on the Southern Baltic Coast, in the Central Polish Lowlands, Polesie and Northern Sub-Carpathia, including coastal lakes (sampling stations I.1, 3–5), a lowland lake with a manmade catchment (V.9), fish ponds (V.4, 7), a through-flow pond (IV.3), village pond (IV.1), peat pit (I.8) and an oxbow lake (VIII.4). Almost all the water bodies were eutrophic, and one was meso/eutrophic; water temperature 18.1–26.3°C, pH 7.9–9.6, conductivity 152–1740 µS/cm, total hardness 9.0–27.8°n, carbonate hardness 5.6–12.2°n, nitrates <5.0–10.0 mg/dm^3 and orthophosphates <0.15–1.50 mg/dm^3.

LITERATURE DATA. Few records were given for *P. boryanum* var. *pseudoglabrum*. Recorded only from fish ponds, including artificially and organically fertilized ones near Łódź (Sitkowska 1992, p. 60, pl. XIII, figs 1–6). However, the description of the taxon given by Sitkowska is ambiguous as described above (NOTES).

Pediastrum boryanum* var. ***cornutum*** (Raciborski) Sulek 1969, p. 218, pl. VII, fig. 2, pl. VIII, fig. 3, pl. IX, photo plate VI, fig. 2 Figs 13A–F, 14A & B

BASIONYM:

P. duplex Meyen var. *cornutum* Raciborski 1889, p. 28, pl. II, fig. 38.

Coenobia 30–96 µm in diameter, with small regularly disposed perforations, 8-, 32-celled. Cells usually tetragonal, sometimes several cells in the coenobium polygonal in outline. Marginal cells 9–19 µm long, 9–16 µm wide. Incision U-shaped or V-shaped, ca. half of cell length. Processes from one fifth to one fourth of cell length. Inner cells

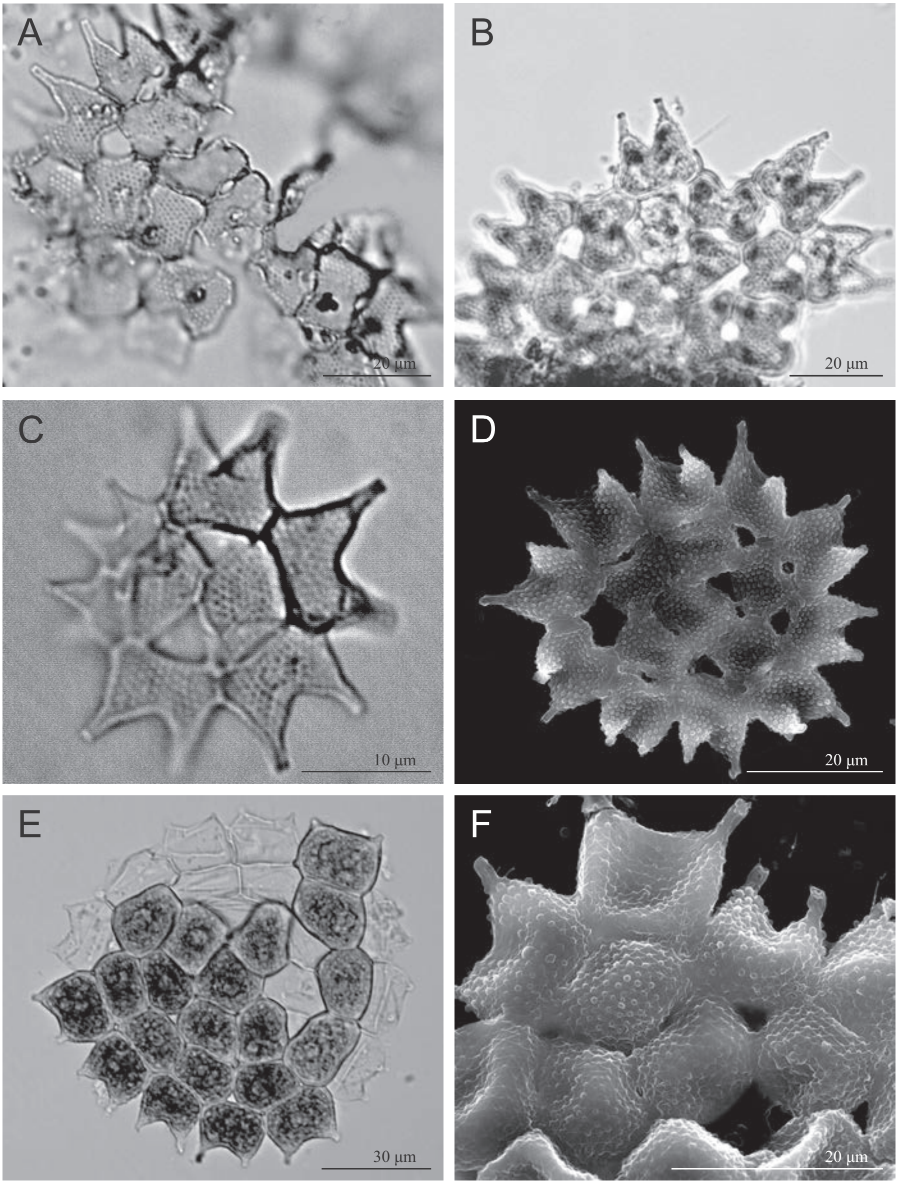

Fig. 13. A–F – *Pediastrum boryanum* var. *cornutum* (Raciborski) Sulek. A–C – field material. D–F – cultured material. A & B – parts of coenobia. C & D – younger coenobia. E & F – older coenobia having rounded cells causing the perforations to disappear. F – details of cell wall ultrastructure. A–C & E – LM. D & F – SEM.

6–13 µm long, 8–18 µm wide. Cell wall surface reticulate with densely disposed granules (12–14 granules in cell width) (type 7c).

Notes. Only 16- and 32-celled coenobia were observed in strain no. 19.090508. They had a greater range of diameter (25–104 µm) and cell dimensions (marginal cells 5–22 µm long, 6–23 µm wide, inner cells 4–18 µm long, 6–22 µm wide) than the coenobia in field material, possibly because few specimens were found in the field. The older cultured coenobia had rounder cells, very shallow or no incisions in the marginal cells, and almost flat cell ornamentation due to wall stretching during coenobium growth (Figs 13E & F, 14A).

Some teratological forms having cells disposed on several planes or without one or two lobes were also observed in the strain (Fig. 14B).

The coenobia of cultured and field material had similar granule density, 11–14 and 12–14 granules in cell width, respectively. Sulek (1969) gave a greater range of granule density in *P. boryanum* var. *cornutum*, from 10 (photo plate VI) to 16 (pl. IX, fig. 1). Parra (1979) presented coenobia having higher granule density, 17–21 granules in cell width (pl. XXI, fig. a, pl. XXII, figs a–d).

Current records. *P. boryanum* var. *cornutum* occurred at 3 of 71 stations, located on the Southern Baltic Coast and Lakelands and in Polesie, including lowland lakes with forest (sampling station III.2) and manmade (V.10) catchments, and a fish pond (I.6). The water bodies ranged from oligo/meso- to eutrophic; water temperature 23.3–23.9°C, pH 7.4–9.1, conductivity 46–233 µS/cm, total hardness 1.8°n, carbonate hardness 1.2°n, nitrates <5.0 mg/dm^3 and orthophosphates <0.15 mg/dm^3.

Literature data. Some records were given for *P. boryanum* var. *cornutum*. Localities include a pool in Łęg near Cracow (Raciborski 1889, p. 28, pl. II, fig. 38 – as synonym *P. duplex* var. *cornutum*), fish ponds in southern Poland (Krzeczkowska-Wołoszyn 1966, without documentation – as synonym *P. duplex* var. *cornutum*), polluted Jezioro Pątnowskie lake in central Poland (Burchardt 1977, without documentation), several eutrophic lakes in the Pojezierze Mazurskie lakeland – Jezioro Mokre, Jezioro Seksty, Jezioro Śniardwy and Jezioro Warnołty (Chudyba 1979, without documentation – as synonym *P. duplex* var. *cornutum*) – coastal Jezioro Łebsko lake (Burchardt *et al.* 2003, without documentation), and eutrophic Jezioro Sumin lake in the Pojezierze Łęczyńsko-Włodawskie lakeland (Pasztaleniec & Poniewozik 2004, p. 43, fig. 9 – as misapplied name *P. subgranulatum*).

******Pediastrum boryanum*** var. ***perforatum*** (Raciborski) Nitardy 1914, p. 179, pl. IX, fig. 10 — Figs 14C–F, 15A & B

Basionym:

P. boryanum ssp. *perforatum* Raciborski 1889, p. 13, pl. II, fig. 11.

Synonym:

P. duplex Meyen var. *genuinum* A. Braun fo. *convergens* Raciborski 1889, p. 29, pl. II, fig. 36.

Coenobia 39–105 µm in diameter, with small regularly or irregularly disposed perforations, 8-, 16-, 32-, 64-celled. Cells tetragonal or polygonal in outline. Marginal cells 10–22 µm long, 9–19 µm wide. Incision U-shaped or V-shaped, from half to two thirds of cell length. Processes of different lengths, from one sixth to one third of cell length. Inner cells 7–15 µm long, 8–19 µm wide. Cell wall surface reticulate with sparsely disposed granules (7–11 granules in cell width) (type 7c).

Notes. The taxon showed great morphological variability. Cells of coenobia found in the coastal lakes usually were distinctly tetragonal in outline (Fig. 14C–E), similar to cells of *P. duplex* var. *duplex* (Figs 19A–F, 20A–D) and *P. boryanum* var. *cornutum* (Figs 13A–F, 14A & B). Only that type of *P. boryanum* var. *perforatum* cell was observed

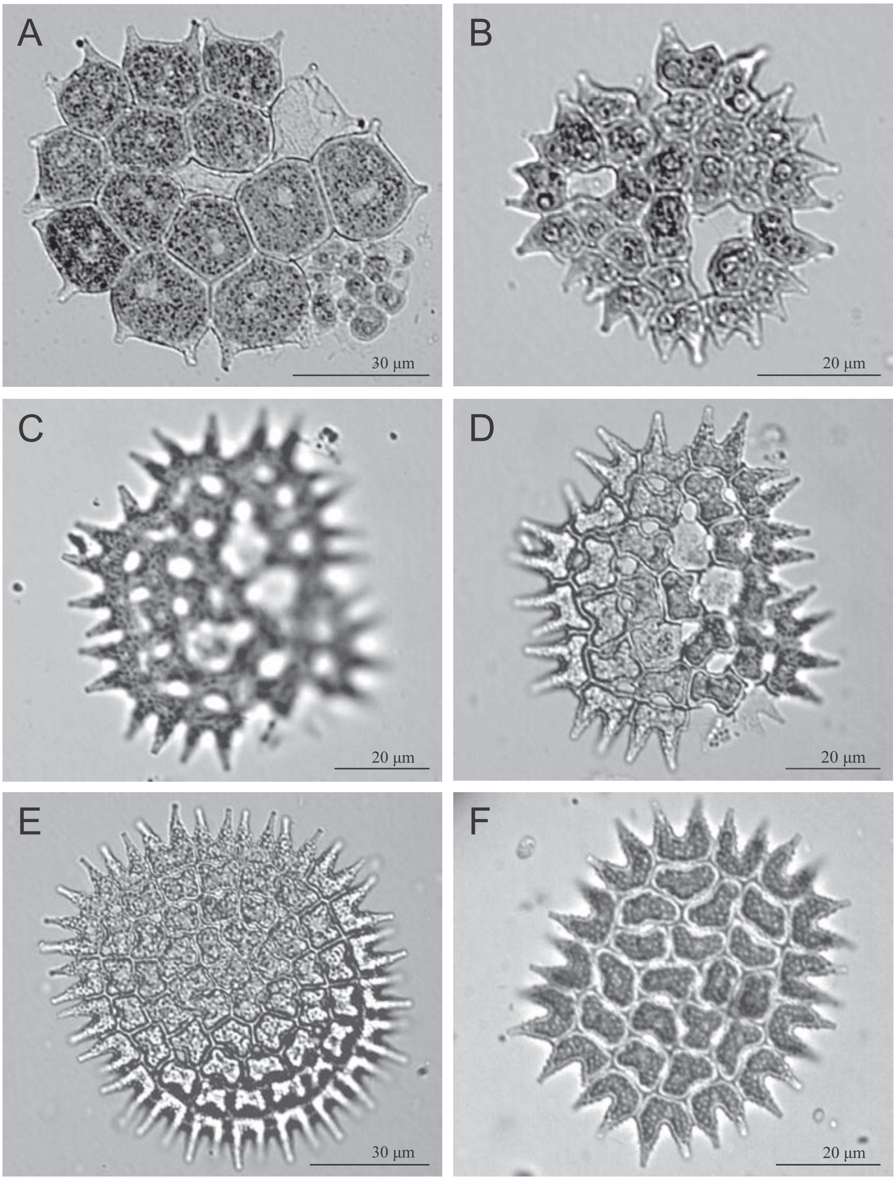

Fig. 14. A & B – *Pediastrum boryanum* var. *cornutum* (Raciborski) Sulek from cultured material. A – older coenobium having rounded cells causing the perforations to disappear. B – teratological form having some undeveloped lobes of the marginal cells. C–F – *P. boryanum* var. *perforatum* (Raciborski) Nitardy from field material. C–E – coenobia having more tetragonal cells, similar to cells of *P. duplex* Meyen. A–F – LM.

by Parra (1979, pl. XXIII, fig. b, pl. XXIV, figs a & d). Both var. *perforatum* and var. *cornutum* had similar granule density in the material I observed. The granules in var. *perforatum* were more sparsely disposed but their density ranges overlapped. According to Nielsen (2000) the taxa cannot be distinguished unequivocally on the basis of cell shape and granule density.

Some coenobia from lowland lakes had polygonal cells (Fig. 15A & B), resembling cells of *P. boryanum* var. *boryanum*. In view of its variability of cell shape and granule density, further taxonomic studies including molecular analyses are needed for proper revision of var. *perforatum* and var. *cornutum*.

Current records. *P. boryanum* var. *perforatum* occurred at 11 of 71 stations, located on the Southern Baltic Coast and in the Eastern and Southern Baltic Lakelands and Central Polish Lowlands, including lowland lakes with mixed (sampling stations II.2, 6, 7, 11, III.5) and forest (II.3, III.3) catchments, coastal lakes (I.1, 3, 5) and a fish pond (IV.2). Eight of the water bodies were eutrophic and the others were mesotrophic, meso/eutrophic or humoeutrophic; water temperature 17.0–25.0°C, pH 8.2–9.6, conductivity 148–560 µS/cm, total hardness 5.0–15.8°n, carbonate hardness 4.0–14.4°n, nitrates ≤5.0 mg/dm^3 and orthophosphates <0.15–0.75 mg/dm^3. A recent finding in coastal lakes was published by Kowalska & Wołowski (2010b, fig. 19).

Literature data. Some records were given for *P. boryanum* var. *perforatum*. Localities include the Zatoka Pucka lagoon (Rumek 1948, without documentation – as misapplied name *P. integrum* var. *perforatum*), humoeutrophic Jezioro Skrzynka lake in Wielkopolska National Park (Krawiecowa 1957, without documentation), Jezioro Uściwierz lake in the Pojezierze Łęczyńsko-Włodawskie lakeland (Malicki 1972, pl. III, fig. j – as misapplied name *P. boryanum* var. *boryanum*), polluted Jezioro Pątnowskie lake (Burchardt 1977, without documentation), a peat pit near that lake (Socha 1981, without documentation), and eutrophic lakes in the Pojezierze Mazurskie lakeland, including Jezioro Łuknajno, Jezioro Klimunt and Jezioro Mokre (Chudyba 1979, without documentation); without localities it was mentioned by Raciborski (1889, p. 29, pl. II, fig. 36 – as synonym *P. duplex* var. *genuinum* fo. *convergens*).

****Pediastrum boryanum*** var. ***longicorne*** Reinsch 1867, p. 96, pl. VII, fig. 6c
Figs 15C–G, 16A–F

Synonyms:

P. boryanum var. *brevicorne* A. Braun fo. *granulatum* (Raciborski) Parra 1979, p. 71, pl. XVIII, figs a–h;
P. boryanum var. *capituligerum* (Lucks) Nitardy 1914, p. 179, pl. VII, fig. 9, pl. IX, fig. 15;
P. boryanum var. *longicorne* fo. *glabrum* Raciborski 1889, p. 14;
P. boryanum var. *longicorne* fo. *glanduliferum* Wołoszyńska 1924, p. 28, pl. II;
P. boryanum var. *longicorne* fo. *granulatum* Raciborski 1889, p. 14, pl. II, fig. 13;
P. glanduliferum Bennett 1892, p. 7, pl. II, figs 5–7;
P. glanduliferum fo. *perforatum* Lucks 1906/1907, p. 46, fig. 18;
P. integrum Nägeli var. *braunianum* (Grunow) Nordstedt fo. *longicorne* Raciborski 1889, p. 6, pl. II, fig. 3;
P. muticum Kützing var. *longicorne* Raciborski 1889, p. 12, pl. II, figs 8 & 9.

Coenobia 40–161 µm in diameter, with small irregularly disposed perforations or without perforations, 16-, 32-, 64-, 128-celled. Cells polygonal, sometimes inner cells tetragonal in outline. Marginal cells 6–32 µm long, 6–23 µm wide. Incision U-shaped, narrow or wide, almost flat in older cells, from half to two thirds of cell length. Processes usually long, from one third to half of cell length, sometimes shorter, from one fifth to one fourth of cell length. Inner cells 4–18 µm long, 5–22 µm wide. Sometimes cells have thick cell walls. Cell wall surface reticulate with sparsely disposed granules (7–10 granules in cell width) (type 7c).

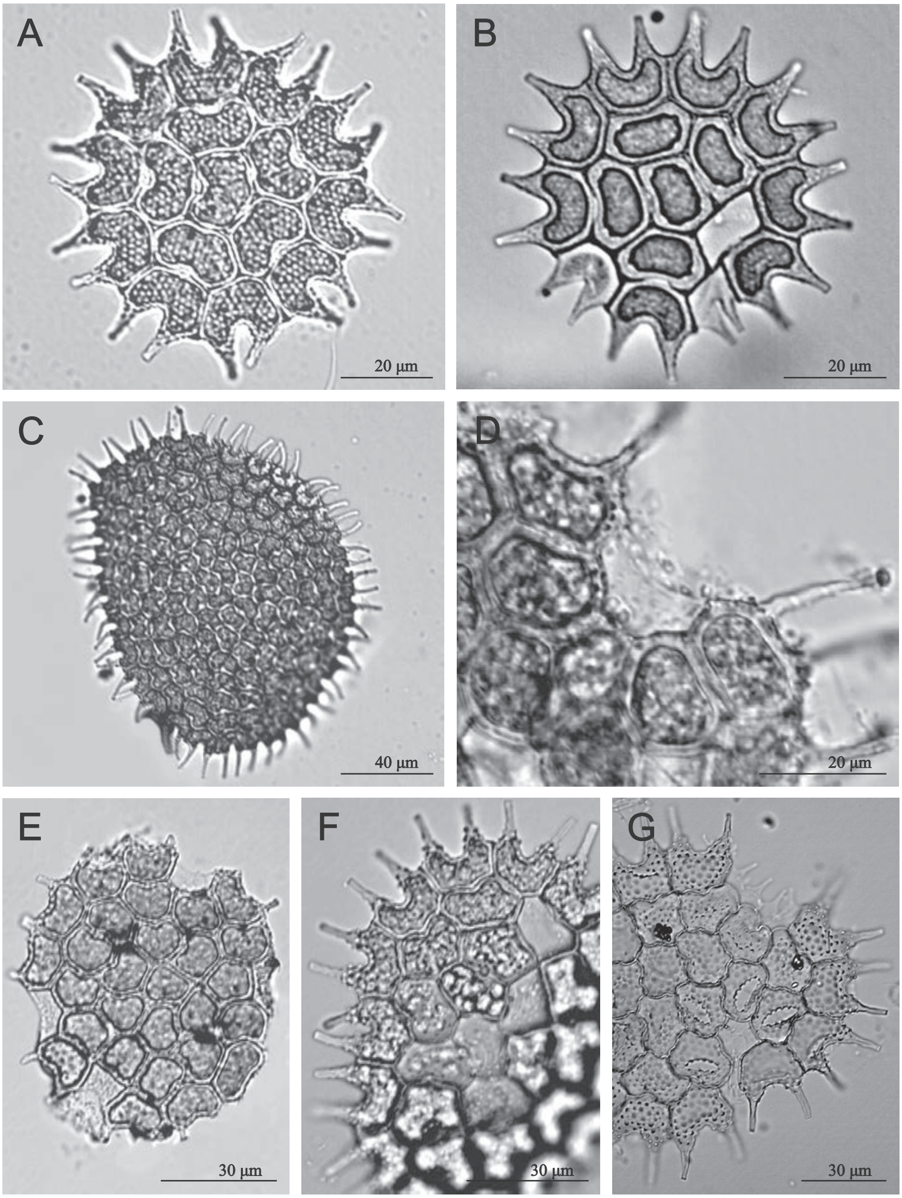

Fig. 15. A & B – *Pediastrum boryanum* var. *perforatum* (Raciborski) Nitardy from field material – coenobia having polygonal cells, similar to *P. boryanum*. C–G – *P. boryanum* var. *longicorne* Reinsch from field material. D – cells having thicker walls. E – untypical coenobium having shorter processes. A–G – LM.

Notes. Coenobia in strain no. 22.280608 usually were composed of 16, rarely 32 or 8 cells; 64- and 128-celled coenobia, as in field material, were not observed. The coenobia of the strain, 30–101 µm in diameter, were smaller than in field material. Marginal cells were 8–24 µm long, 7–18 µm wide, inner cells 4–12 µm long, 7–17 µm wide.

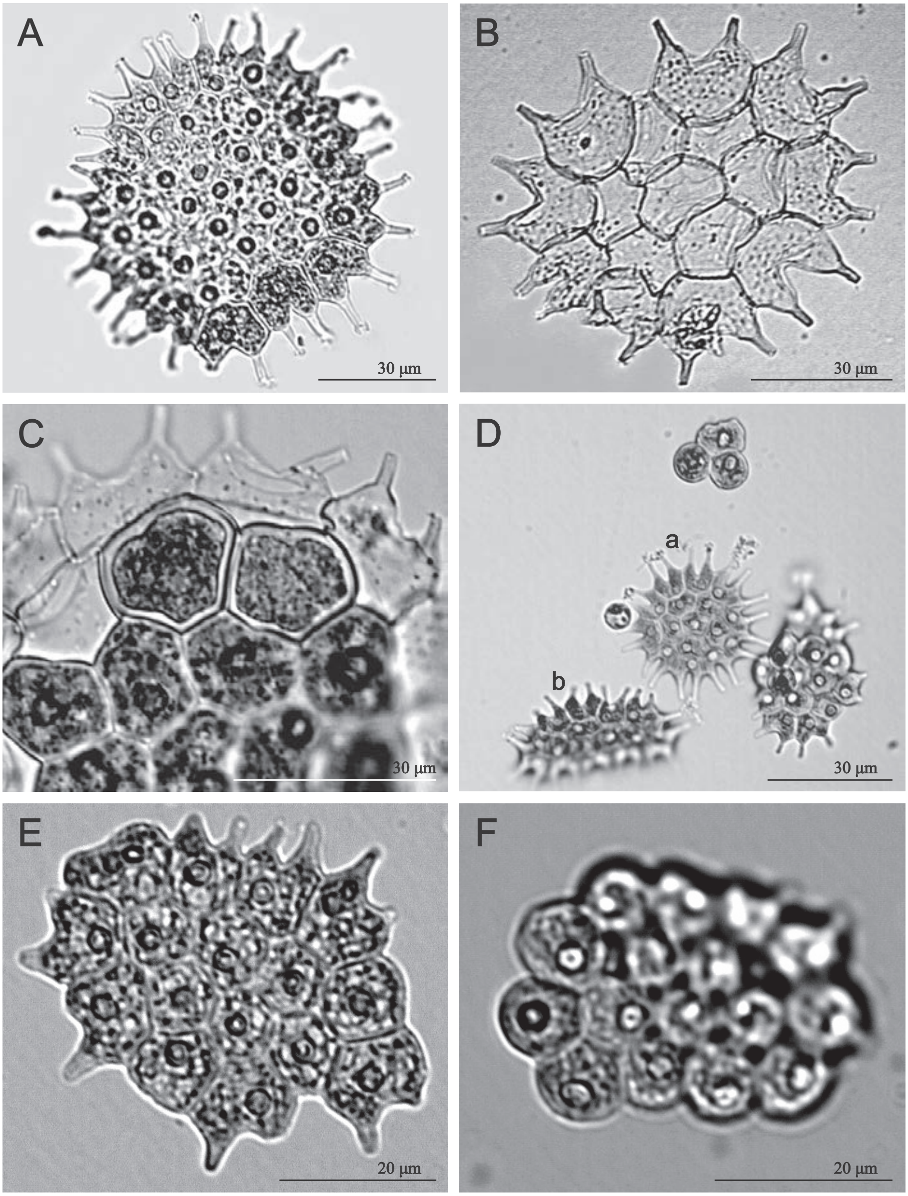

Fig. 16. A–F – *Pediastrum boryanum* var. *longicorne* Reinsch from cultured material (LM). B – coenobium with shorter processes, similar to *P. boryanum* var. *boryanum*. C – coenobium with thicker cell walls. D–F – teratological forms having improperly developed marginal cells and forming groups with fewer cells (without Da, b).

In two strains (nos 22.280608 and 13.280608), teratological forms of *P. boryanum* var. *longicorne* (Fig. 16D–F, without Da, b) were observed; in the second these forms were in the majority. They were flat or spherical agglomerations with a reduced number of rounded cells without incisions and rarely bearing processes.

In both field and cultured material I found coenobia with shorter processes (Figs

15E, 16B), typical for *P. boryanum* var. *boryanum*. Parra (1979) noted that length of processes is a highly variable character in *P. boryanum* var. *longicorne*.

Some coenobia with thicker walls (Figs 15D & 16C) were observed in both types of material. Chang & Chang-Schneider (1980) mentioned a coenobium of cultured *P. boryanum* var. *longicorne* having a group of thick-walled dark green cells in the middle, surrounded by empty cells, possibly a resting stage of the taxon.

Only coenobia having granules on their reticulate surface were observed in the studied material. This is not in accord with the original description of the variety given by Reinsch (1867), who stated that in *P. boryanum* var. *longicorne* the surface is smooth and only its processes are sometimes granulated. Possibly he did not notice the mesh and granules because they are not well visible in younger or living cells of the variety. Raciborski (1898) distinguished two forms of var. *longicorne*, *granulata* and *glabra*, the second having a smooth surface which was not seen by him. Most recent descriptions of the taxon (Sulek 1969; Parra 1979; Komárek & Jankovská 2001) describe its surface as reticulate with granules. Granule density was the same in the field and cultured material I studied.

Wołoszyńska (1924), who described the form *glanduliferum*, observed both younger and older coenobia having sticky bubbles on the ends of the processes. The bubbles enable the coenobia to adhere to surfaces. She also observed tiny bubbles in coenobia that had been released from maternal cells. Because of this she stated that the bubbles are an integral feature of the form.

Current records. *P. boryanum* var. *longicorne* occurred at 12 of 71 stations, located on the Southern Baltic Coast and in the Eastern and Southern Lakelands, Central Polish Lowlands, Polesie and Northern Sub-Carpathia, including coastal lakes (sampling stations I.3, 5), lowland lakes with manmade (V.8, 10), mixed (II.12, III.5) and forest (III.4) catchments, a delta lake (I.10), park pond (VIII.7), suburban pond (III.6), through-flow pond (IV.3) and fish pond (IV.2). The water bodies ranged from meso- to eutrophic, and one was humoeutrophic; water temperature 17.0–25.2°C, pH 8.0–9.4, conductivity 141–614 µS/cm, total hardness 5.0–12.8°n, carbonate hardness 4.0–9.2°n, nitrates ≤5.0 mg/dm^3 and orthophosphates <0.15–0.25 mg/dm^3. A recent finding in coastal lakes was published by Kowalska & Wołowski (2010b, fig. 20).

Literature data. Very many records were given for *P. boryanum* var. *longicorne* from e.g. lakes in Pomerania including Jezioro Drwęckie in Ostróda (Krause 1906, fig. 4a, on the left – as misapplied name *P. pertusum*), Jezioro Otomin and Jezioro Osowskie (Lucks 1906/1907, p. 46, fig. 17 – as synonym *P. glanduliferum*, fig. 18 – as synonym *P. glanduliferum* fo. *perforatum*), Jezioro Wigry lake (Wołoszyńska 1924, p. 28, pl. II – as synonym *P. boryanum* var. *longicorne* fo. *glanduliferum*), eutrophic Jezioro Kortowskie lake near Olsztyn (Wysocka 1959, fig. 7 – as synonym *P. boryanum* var. *longicorne* fo. *glanduliferum*), dystrophic Jezioro Moczadło lake in the Bory Tucholskie forest (Oleksowicz 1986, fig. 101), two eutrophic coastal lakes, Jezioro Gardno and Jezioro Łebsko (Picińska-Fałtynowicz 1997, pl. II, fig. 11 – as misapplied name *P. boryanum* var. *boryanum*), eutrophic Jezioro Sumin lake (Pasztaleniec & Poniewozik 2004, p. 40, fig. 4) and Jezioro Uściwierz lake in the Pojezierze Łęczyńsko-Włodawskie lakeland (Malicki 1972, pl. III, figs g, i & k), eutrophic Jezioro Maltańskie lake in Poznań (Stefko 1976, pl. XI, fig. 3), Jezioro Pątnowskie lake in Wielkopolska Province (Burchardt 1977, pl. XIII, fig. 6 – as synonym *P. muticum* var. *longicorne*), lakes in the Tatra Mountains (Wołoszyńska 1925, p. 52, fig. 4 – as synonym *P. boryanum* var. *longicorne* fo. *glanduliferum*), eutrophic

Siemianówka dam reservoir (Wołowski & Grabowska 2007, fig. 59), natural ponds and fish ponds near Łódź (Sitkowska 1992, p. 59, pl. XI, figs 4 & 5, pl. XII, figs 1–4), the Vistula river, ponds in Tyniec, swamps in Kapelanka, a pool in Łęg near Cracow (Raciborski 1889, p. 6, pl. II, fig. 3 – as synonym *P. integrum* var. *braunianum* fo. *longicorne*, p. 12, pl. II, figs 8 & 9 – as synonym *P. muticum* var. *longicorne*, p. 14 – as synonym *P. boryanum* var. *longicorne* fo. *glabrum*, pl. II, fig. 13 – as synonym *P. boryanum* var. *longicorne* fo. *granulatum*), an aquarium in the Botanic Garden in Warsaw (Cybulski 1883, p. 256, fig. 16 – as misapplied name *P. boryanum*) and a settling pond in Warsaw (Humblet-Pawłowska 1939, pl. V, fig. 125).

****Pediastrum boryanum*** var. ***brevicorne*** A. Braun 1855, p. 86 — Fig. 17A–G

SYNONYM:

P. muticum Kützing 1849, p. 193.

Coenobia 55–97 µm in diameter, without perforations, 16-, 32-celled. Cells polygonal in outline. Marginal cells 14–19 µm long, 11–19 µm wide, with very short lobes. Incision broad and shallow, V-shaped or U-shaped, maximally to ca. one third of cell length. Processes short, from one fifth to one fourth of cell length, sometimes off plane of coenobium. Inner cells 9–15 µm long, 12–18 µm wide. Cell wall surface reticulate with rather densely disposed granules (10–14 granules in cell width) (type 7c).

NOTES. In strain no. 06.030608 the coenobia were composed of 16 and 32 cells. The ranges of coenobium and cell dimensions were greater than in the field material. The coenobia were 30–104 µm in diameter, marginal cells 8–18 µm long, 7–20 µm wide, inner cells 5–16 µm long, 7–20 µm wide. Younger coenobia (Fig. 17D) closely resembled *P. boryanum* var. *boryanum* in cell shape. Parra (1979) noted that the similar shape of young specimens of these varieties can cause them to be confused with each other, but presented the morphological variability of *P. boryanum* var. *brevicorne* on the basis of a single strain (pl. XVI & XVII) without taking field material into account. Nielsen (2000) stated that var. *brevicorne* should be rejected and included in var. *boryanum*, and suggested that the morphological structure of the marginal cells seems to depend on the ontogenetic stage.

In coenobia of both cultured and field material the processes were sometimes off the plane of the coenobium. Such an arrangement was also observed by Parra (1979, pl. XVI, fig. d, pl. XVII, figs b–d, g, j, k–l). In the strain there were many teratological forms (e.g. Fig. 17F) having only one or no processes on each cell. There were similar forms in a strain cultured by Parra (1979, pl. XVII, figs f & i).

In the field material only two empty coenobia of *P. boryanum* var. *brevicorne* were found. They had more sparsely disposed granules (10–14 in cell width; Fig. 17A–C) than the coenobia from cultured material (15–18 in cell width; Fig. 17G). The granules on a smaller coenobium from field material were not so tiny and delicate, and were rather sparsely disposed (Fig. 17B & C), differing from the description and iconography of *P. boryanum* var. *brevicorne* given by Komárek & Jankovská (2001).

Molecular analyses are needed to determine whether var. *brevicorne* is a taxon or rather is a morphotype of *P. boryanum* var. *boryanum*.

CURRENT RECORDS. *P. boryanum* var. *brevicorne* occurred at 2 of 71 stations, located on the Southern Baltic Coast and in the Central Polish Lowlands: a eutrophic

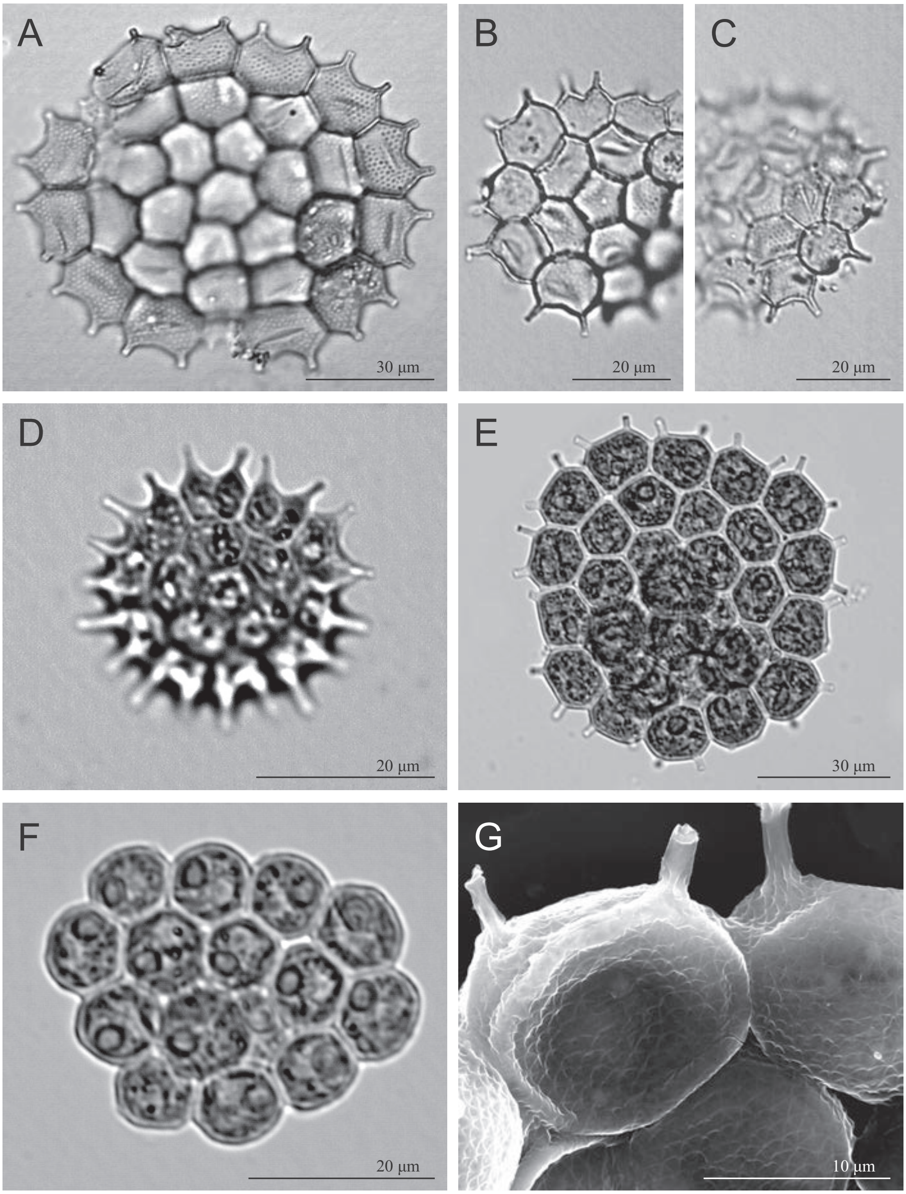

Fig. 17. A–G – *Pediastrum boryanum* var. *brevicorne* A. Braun. A–C – field material. D–G – cultured material. B & C – coenobium having not so tiny and delicate, rather sparsely disposed granules, similar to *P. boryanum* var. *boryanum*. D – younger coenobium having cell shape similar to *P. boryanum* var. *boryanum*. F – teratological form without any lobes and processes. G – details of cell wall ultrastructure. A–F – LM. G – SEM.

coastal lake (sampling station I.1) and a eutrophic through-flow pond (IV.4); water temperature 18.8–24.6°C, pH 8.8–9.6, conductivity 181–425 µS/cm, total hardness 12.0°n, carbonate hardness 9.2°n, nitrates <5.0 mg/dm^3 and orthophosphates 0.75 mg/dm^3. A recent finding in a coastal lake was published by Kowalska & Wołowski (2010b, fig. 21).

Literature data. Some records were given for *P. boryanum* var. *brevicorne*. Localities include two lakes, Jezioro Otomin and Sehlener See, in western Pomerania (Lucks 1906/1907, p. 46, fig. 20 – as misapplied name *P. boryanum* var. *brevicorne* fo. *punctatum*), humoeutrophic Jezioro Skrzynka lake in Wielkopolska National Park (Krawiecowa 1957, without documentation – as synonym *P. muticum*), Jezioro Klimunt lake in the Pojezierze Mazurskie lakeland (Chudyba 1979, without documentation – as synonym *P. muticum*), Pławniowice Duże dam reservoir in Silesia (Skalska 1984, p. 197, fig. 7 – as misapplied name *P. duplex* var. *lividum*) and the Płonia river in the catchment of Jezioro Miedwie lake in northern Poland (Rozmiarek 1984, without documentation).

****Pediastrum boryanum*** var. ***forcipatum*** (Corda) Chodat 1902, p. 229

Figs 4C, 18A–F

Basionym:

Euastrum forcipatum Corda 1839, p. 238, pl. II, fig. 7.

Synonym:

P. forcipatum (Corda) A. Braun 1855, p. 86 (pro parte).

Coenobia 52–124 µm in diameter, without perforations, 16-, 32-celled. Cells polygonal in outline. Marginal cells 12–36 µm long, 9–34 µm wide. Incision U-shaped or V-shaped, from half to two thirds of cell length. Lobes long or short, terminating in processes up to ca. one third of cell length. Inner cells 7–27 µm long, 9–39 µm wide. Cell wall surface very densely granulate (17–26 granules in cell width) (type 3).

Notes. Cell wall ornamentation in *P. boryanum* var. *forcipatum* was poorly visible under lower LM magnification because the granules were very densely disposed. Tiny punctae were observed between the granules in the field material (Figs 4C, 18E & F). Such punctae were also presented in photos given by Parra (1979) and Nielsen (2000) but without any information on them in the descriptions of the taxon. Some cells in the collected material had an almost flat surface with clearly visible triangular or rounded punctae between flattened granules (Fig. 18F). Such a surface was the effect of cell wall stretching during coenobium growth.

Scabrate ornamentation in the middle of the cell surface was also observed (Fig. 18E). It is not clear whether such a surface represents the natural variability of the taxon or is formed under unfavourable environmental conditions. Further study of its cell wall ultrastructure is needed.

Current records. *P. boryanum* var. *forcipatum* occurred at 20 of 71 stations, located on the Southern Baltic Coast and Lakelands, in the Central Polish Lowlands, Polesie, Wyżyna Śląsko-Krakowska upland and Northern Sub-Carpathia, including coastal lakes (sampling stations I.1, 3–5), lowland lakes with mixed (I.9, V.2) and manmade (V.9) catchments, a delta lake (I.10), fish ponds (III.9, V.1, 3, 4, 6, 7), village ponds (IV.1, VII.2), a suburban pond (III.6), peat pits (I.7, 8) and an oxbow lake (VIII.4). Almost all the water bodies were eutrophic except for a mesotrophic one; water temperature 18.0–26.3°C, pH 7.9–9.6, conductivity 152–1740 µS/cm, total hardness 9.0–27.8°n, carbonate hardness 5.6–12.2°n, nitrates <5.0–10.0 mg/dm^3 and orthophosphates <0.15–1.50 mg/dm^3. A recent finding in coastal lakes was published by Kowalska & Wołowski (2010b, fig. 22).

Literature data. Few records were given for *P. boryanum* var. *forcipatum*. Localities include

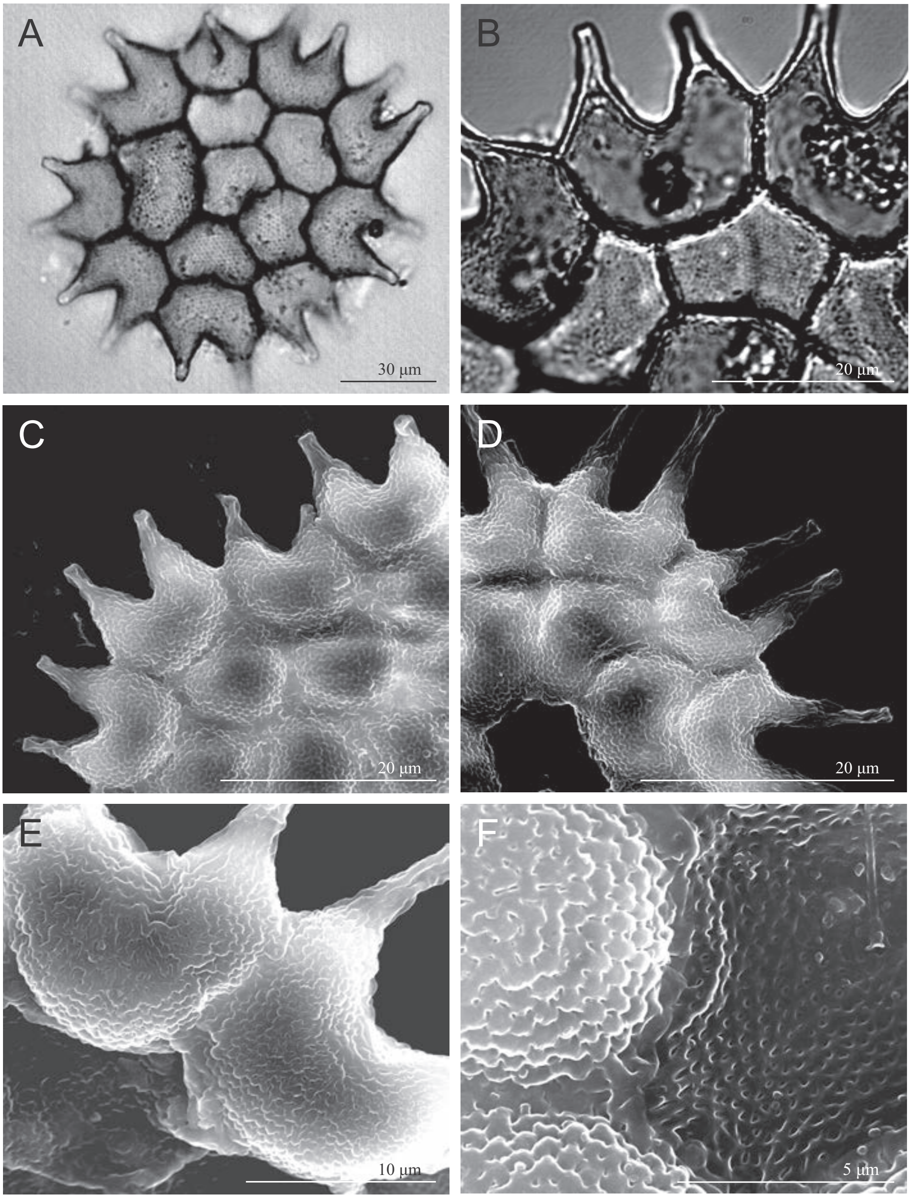

Fig. 18. A–F – *Pediastrum boryanum* var. *forcipatum* (Corda) Chodat from field material. E – deformed granulate cell wall ornamentation, similar to scabrate ornamentation in *P. boryanum* var. *pseudoglabrum* Parra. F – details of cell wall ultrastructure. A & B – LM. C–F – SEM.

Jezioro Uściwierz lake in the Pojezierze Łęczyńsko-Włodawskie lakeland (Malicki 1972, pl. III, fig. h – as misapplied name *P. boryanum* var. *boryanum*), fish ponds, including polluted ones, dam reservoirs in southern Poland including the Goczałkowice, Rożnów, Wisła-Czarne, Porąbka, Dobczyce and Czorsztyn reservoirs, and Puławy reservoir (Bucka & Wilk-Woźniak 2002, p. 166, fig. 193 – as misapplied name *P. boryanum*) and a water body originated from an oxbow lake of the Vistula river in Puławy (Shubert & Wilk-Woźniak 2003, fig. 10 – as misapplied name *P. boryanum*).

Pediastrum subgranulatum (Raciborski) Komárek et Jankovská 2001 p. 53, fig. 29a–f Fig. 30C

Basionym:

P. duplex var. *subgranulatum* Raciborski 1889, p. 23, pl. II, fig. 28.

Coenobia up to 160 µm in diameter, round in outline, regularly perforated (perforations always smaller than cell diameter), (8)-, 16-, 64-celled. Cells usually arranged concentrically, tetragonal or pentagonal in outline, with slightly concave sides in the form of an H. Marginal cells 5.5–28.5 µm long, 5–25 µm wide, with two long prominent radial conical lobes situated exactly on the coenobial plane. The lobes narrow continually and end with short cylindrical rosette-like processes. Inner cells 4–20 µm long, (5)6–25 µm wide. Cell wall surface reticulate with densely disposed granules (type 7c).

Notes. *P. subgranulatum* is very similar to *P. duplex* var. *duplex* morphologically. Because of this it was previously regarded as a variety of *P. duplex* (Raciborski 1889). A basic difference between *P. subgranulatum* and *P. duplex* var. *duplex* is the cell wall surface, which in the former is always reticulate with granules and in the latter is smooth. It is difficult to state which species is behind the name *P. duplex* var. *clathratum* (A. Braun) Lagerheim (1882). The author gives no iconography but only references to *P. pertusum* Kützing var. *clathratum* A. Braun in Reinsch (1867), and the figure given by Reinsch (1867, pl. X, fig. 5) is confusing, with no clear reticulate pattern on the cell wall surface but only several irregularly disposed granules.

Literature data. Few records were given for *P. subgranulatum*. Localities include ponds in Jaszczurowa near Wadowice (Gutwiński 1897), the Zatoka Pucka lagoon (Rumek 1948), a eutrophic peat bog (Krawiecowa 1957), ponds in southern Poland (Siemińska & Siemińska 1967) and a fertilized fish pond in central Poland (Socha 1981). None of the references give documentation, and the species is noted as the synonym *P. duplex* var. *subgranulatum*.

****Pediastrum duplex*** Meyen 1829, p. 772, pl. XLIII, figs 6, 9–10, 16–19
Figs 4A, E & H, 19A–F, 20A–F, 21A–F, 22A–F, 23A–F

Coenobia 27–132 µm in diameter, round, oval or irregular in outline, perforated, 8-, 16-, 32-, 64-celled. Cells arranged concentrically, irregularly or spirally. Cells H-shaped, tetragonal in outline. Marginal cells 7–26 µm long, 6–23 µm wide, with concave or straight sides, each with two conical lobes on or off plane of coenobium, terminating in short cylindrical processes. Incision V-shaped or U-shaped. Inner cells 5–21 µm long, 6–26 µm wide, with concave or straight sides. Cell wall surface smooth (type 1), araneose (type 5) or reticulate with granules (type 7a).

Notes. The species is highly variable morphologically. Its four varieties differ with regard to cell shape, perforation size and type of cell wall surface. High molecular variability has been observed in *P. duplex*; some strains have stronger phylogenetic relationships to other *Pediastrum* species such as *P. angulosum* or *P. boryanum* (McManus & Lewis 2011).

In strain no. 16.160708 there were 16- and 32-celled coenobia, 36–76 µm in diameter. Marginal cells were 6–16 µm long, 5–18 µm wide, inner cells 4–14 µm long, 6–20 µm wide. Older coenobia of the strain had bigger cells, with incisions to ca. half of cell length, and rounded lobes (Figs 20F, 21A & B). Such cells in *P. duplex* were observed in lakes in northern Poland by Lucks (1906/1907) and in cultured material under lower pH by Neustupa & Hodač (2005).

Current records. *P. duplex* occurred at 35 of 71 stations, located on the Southern Baltic Coast, in the Eastern and Southern Baltic Lakelands, Central Polish Lowlands, Polesie, Wyżyna Śląsko-Krakowska upland and Northern Sub-Carpathia, including coastal lakes (sampling stations I.1–5), lowland lakes with mixed (I.9, 11, II.11, III.13, 14, V.2), forest (II.1, III.4) and manmade (V.9, 10) catchments, a delta lake (I.10), fish ponds (I.6, III.9, IV.2, V.1, 3, 4, 6, 7), through-flow ponds (IV.3, 4), village ponds (IV.1, VII.2), a park pond (VIII.6), suburban pond (III.6), field pond (III.11), peat pits (I.7–8) and an oxbow lake (VIII.4). It usually had a share of ≤0.2% (26 sampling stations) and sometimes 0.3–3% (9) in the algal communities. The water bodies were meso- to eutrophic; most were eutrophic (28) and one was humoeutrophic; water temperature 17.0–26.3°C, pH 7.5–9.6, conductivity 141–1740 µS/cm, total hardness 5.0–27.8°n, carbonate hardness 4.0–15.6°n, nitrates <5.0–10.0 mg/dm^3 and orthophosphates <0.15–1.50 mg/dm^3. A recent finding in coastal lakes was published by Kowalska & Wołowski (2010b, figs 23 – as misapplied name *P. duplex* var. *duplex*, 25 – as misapplied name *P. duplex* var. *gracillimum*).

Literature data. Very many records were given for *P. duplex* from e.g. lakes (e.g. Lucks 1906/1907, p. 45, fig. 15 – as misapplied name *P. duplex* var. *rotundatum*; Malicki 1972, pl. IV, fig. b – as misapplied name *P. duplex* var. *duplex*), including paraoligotrophic (Wojciechowski 1971, pl. XI, fig. 8 – as misapplied name *P. duplex* var. *duplex*) and eutrophic ones (e.g. Kotlińska 1976, pl. XVI, figs 253 – as misapplied name *P. duplex* var. *reticulatum*, 254 – as misapplied name *P. duplex* var. *rugulosum*; Stefko 1976, pl. XI, fig. 10 – as misapplied name *P. duplex* var. *reticulatum*; Socha 1993, p. 47, pl. XII, fig. 12; Pasztaleniec & Poniewozik 2004, p. 41, fig. 6 – as misapplied name *P. duplex* var. *gracillimum*; Kowalska & Luścińska 2006, p. 50, pl. XIII, figs 4 – as misapplied name *P. duplex* var. *duplex*, 5 – as misapplied name *P. duplex* var. *gracillimum*), as well as ponds (Sitkowska 1992, p. 62, pl. XVII, figs 1–6 – as misapplied name *P. duplex* var. *gracillimum*), including fertilized and unfertilized fish ponds (Sosnowska 1956, pl. I, fig. 12 – as misapplied name *P. duplex* var. *gracillimum*), various water bodies (Kadłubowska 1961, p. 89, pl. XI, fig. 3), dam reservoirs (Bucka & Wilk-Woźniak 2002, p. 168, figs 186 & 194; Wołowski & Grabowska 2007, p. 215, fig. 62 – as misapplied name *P. duplex* var. *gracillimum*), a lagoon (Luścińska 2005, pl. VIII, figs 15 – as misapplied name *P. duplex* var. *duplex*, 16 – as misapplied name *P. duplex* var. *gracillimum*), peat bogs (Piątek 2007, p. 56, fig. 315 – as misapplied name *P. duplex* var. *gracillimum*) and a river (Luer-Jeziorańska 1939, pl. XI, figs 197 – as misapplied name *P. duplex* var. *clathratum*, 198 – as misapplied name *P. duplex* var. *reticulatum*).

**Pediastrum duplex* var. *duplex* — Figs 4A, 19A–F, 20A–D

Synonyms:

P. duplex var. *lividum* Raciborski 1889, p. 28, pl. II, fig. 31;
P. pertusum Kützing 1845, p. 143 (pro parte);
P. pertusum var. *brachylobum* A. Braun 1855, p. 93, 95, pl. VI, fig. 25;
P. pertusum var. *genuinum* Kirchner 1878, p. 96;
? *P. duplex* var. *reticulatum* Lagerheim 1882, p. 56, pl. II, fig. 1;
? *P. duplex* var. *rotundatum* Lucks 1906/1907, p. 45, fig. 15.

Coenobia 31–96 µm in diameter, usually with small perforations, 16-, 32-, 64-celled. Marginal cells 7–22 µm long, 6–22 µm wide. Incision less than half of cell length. Inner

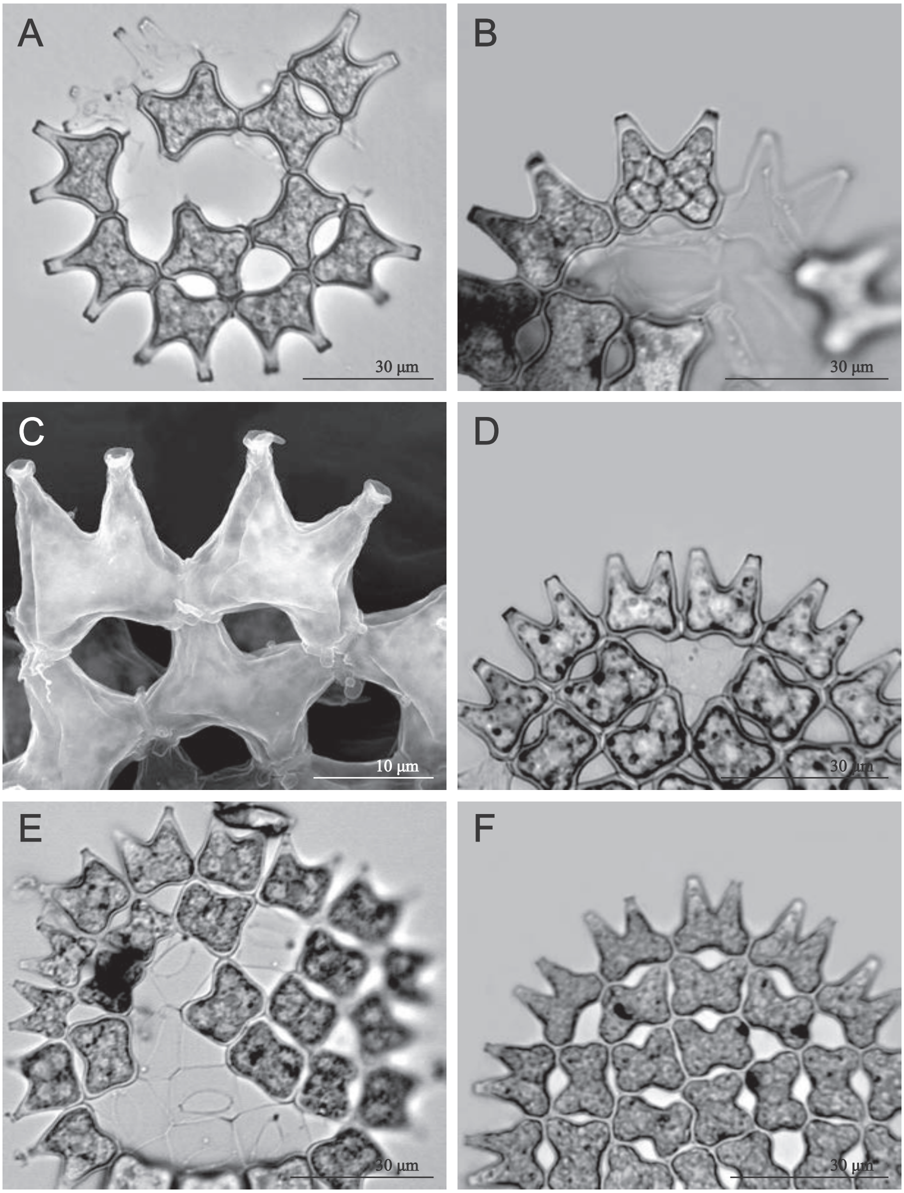

Fig. 19. A–F – *Pediastrum duplex* Meyen var. *duplex* from field material. B–F – parts of various specimens. C – details of cell wall ultrastructure. A, B & D–F – LM. C – SEM.

cells 5–18 µm long, 6–23 µm wide, with concave or straight sides. Cell wall surface smooth (type 1).

Notes. Only a smooth surface was observed in both field and cultured material of this taxon. Parra (1979) distinguished a second type: almost smooth with delicate elongated elements (Lat. *membrana striolata*; pl. XXVII, figs a & b, pl. XXIX, figs a & b), but that type may have been an artefact of preparation for SEM.

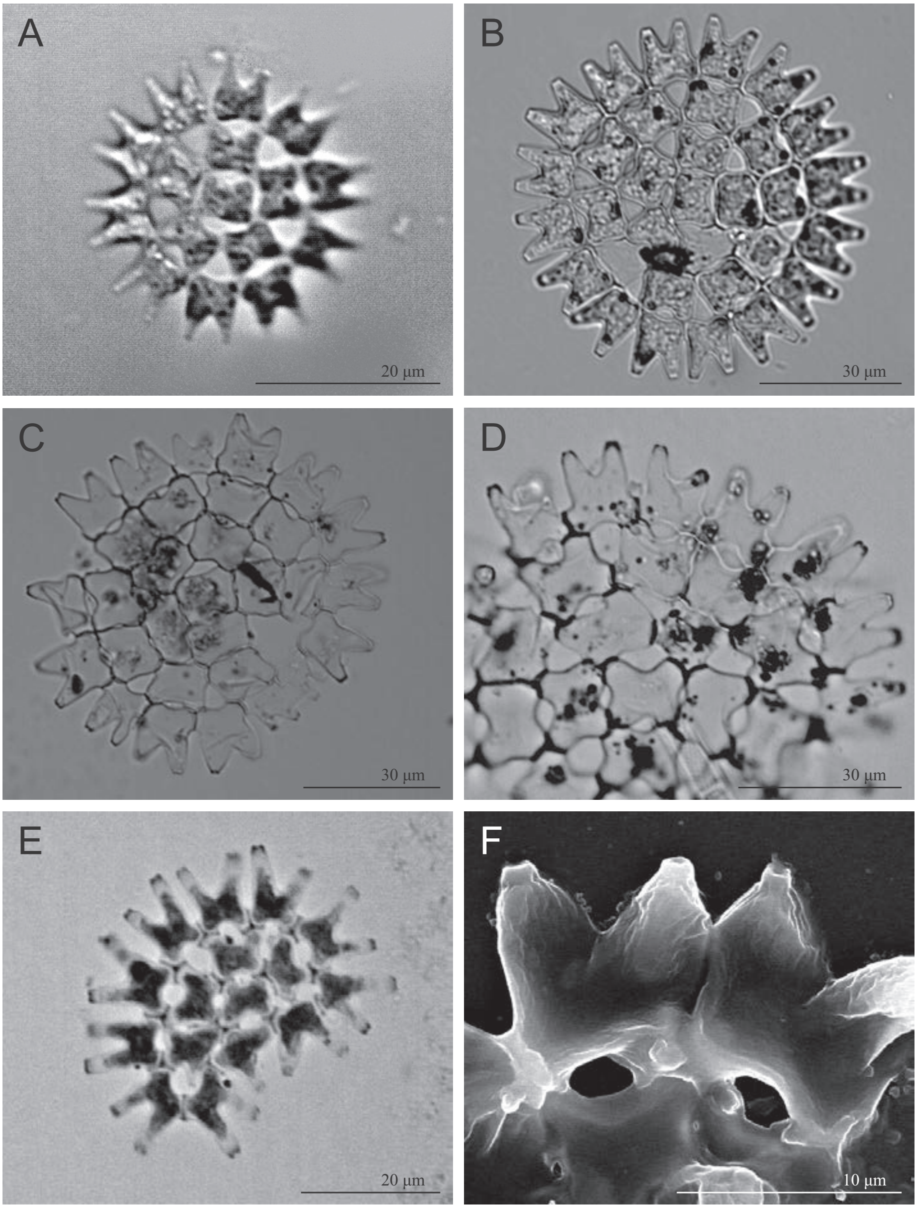

Fig. 20. A–D – *Pediastrum duplex* Meyen var. *duplex* from field material. E & F – *Pediastrum duplex* cf. var. *duplex* from cultured material. F – part of untypical form having rounded lobes. A–E – LM. F – SEM.

W. West & G.S. West (1895) described *P. duplex* var. *gracillimum* as having slender cells (Lat. *cellulis gracillimis*) and very large perforations (Lat. *lacunis permagnis*). They noted that the variety differs from *P. duplex* var. *reticulatum* in having much slimmer cells, narrower processes with indented apices and much larger perforations between the cells. Unfortunately they provided no iconography for the taxon. Sulek (1969) and Parra (1979) regarded var. *gracillimum* as a synonym of *P. duplex* var. *duplex*. They noted that older cells of *P. duplex* are more rounded, so that cell shape and perforation size are not constant in the ontogenic cycle. Perforation size also seems to depend on the cell arrangement. In view of this, the 16-celled coenobium of *P. duplex* var. *reticulatum* presented by Lagerheim (1882) is a doubtful synonym of *P. duplex* var. *duplex* showing a close relationship to *P. duplex* var. *gracillimum* with regard to its somewhat slender cells and large perforations.

It was difficult to differentiate between some specimens of *P. duplex* var. *gracillimum* and *P. duplex* var. *duplex* in this work. Some intermediate forms could not be assigned to any of the varieties. Problems in distinguishing between the two varieties could be resolved with the aid of molecular and morphometric methods. The latest studies using both methods have confirmed the separation of these taxa, even placing *P. duplex* var. *gracillimum* in a separate genus as *Lacunastrum gracillimum* (W. West et G.S. West) H. McManus (McManus & Lewis 2011; McManus *et al.* 2011).

Current records. *P. duplex* var. *duplex* occurred at 8 of 71 stations, located on the Southern Baltic Coast and Lakelands, in the Central Polish Lowlands and Northern Sub-Carpathia, including a coastal lake (sampling station I.3), lowland lakes with mixed catchments (I.11, III.13), through-flow ponds (IV.3, 4), a park pond (VIII.6), field pond (III.11) and an oxbow lake (VIII.4). Most of the water bodies were eutrophic, and one was meso/eutrophic; water temperature 18.1–24.5°C, pH 7.5–8.9, conductivity 181–1588 µS/cm, total hardness 11.6–20.6°n, carbonate hardness 6.4–15.6°n, nitrates <5.0–10.0 mg/dm^3 and orthophosphates <0.15–0.50 mg/dm^3.

Literature data. Some records were given for *P. duplex* var. *duplex*. Localities include lakes in western Pomerania (Lucks 1906/1907, p. 44, fig. 14 – as misapplied name *P. duplex* var. *brachylobum*), Jezioro Uściwierz lake and Jezioro Bikcze lake in the Pojezierze Łęczyńsko-Włodawskie lakeland (Malicki 1972, pl. IV, figs e & f), Jezioro Rusałka lake (Kotlińska 1976, pl. XVI, fig. 249 – as misapplied name *P. duplex*) and Jezioro Maltańskie lake (Stefko 1976, pl. XI, fig. 9 – as misapplied name *P. duplex*), two eutrophic lakes in Poznań, polluted Jezioro Pątnowskie lake near Konin (Burchardt 1977, pl. XIII, fig. 8 – as misapplied name *P. duplex*), a pond in the Botanic Garden in Cracow (Wołowski & Kowalska 2009, fig. 38), peat bogs in the Wyżyna Krakowsko-Częstochowska upland (Piątek 2007, p. 56, fig. 314), the Jeziorka river (Luer-Jeziorańska 1939, pl. XI, figs 196 – as misapplied name *P. duplex*, 199 – as misapplied name *P. duplex* var. *subgranulatum*, 200 – as synonym *P. duplex* var. *lividum*) and Chełmek (Raciborski 1889, p. 28, pl. II, fig. 31 – as synonym *P. duplex* var. *lividum*).

***Pediastrum duplex** var. **gracillimum** W. West et G.S. West 1895, p. 52 Fig. 21C–F

Coenobia 50–70 µm in diameter, 16-celled. Perforations usually larger and cells more slender than in var. *duplex*. Marginal cells 9–16 µm long, 8–15 µm wide. Incision more than half of cell length. Inner cells 8–12 µm long, 10–16 µm wide, with concave sides. Cell wall surface smooth (type 1).

Current records. *P. duplex* var. *gracillimum* occurred at 4 of 71 stations, located on the Southern Baltic Coast and in Polesie, including lowland lakes with manmade catchments (sampling stations V.8, V.10), a fish pond (V.3) and a peat pit (I.8). Half of the water bodies were meso/eutrophic and half were eutrophic; water temperature 21.6–25.2°C, pH 8.4–9.2, conductivity 141–388 µS/cm.

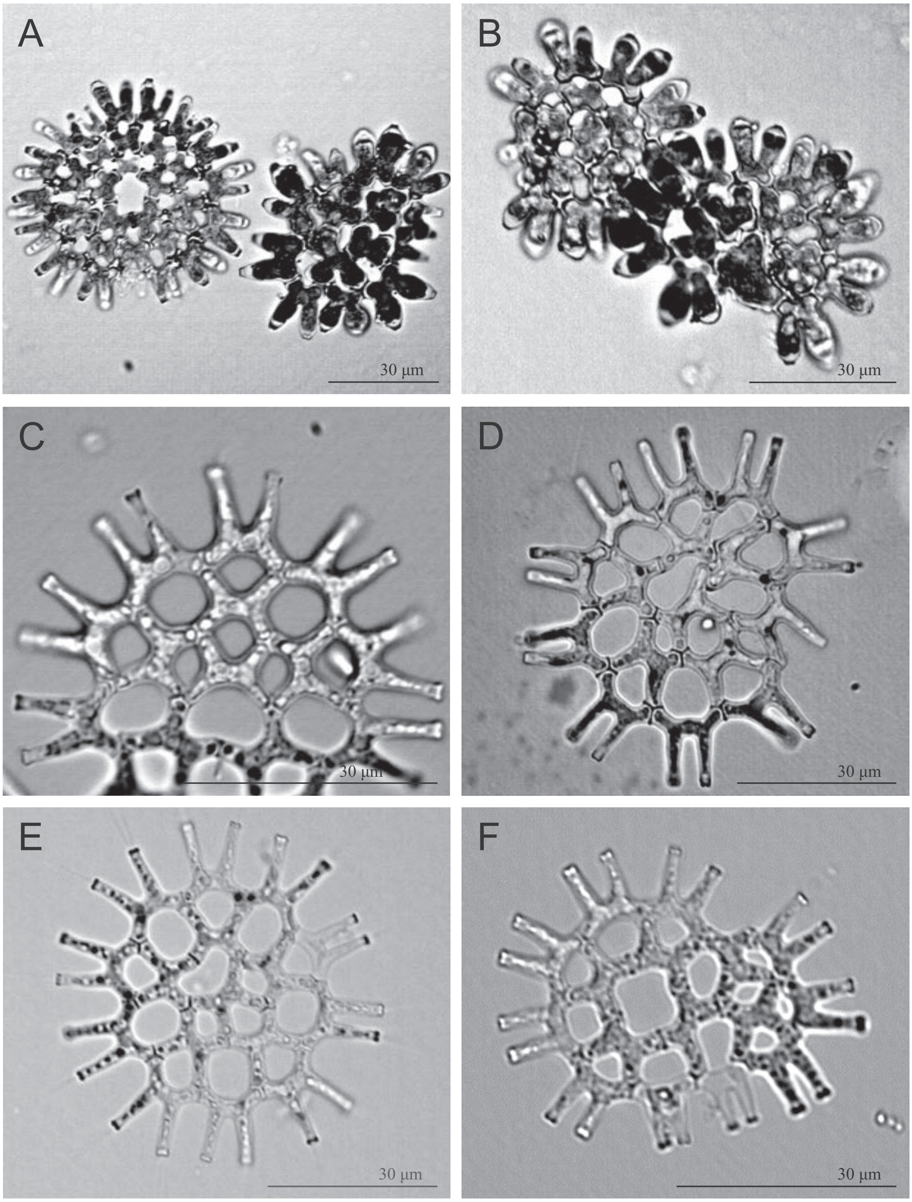

Fig. 21. A & B – *Pediastrum duplex* Meyen cf. var. *duplex* from cultured material – untypical forms having rounded lobes. C–F – *Pediastrum duplex* var. *gracillimum* W. West et G.S. West from field material. A–F – LM.

Literature data. Few records were given for *P. duplex* var. *gracillimum*. Localities include a lake in Długa Goślina in central Poland (Wawrzyniak 1924, without documentation), Jezioro Lednica lake (Wawrzyniak 1930, without documentation), three other lakes in central Poland (Półtoracka 1968, without documentation), a fish pond in southern Poland (Szklarczyk-Gazdowa 1965, without documentation) and Jezioro Kortowskie lake in Olsztyn (Chudyba 1974, without documentation).

****Pediastrum duplex** var. **rugulosum** Raciborski 1889, p. 24, pl. II, fig. 29

Figs 4H, 22A–F, 23A–C

Coenobia 81–132 µm in diameter, with small perforations, 32-, 64-celled. Marginal cells 13–24 µm long, 12–22 µm wide. Incision ca. half of cell length. Inner cells 9–20 µm long, 13–23 µm wide, with concave or straight sides. Cell wall surface reticulate with granules (type 7a).

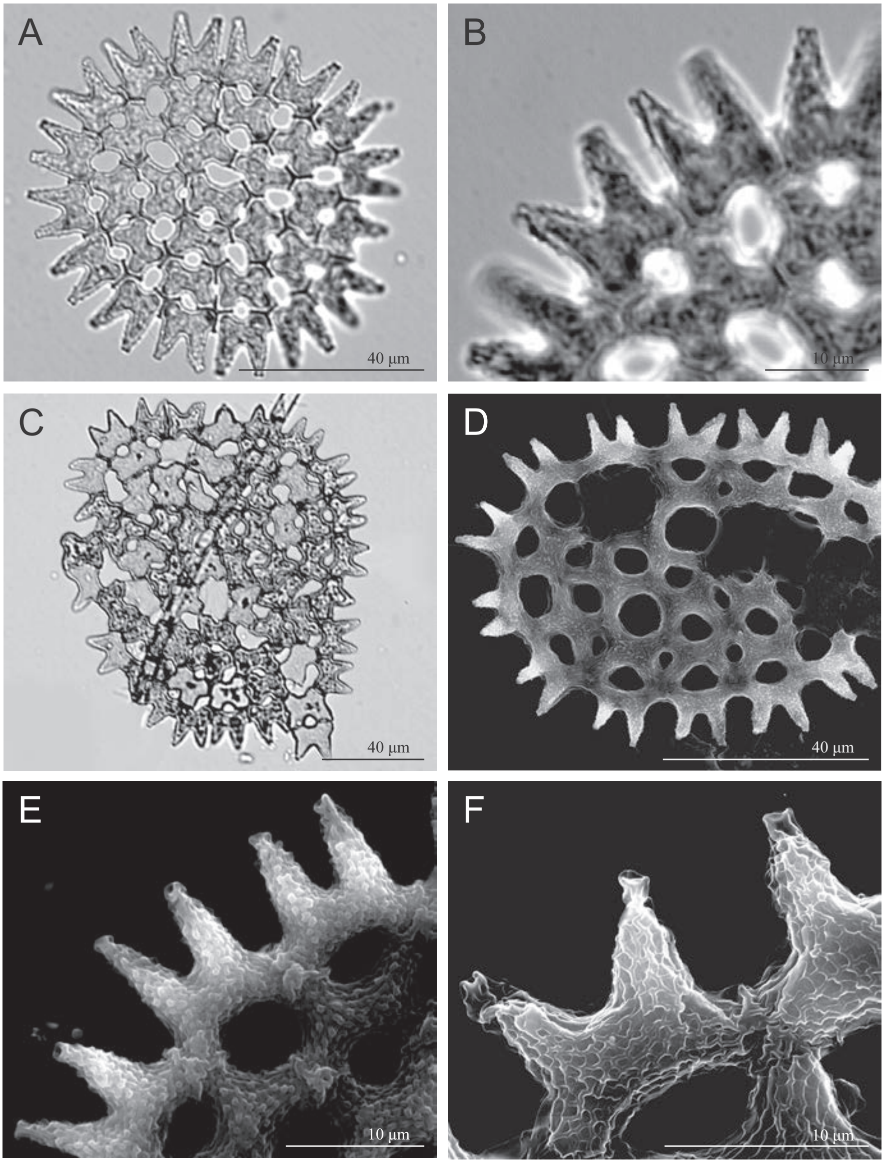

Fig. 22. A–F – *Pediastrum duplex* var. *rugulosum* Raciborski from field material. B – cells with ornamented surface. E – part of more intensively granulated coenobium. F – typically developed cell wall pattern. A–C – LM. D–F – SEM.

Notes. Strain no. 13.090508 was composed mostly of 32-, sometimes 16-celled coenobia; 64-celled coenobia were not observed. The diameter of the coenobia (52–108 µm) was slightly smaller than in field material, but the cell dimensions (marginal cells 9–27 µm long, 8–25 µm wide, inner cells 6–19 µm long, 8–24 µm wide) were similar to those of field material. Older coenobia in this strain had bigger cells with shallower incisions from one fourth to one third of cell length, and conical lobes, as well as cells with deeper incisions from one third to half of cell length, and rounded lobes (Fig. 23A). Such cells of *P. duplex* were observed under lower pH by Neustupa & Hodač (2005).

In strain no. 10.090508 the cell ornamentation of coenobia resembled that which prevailed in the field material, reticulate with granules (Figs 4H, 23B), but some coenobia from field material (sampling station III.6) had so many granules that the mesh on which they presumably were disposed was not clearly visible (Fig. 22E). Hindák & Hindáková (2008), who noted that the surface of *P. duplex* var. *rugulosum* is granulated, not reticulate, presumably were basing that observation on similar coenobia. The intensity of granulation in *P. duplex* var. *rugulosum* may be connected with ontogenetic or environmental factors. It should be studied from both field and cultured material.

Current records. *P. duplex* var. *rugulosum* occurred at 10 of 71 stations, located on the Southern Baltic Coast and Lakelands, and in the Central Polish Lowlands and Polesie, including coastal lakes (sampling stations I.2, 4), a lowland lake with a forest catchment (III.4), fish ponds (IV.2, V.3, 6, 7), a suburban pond (III.6), through-flow pond (IV.3) and peat pit (I.8). The water bodies ranged from meso/eu- to eutrophic, with most of them eutrophic, two meso/eutrophic and one humoeutrophic; water temperature 17.0–26.3°C, pH 8.2–9.3, conductivity 148–1740 µS/cm, total hardness 5.0–27.8°n, carbonate hardness 4.0–8.2°n, nitrates ≤5.0 mg/dm^3 and orthophosphates <0.15–0.25 mg/dm^3. A recent finding in coastal lakes was published by Kowalska & Wołowski (2010b, fig. 27).

Literature data. Some records were given for *P. duplex* var. *rugulosum*. Localities include paraoligotrophic Jezioro Czarne-Sosnowickie lake and Jezioro Bialskie lake (Wojciechowski 1971, pl. XXIII, figs 7 & 8), Jezioro Bikcze lake (Malicki 1972, pl. IV, figs c & d) in the Pojezierze Łęczyńsko-Włodawskie lakeland, polluted Jezioro Pątnowskie lake (Burchardt 1977, without documentation) and Jezioro Gosławickie lake in Wielkopolska Province (Szyszka 1978, without documentation), fish ponds near Łódź (Sitkowska 1992, p. 61, pl. XV, figs 3 & 4, pl. XVI, figs 2 & 3 – as misapplied name *P. duplex* var. *duplex*, p. 63, pl. XVIII, figs 1–6, pl. XIX, figs 1–3, pl. XX, figs 1–4) and ponds at Pieskowa Skała in the Wyżyna Krakowsko-Częstochowska upland (Wołowski *et al.* 2008, p. 120, fig. 13 – as misapplied name *P. duplex*).

****Pediastrum duplex*** var. ***asperum*** (A. Braun) Hansgirg 1888, p. 112 Figs 4E, 23D–F

Basionym:

P. pertusum Kützing var. *asperum* A. Braun 1855, p. 93, pl. VI, figs 15–24.

Synonyms:

P. duplex var. *subintegrum* Raciborski 1889, p. 26, pl. II, fig. 39;
P. angulosum (Ehrenberg) Meneghini var. *asperum* Sulek 1969, p. 220, pl. X, figs 4–6, pl. with photos VII, figs 3–5.

Coenobia 78–132 µm in diameter, with small perforations, 16-, 32-, 64-celled. Marginal cells 10–21 µm long, 10–23 µm wide. Incision to ca. half of cell length. Inner

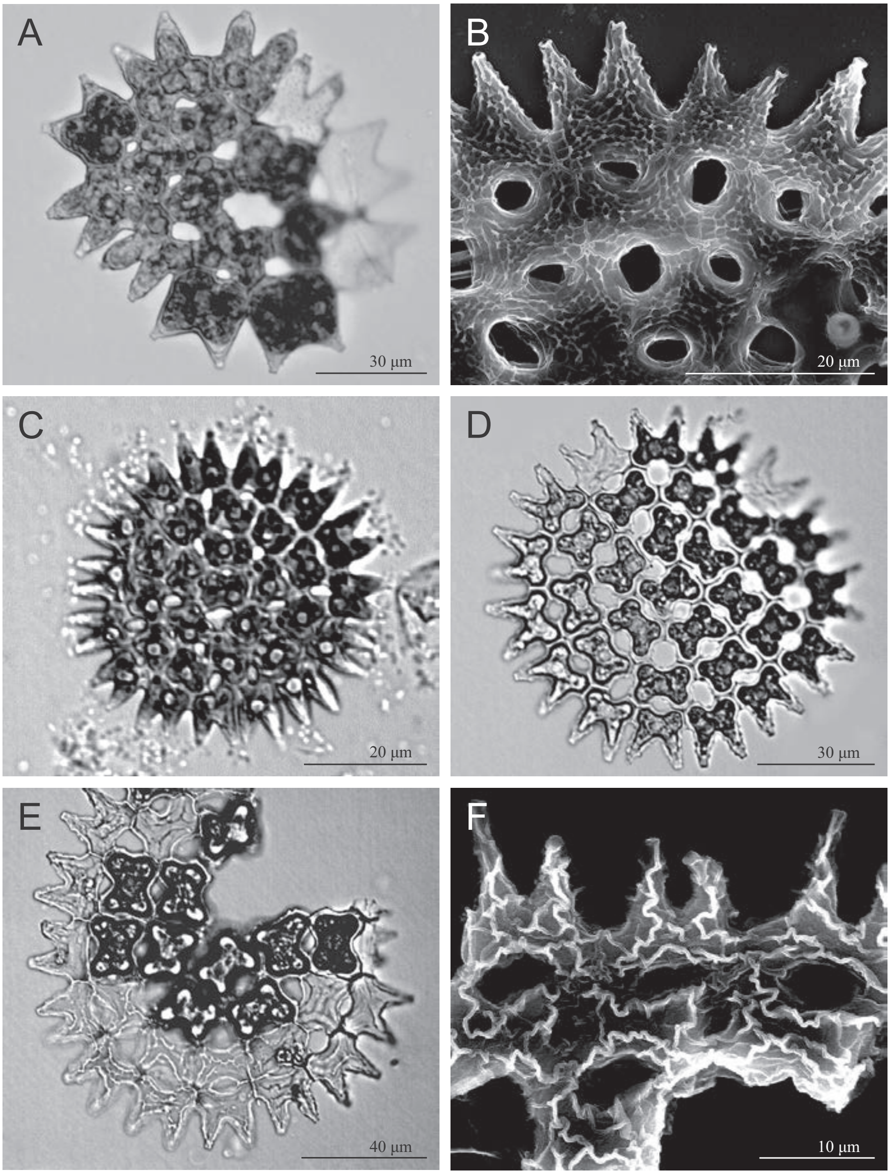

Fig. 23. A–C – *Pediastrum duplex* var. *rugulosum* Raciborski from cultured material. A – untypical form having rounded lobes. D–F – *P. duplex* var. *asperum* (A. Braun) Hansgirg from field material. F – details of cell wall ultrastructure. A & C–E – LM. B & F – SEM.

cells 11–21 μm long, 15–26 μm wide, with concave or straight sides. Cell wall surface araneose (type 5).

NOTES. Most of the observed coenobia were incomplete, lacking several cells (Fig. 23E). Chang & Chang-Schneider (1980) noted incomplete coenobia of another taxon, *P. boryanum* var. *longicorne*, especially at the end of the vegetative season when environmental conditions do not favour *Pediastrum* growth.

Current records. *P. duplex* var. *asperum* occurred at 8 of 71 stations, located on the Southern Baltic Coast and in the Central Polish Lowlands and Polesie, including fish ponds (sampling stations I.6, IV.2, V.1, 4, 6, 7), a through-flow pond (IV.3) and a lake with a manmade catchment (V.10). The water bodies ranged from meso/eu- to eutrophic; water temperature 17.0–26.3°C, pH 8.0–9.1, conductivity 141–412 µS/cm, total hardness 10.0–10.6°n, carbonate hardness 7.2–10.0°n, nitrates 5.0 mg/dm^3 and orthophosphates <0.15 mg/dm^3.

Literature data. Some records were given for *P. duplex* var. *asperum*. Localities include ditches overgrown with *Sphagnum* sp. near a forest between Cetula and Radawa in south-eastern Poland (Gutwiński 1884, without documentation – as synonym *P. pertusum* var. *asperum*), a ditch by a road in a forest near Międzyrzec in eastern Poland (Eichler 1895, without documentation), fish ponds in Silesia (Schröder 1897, without documentation), a pond in Borek Fałęcki in Cracow (Raciborski 1889, p. 26, pl. II, figs 34, 35 & 39 – as synonym *P. duplex* var. *subintegrum*), dystrophic Suchar Rzepiskowy lake near Wigry (Ryppowa 1927, without documentation) and the Zatoka Pucka lagoon (Rumek 1948, without documentation).

*__Pediastrum alternans__ Nygaard 1949, p. 42, fig. 16 Figs 4G, 24A–F, 25A–F

Coenobia 81–130 µm in diameter, round or oval in outline, with very small perforations, 16-, 32-, 64-celled. Marginal cells 14–37 µm long, 11–26 µm wide, with two conical lobes, terminating in long hyaline processes ca. one third of cell length. Lobes alternately above and beneath plane of coenobium. Incision between lobes of the same cell U-shaped, ca. two thirds cell length, usually deeper than incision between lobes of two neighbouring cells. Inner cells 7–25 µm long, 10–25 µm wide, irregularly polygonal. Walls of adjacent cells and lobe margins undulate. Cell wall surface rugulate with verrucas (type 6b).

Notes. Coenobia from the cultured material (strain no. 01.160708) were smaller (26–78 µm) and had fewer cells (8 or 16) than coenobia from the field material. Their marginal cells were 8–21 µm long and 6–17 µm wide; inner cells were 7–13 µm long, 8–16 µm wide. Incisions between lobes of the same marginal cells were often shallower than two thirds of cell length and processes were shorter than one third of cell length (Fig. 25B–F).

In both field and cultured material a new taxonomic characteristic was observed – verrucas sparsely disposed on the cell wall surface (Figs 4G, 24A–F, 25A–F). The verrucas were well visible in empty cells under lower magnification, in living cells under higher magnification, and of course in SEM. An older coenobium from cultured material had distinct wrinkles and verrucas on its surface; a very young coenobium had a not fully developed cell wall – almost smooth, but also with verrucas (Fig. 25F). Nygaard (1949) noted that cell wall ornamentation in this species is delicately rugulate and distinctly irregular (Lat. *rugulis delicatissimis et irregularibus instructa*). Kowalska & Wołowski (2010b) made a detailed taxonomic study of cell wall ornamentation in *P. alternans*.

Current records. *P. alternans* occurred at 4 of 71 stations, located on the Southern Baltic Coast, only in eutrophic coastal lakes (sampling stations I.1, 3–5). The species

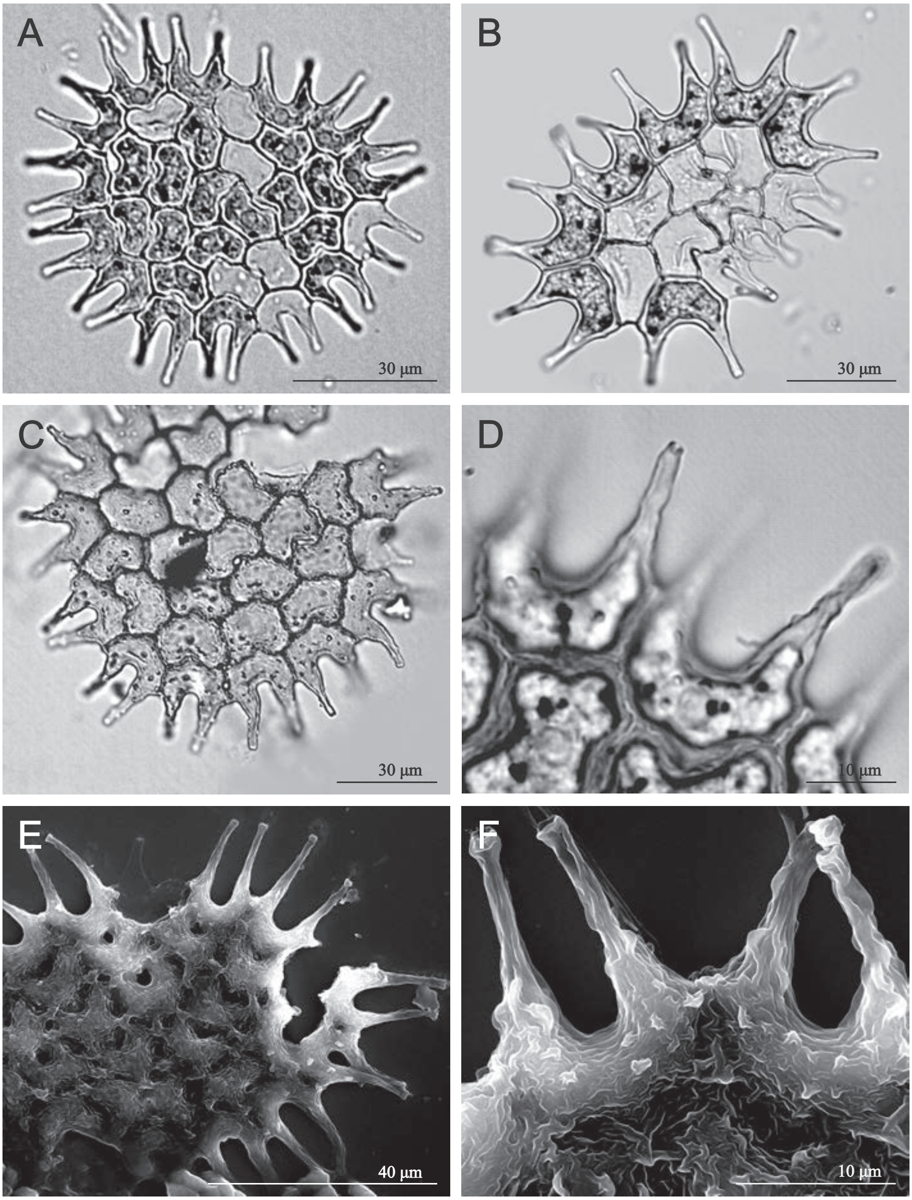

Fig. 24. A–F – *Pediastrum alternans* Nygaard from field material. C – empty coenobium with cell wall ornamentation. D – details of marginal cells. F – details of cell wall ultrastructure. A–D – LM. E & F – SEM.

had a share of ≤0.2% in the algal communities. Water temperature in these lakes was 19.5–25.0°C, pH 8.9–9.6, conductivity 152–1740 µS/cm, total hardness 9.0–27.8°n, carbonate hardness 5.6–9.2°n, nitrates <5.0 mg/dm^3 and orthophosphates <0.15–0.75 mg/dm^3. A recent finding in coastal lakes was published by Kowalska & Wołowski (2010b, p. 230, figs 9–15).

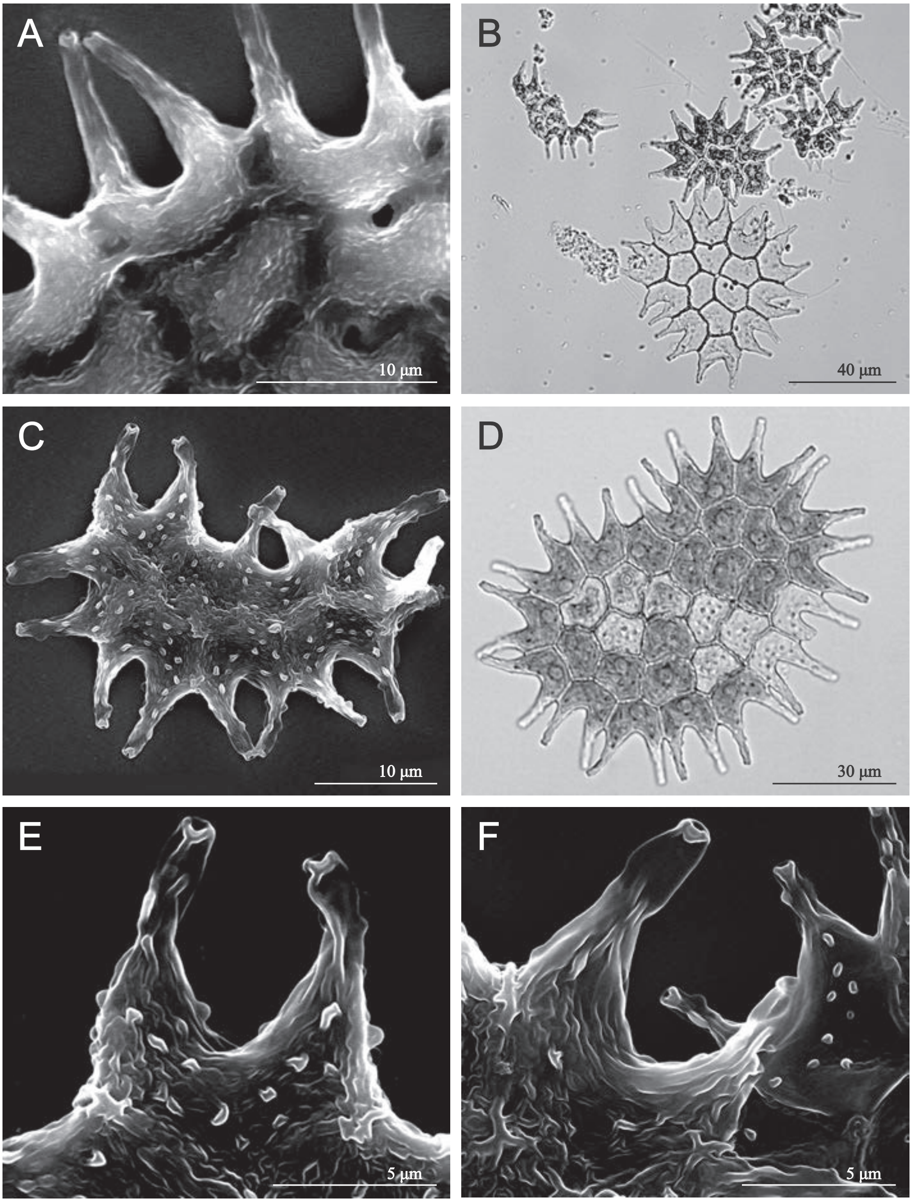

Fig. 25. A–F – *Pediastrum alternans* Nygaard. A – details of a very delicate rugulate cell wall surface in coenobium from field material. B–F – cultured material. B – several coenobia. F – differences in cell wall ornamentation between younger (smaller marginal cell) and older (bigger marginal cell) coenobia. A, C, E & F – SEM. B & D – LM.

Literature data. Few records were given for *P. alternans*. Localities include three localities in the Pojezierze Łęczyńsko-Włodawskie lakeland: paraoligotrophic Jezioro Czarne-Sosnowickie lake and Jezioro Bialskie lake (Wojciechowski 1971, pl. XII, fig. 1 – as misapplied name *P. boryanum* var. *longicorne*) and eutrophic Jezioro Sumin lake (Pasztaleniec & Poniewozik 2004, fig. 14).

Pediastrum angulosum* var. *angulosum* (Ehrenberg) Meneghini 1840, p. 211

Fig. 26A–F

BASIONYM:

Micrasterias angulosa Ehrenberg 1834, p. 301.

SYNONYMS:

P. angulosum var. *araneosum* Raciborski 1889, p. 18, pl. II, figs 19–21 & 40;
P. angulosum var. *araneosum* fo. *brevicorne* Raciborski 1889, p. 20, pl. II, fig. 23;
P. angulosum var. *araneosum* fo. *obsoletum* Raciborski 1889, p. 19, pl. II, fig. 22;
P. araneosum (Raciborski) G.M. Smith 1916, p. 476;
P. araneosum var. *rugulosum* (G.S. West) G.M. Smith 1916, p. 476, pl. XXV, fig. 14;
P. boryanum (Turpin) Meneghini var. *rugulosum* G.S. West 1907–1909, p. 132, pl. V, fig. 22;
P. vagum Kützing 1845, p. 143.

Coenobia 112–223 μm in diameter, round or oval in outline, with very small perforations, incomplete 16-, 64-, 128-celled. Cells arranged irregularly. Marginal cells 13–29 μm long, 13–34 μm wide, each with two short conical lobes on plane of coenobium, terminating in short cylindrical processes. Incision shallow, maximally to half of cell length, U-shaped. Inner cells 11–27 μm long, 13–31 μm wide, polygonal, connected by their sides. Walls of adjacent cells thick, sometimes to ca. one fourth or even one third of cell length, sometimes undulate. Cell wall surface araneose (type 5).

NOTES. *P. angulosum* has two varieties: var. *angulosum* (noted in this study), and var. *coronatum* (Raciborski) Komárek & Jankovská (2001) having marginal cells with very short lobes which are bent toward each other.

Coenobia in the studied material were incomplete, lacking several cells (Fig. 26A–F). Chang & Chang-Schneider (1980) noted incomplete coenobia of *P. boryanum* var. *longicorne*, especially at the end of the vegetative season when environmental conditions do not favour *Pediastrum* growth.

One coenobium had very thick cell walls (Fig. 26B). Chang & Chang-Schneider (1980) mentioned a coenobium of another taxon, *P. boryanum* var. *longicorne* from cultured material, having a group of thick-walled dark green cells in the middle, surrounded by empty cells, which could be a resting stage of the taxon. Such resting cells might also have been produced in the observed *P. angulosum* var. *angulosum* specimens.

CURRENT RECORDS. *P. angulosum* var. *angulosum* occurred at 4 of 71 stations, located in the Southern Baltic Lakelands and Polesie, including lowland lakes with forest (sampling stations III.1, 2, 4) and manmade (V.10) catchments. The taxon always had a share of ≤0.2% in the algal communities. The water bodies ranged from oligo/meso- to meso/eutrophic and one was humoeutrophic; water temperature 22.5–24.7°C, pH 7.4–8.4, conductivity 46–148 μS/cm, total hardness 1.8–5.0°n, carbonate hardness 1.2–4.0°n, nitrates <5.0 mg/dm^3 and orthophosphates <0.15–0.25 mg/dm^3.

LITERATURE DATA. Many records were given for *P. angulosum* var. *angulosum*. Localities include the Molkówka peat bogs near the Dolina Chochołowska valley in the Tatra Mountains (Raciborski 1889, p. 18, pl. II, figs 19–21 & 40 – as synonym *P. angulosum* var. *araneosum*, p. 19, pl. II, fig. 22 – as synonym *P. angulosum* var. *araneosum* fo. *obsoletum*, p. 20, pl. II, fig. 23 – as synonym *P. angulosum* var. *araneosum* fo. *brevicorne*), dystrophic Toporowy Staw Wyżni lake in the Tatra Mountains

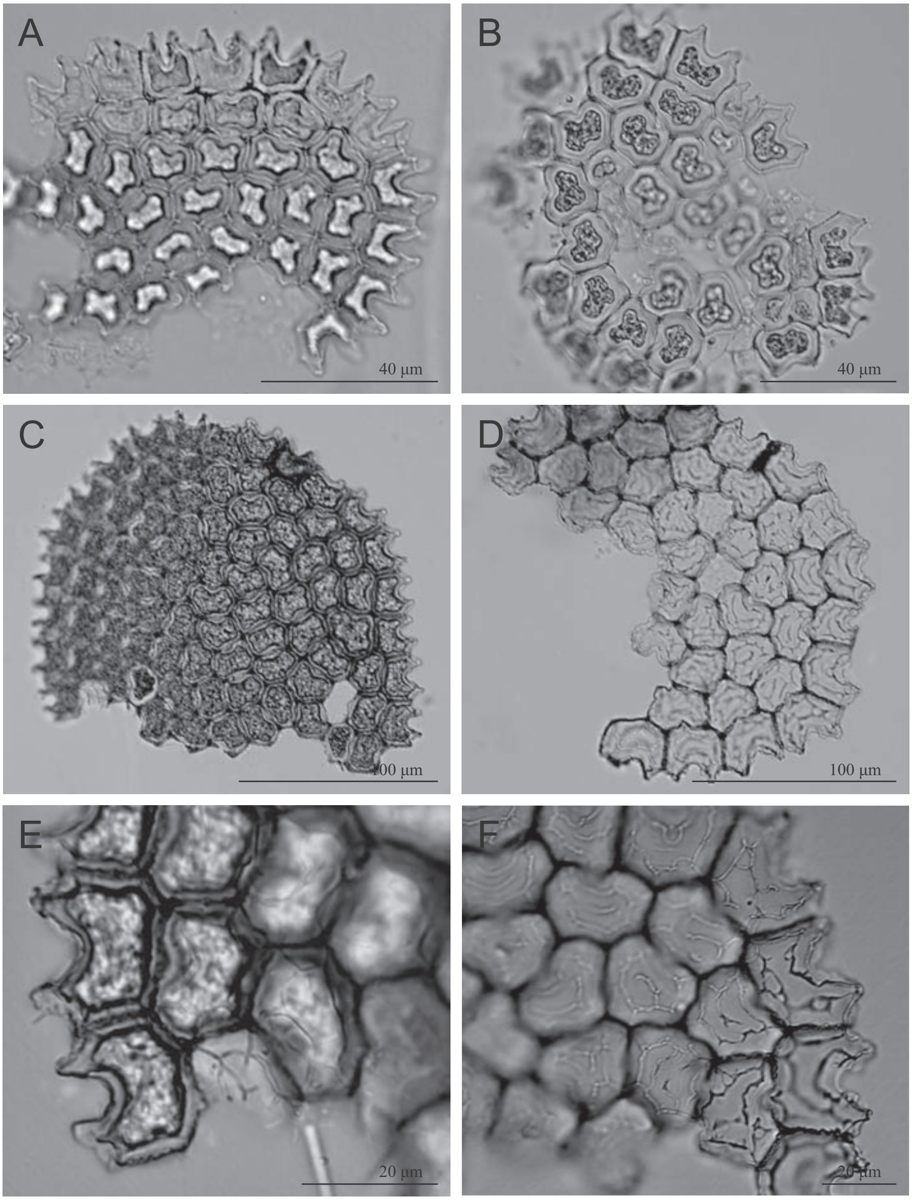

Fig. 26. A–F – *Pediastrum angulosum* (Ehrenberg) Meneghini var. *angulosum* from field material (LM). B – coenobium having thick cell walls. E & F – details of cell wall ornamentation.

(Siemińska 1967, p. 173, fig. 18 – as misapplied name *P. angulosum*), lakes in western Pomerania (Lucks 1906/1907, p. 45, fig. 16 – as synonym *P. angulosum* var. *araneosum*), several lakes in the Pojezierze Łęczyńsko-Włodawskie lakeland, including paraoligotrophic Jezioro Czarne-Sosnowickie lake and Jezioro Bialskie lake (Wojciechowski 1971, pl. XXIII, figs 3 & 4), eutrophic Jezioro Sumin lake (Pasztaleniec & Poniewozik 2004, p. 45, figs 15 & 16), Jezioro Uściwierz lake (Malicki 1972, pl. I, fig. d) and fish ponds in Gołysz, southern Poland (Krzeczkowska-Wołoszyn 1966, p. 118, figs 49 & 50 – as synonym *P. araneosum* var. *rugulosum*).

Pediastrum argentinense Bourrelly et Tell in Tell 1979, p. 43, fig. 15 Fig. 30D

Synonyms:

P. duplex Meyen var. *cohaerens* Bohlin 1897, p. 31, pl. II, fig. 1;
P. duplex var. *rectangulare* Bohlin 1897, p. 31, pl. II, fig. 3;
P. duplex var. *reticulatum* Lagerheim fo. *cohaerens* (Bohlin) Brunnthaler 1915, p. 95, fig. 57e;
P. duplex var. *reticulatum* fo. *rectangulare* (Bohlin) Brunnthaler 1915, p. 95, fig. 57f.

Coenobia up to 150 µm in diameter, large, very round or oval in outline, with small perforations, 16-, 32-, 64-celled. Cells arranged concentrically but with numerous irregularities. Cells H-shaped, tetragonal, rarely triangular in outline, with straight or slightly concave sides. Marginal cells 12–20 µm long, 9–24 µm wide, each with two widely spaced, short and broad lobes terminating in warts, often connecting adjacent cells. Between the lobes a very broad and shallow V-shaped incision. Inner cells 12–20 µm long, 9–24 µm wide. Cell wall surface rugulate with granules or reticulate with granules (types 6a, 7a).

Notes. Morphologically the species closely resembles *P. duplex* var. *rugulosum* in cell shape and wall ultrastructure. Especially the younger coenobia of *P. argentinense* have H-shaped cells, as in *P. duplex*. Older coenobia have typical rectangular cells with marginal lobes often widely spaced and connecting the adjacent cells.

Literature data. Some records were given for *P. argentinense*. Localities include Jezioro Lednica lake (Wawrzyniak 1930, without documentation – as synonym *P. duplex* var. *cohaerens*), Nowy Kanał Bydgoski canal (Michalski *et al.* 1936, without documentation – as synonym *P. duplex* var. *reticulatum* fo. *rectangulare*), the small Miłosławka river (Gabański *et al.* 1937, without documentation – as synonym *P. duplex* var. *reticulatum* fo. *rectangulare*), dystrophic and partly eutrophic Jezioro Skrzynka lake (Krawiecowa 1957, without documentation – as synonym *P. duplex* var. *cohaerens*) and polluted Jezioro Pątnowskie lake in central Poland (Burchardt 1977, without documentation – as synonym *P. duplex* var. *rectangulare*), fish ponds in southern Poland (Szklarczyk-Gazdowa 1965, without documentation – as synonym *P. duplex* var. *cohaerens*), and the Baltic Sea, including the Zatoka Pucka lagoon (Rumek 1948, without documentation – as synonym *P. duplex* var. *reticulatum* fo. *cohaerens*).

*****Pediastrum privum*** (Printz) Hegewald in Hegewald et Schnepf 1979, p. 25, figs 2–7 Fig. 27A–F

Basionym:

P. integrum Nägeli var. *privum* Printz 1913, p. 73, pl. V, fig. 147.

Coenobia 12–18 µm in diameter, without perforations, four-celled composed of triangular cells, eight-celled composed of trapezoidal, trigonal or parallelogrammatic cells. Cells 4–6 µm long, 5–10 µm wide. Margin of marginal cells straight or slightly concave, sometimes forming very small lobes. Processes short, reduced, visible only in some cells as small warts at coenobium corners.

Notes. Mainly 4-celled, very rarely 8-celled coenobia were found in the field material. Kowalska & Wołowski (2010a) described the morphological variability of *P. privum* in this material.

Under LM, morphologically the observed 4-celled coenobia closely resemble another coccal green alga, *Crucigenia tetrapedia* (Kirchner) W. et G.S. West. However, *P. privum* has small warts at the coenobium corners and an ornamented cell wall, whereas

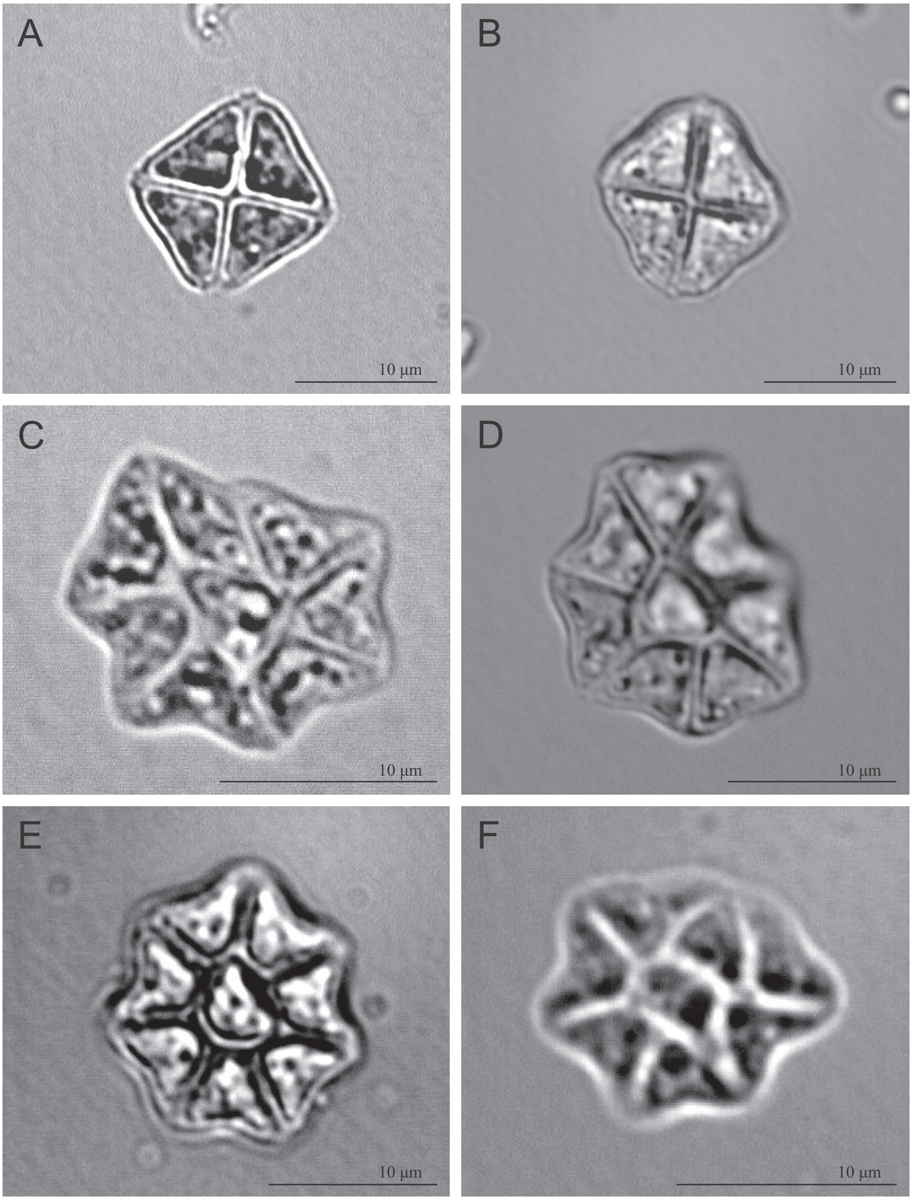

Fig. 27. A–F – *Pediastrum privum* (Printz) Hegewald from field material (LM).

C. tetrapedia has no warts and no cell wall ornamentation. Cell wall ornamentation in *P. privum* was not observed in this study. According to Parra (1979) the cell wall surface is irregularly reticulate, sometimes having granule-like elements in LM (type 7a?). An *et al.* (1999) observed irregularly arranged folds and Hegewald & Jeon (2000) observed wrinkles on the surface of *P. privum* (types 6a?, 6b?).

Molecular data revealed a close phylogenetic connection between *P. privum* and *P. tetras* (McManus & Lewis 2005).

CURRENT RECORD. *P. privum* had a share of ≤0.2% in a humoeutrophic lowland lake with a forest catchment (sampling station III.4) in the Southern Baltic Lakelands; water temperature 24.7°C, pH 8.2, conductivity 148 µS/cm, total hardness 5.0°n, carbonate hardness 4.0°n, nitrates <5.0 mg/dm^3 and orthophosphates 0.25 mg/dm^3. The record was published by Kowalska & Wołowski (2010a, p. 140, fig. 2a–f).

LITERATURE DATA. The only previously given Polish locality of this species is Jezioro Czyste Małe lake in the Pojezierze Lubuskie lakeland (Pełechaty *et al.* 2007, without documentation).

Pediastrum obtusum Lucks 1906/1907, p. 43, fig. 5 Fig. 30E

SYNONYM:

P. tetras (Ehrenberg) Ralfs fo. *granulatum* Raciborski 1889, p. 32, pl. II, fig. 43.

Coenobia up to 144 µm in diameter, very round or broadly oval in outline, without perforations, 8-, 16-, 32-celled. Marginal cells ca. 18 µm long, 10–12 µm wide, trapezoidal, shorter base of trapezoid directed inward. Incision narrow, dividing cell into two main broad lobes on plane of coenobium, connected along the whole length with adjacent cells. Incision terminating in rounded widening in middle of cell. Lobes divided by V-shaped incision into secondary lobes of the same shape and size. Inner cells ca. 18 µm long, 10–12 µm wide, 4–6-gonal in outline, connected by their sides, with very narrow linear incision. Cell wall surface verrucate (type 4).

NOTES. Morphologically the species resembles *P. tetras* and *P. biradiatum*. Like those two species, *P. obtusum* has marginal cells divided into main and secondary lobes, but the lobes in *P. obtusum* are of the same shape and size, with very narrow incisions between the main lobes, terminating in a rounded widening.

LITERATURE DATA. Few records were given for *P. obtusum*. Localities include Tyniec near Cracow (Raciborski 1889, p. 32, pl. II, fig. 43 – as synonym *P. tetras* fo. *granulatum*), a lake (German: Kleine Barschsee) near Człuchów in western Pomerania (Lucks 1906/1907, p. 43, fig. 5), organically or artificially fertilized and unfertilized fish ponds in Gołysz, southern Poland (Krzeczkowska-Wołoszyn 1971, 1977, without documentation; Urbaniec-Brózda 1985, without documentation) and Goczałkowice dam reservoir (Bombówna & Bucka 1974, without documentation; E. Krzyżanek & M. Krzyżanek 1986, without documentation).

****Pediastrum tetras*** (Ehrenberg) Ralfs 1844, p. 469, pl. XII, fig. 4 Fig. 28A–F

BASIONYM:

Micrasterias tetras Ehrenberg 1838, p. 155, pl. XI, fig. 1.

SYNONYMS:

P. tetras var. *caudatum* (A. Braun) Raciborski 1889, p. 32, pl. II, fig. 41;
P. tetras var. *excisum* (A. Braun) Hansgirg 1888, p. 112;
P. tetras var. *tetraodon* (Corda) Hansgirg 1888, p. 112;
P. caudatum A. Braun 1855, p. 101;
P. constrictum (Hassall) Lucks 1906/1907, p. 47, fig. 23;
P. cruciatum Haeckel 1899–1904, p. 170, pl. XXXIV, fig. 5;
P. ehrenbergii A. Braun 1855, p. 97, pl. V, figs h 3 & 4;
P. incisum Hassal 1845, pl. XCII, fig. 8;
P. rotula (Ehrenberg) Kützing 1845, p. 143 (pro parte).

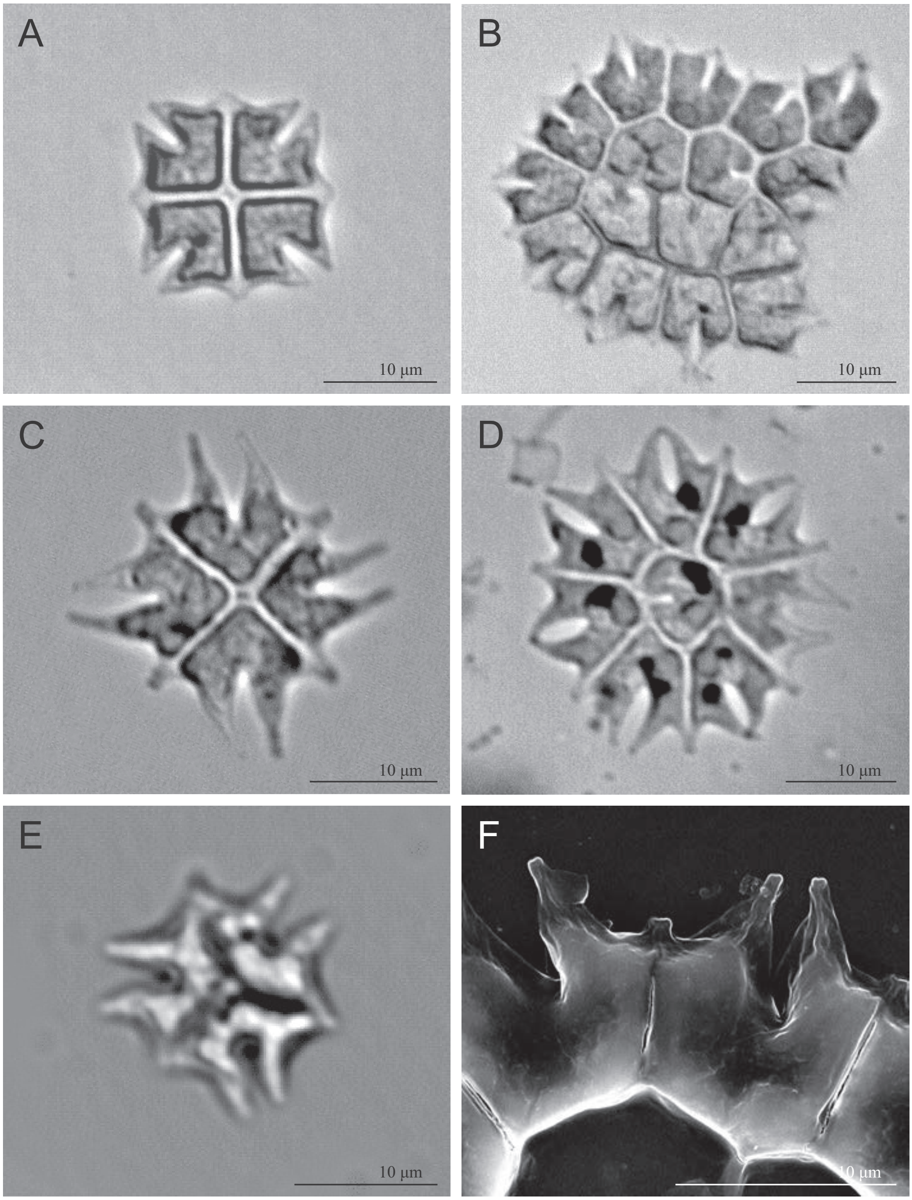

Fig. 28. A–F – *Pediastrum tetras* (Ehrenberg) Ralfs from field material. E – teratological form composed of only three cells. F – details of cell wall ultrastructure. A–E – LM. F – SEM.

Coenobia 18–63 µm in diameter, round or irregular in outline, without perforations, 4-, 8-, 16-, 32-celled, exceptionally 3-celled. Marginal cells 7–13 µm long, 6–14 µm wide, trapezoidal, shorter base of trapezoid directed inward. Incision narrow, U-shaped or V-shaped, maximally to ca. half of cell length, dividing cell into two broad lobes on plane of coenobium, connected along its whole length with neighbouring cells. Lobes divided into secondary lobes by U-shaped or V-shaped incision. Secondary lobes near axis of cell are slightly longer, sometimes with longer processes; the other two are slightly shorter, with short processes. Inner cells 5–10 µm long, 5–10 µm wide, 4-, 5- or 6-gonal in outline, with very narrow linear incision. Cell wall surface smooth (type 1).

Herbarium material. Wittrock & Nordstedt, Algae aquae dulcis exsiccatae praecipue scandinavicae, no. 235, leg. G. Thuret comm. E. Bornet, August 1848, ut *P. simplex* (BM, M).

Notes. Coenobia *P. tetras* from field material had secondary lobes of various length, situated near the axis of the cell (Fig. 28A–F). According to Sulek (1969) the character is of no taxonomic value. Because it shows highly variable morphology, many intraspecific taxa have been described (e.g. A. Braun 1855; Hansgirg 1888; Raciborski 1889) and later synonymised (Parra 1979; Komárek & Jankovská 2001). The latter authors suggested that there are various geographically restricted morphotypes.

I observed a 3-celled teratological coenobium (Fig. 28E). Rojo *et al.* (2009) observed alternation of *P. tetras* generations in the cultured material: 2- and 4-celled coenobia emerged from polyeders (immoveable cells formed from moving cells after zygote division during sexual reproduction), and then 8- and 16-celled coenobia from maternal cells during asexual reproduction.

In a coenobium under SEM the cell wall surface appeared smooth, with some roughness resembling granules or verrucas (Fig. 28F). Sulek (1969) noted the same type of cell wall ultrastructure in LM. Parra (1979) observed three different types of ornamentation in this species, including reticulate with granules or rugulate with granules, as well as irregularly granulate, which occurred when the mesh disappeared. Wu (1987) distinguished *P. tetras* var. *tetras* having a reticulate surface and *P. tetras* var. *tetraodon* with granulate ornamentation. The differences between observations point to the need for further study of cell wall ultrastructure in *P. tetras*. Further morphological and molecular studies of populations from distant localities are called for.

Current records. *P. tetras* occurred at 30 of 71 stations, located on the Southern Baltic Coast, in the Eastern and Southern Baltic Lakelands, Central Polish Lowlands, Polesie, Wyżyna Śląsko-Krakowska upland and Northern Sub-Carpathia, including coastal lakes (sampling stations I.2, 4, 5), lowland lakes with mixed (I.9, II.7, III.5, V.2) and forest (II.1, III.2, 4) catchments, a delta lake (I.10), fish ponds (III.9, IV.2, V.1, 3–7), through-flow ponds (IV.3, 4), village ponds (IV.1, VII.1), a park pond (VIII.6), suburban pond (III.6), field pond (III.11), peat pits (I.7, 8), a clay pit (VIII.3) and an oxbow lake (VIII.4). The species usually had a share of ≤0.2% (26 sampling stations) and sometimes 0.3–3% (4) in the algal communities. The water bodies ranged from oligo/meso- to eutrophic, most of them eutrophic (24) and one humoeutrophic; water temperature 17.0–26.3°C, pH 7.4–9.4, conductivity 46–1740 µS/cm, total hardness 1.8–27.8°n, carbonate hardness 1.2–15.6°n, nitrates <5.0–10.0 mg/dm^3 and orthophosphates <0.15–1.50 mg/dm^3. A recent finding in coastal lakes was published by Kowalska & Wołowski (2010b, fig. 26).

Literature data. Very many records were given for *P. tetras* from e.g. lakes (e.g. Lucks 1906/1907, p. 44, figs 9–11 – as synonym *P. tetras* var. *tetraodon*, p. 47, fig. 23 – as synonym *P. constrictum*; Malicki 1972, pl. II, fig. c), including eutrophic (e.g. Kowalski 1975, p. 361, fig. 23 – as synonym

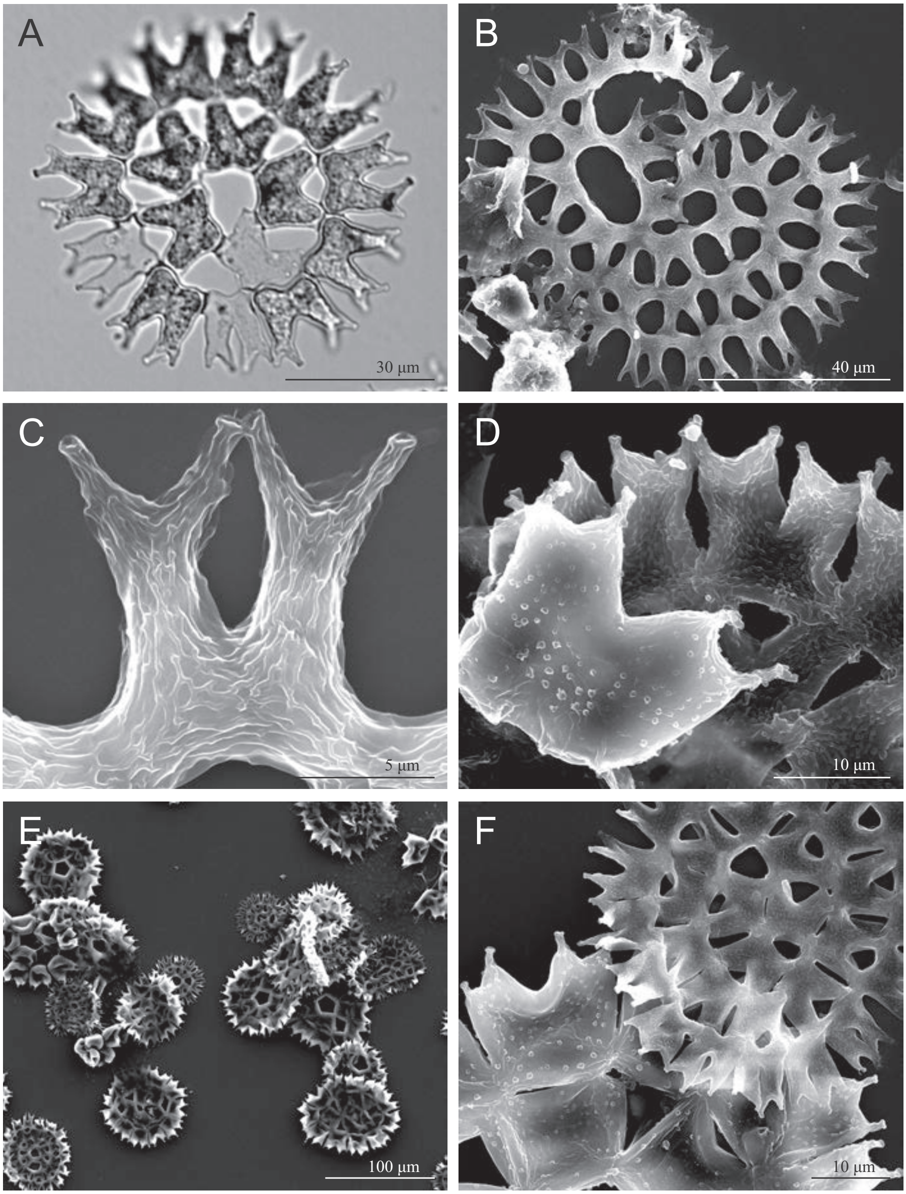

Fig. 29. A–F – *Pediastrum biradiatum* Meyen var. *biradiatum*. A–C – field material. D–F – cultured material. C – details of cell wall ultrastructure. D & F – differences in cell shape and cell wall ornamentation between younger and older coenobia. E – coenobia of various size. A – LM. B–F – SEM.

P. tetras var. *tetraodon*; Stefko 1976, pl. XI, fig. 7 – as misapplied name *P. biradiatum*; Burchardt 1977, pl. XIII, fig. 5), paraoligotrophic (Wojciechowski 1971, pl. XII, figs 2 & 5) and coastal lakes (Picińska-Fałtynowicz 1997, fig. 12), dam reservoirs (Bucka & Wilk-Woźniak 2002, p. 170, figs 187, 188 & 195; Wołowski & Grabowska 2007, fig. 60 – as misapplied name *P.* cf. *tetras*), ponds (e.g. Kadłubowska 1961, p. 90, pl. XI, fig. 5; Sitkowska 1992, p. 68, pl. XXX, figs 1–4 & 6, pl. XXXI, figs 2–6; Wołowski *et al.* 2008, p. 120, fig. 14; Wołowski & Kowalska 2009, fig. 39), fish ponds (e.g. Sosnowska 1956, pl. I, fig. 14 – as synonym *P. tetras* var. *tetraodon*), pools in peat bogs (Wasylik

1961, p. 268, pl. V, figs 20 & 21), peat pits (Kowalski 1975, p. 361, fig. 23 – as synonym *P. tetras* var. *tetraodon*), a settling pond (Humblet-Pawłowska 1939, pl. V, fig. 129) and a river (Luer-Jeziorańska 1939, pl. XII, figs 205 & 206).

Pediastrum longecornutum (Gutwiński) Comas 1989, p. 142, fig. 7a–b Fig. 30F

Basionym:

P. biradiatum Meyen var. *longecornutum* Gutwiński 1896, p. 3, pl. VII, fig. 64.

Coenobia up to 82 µm in diameter, round in outline, with distinct and regularly disposed perforations, 4-, 8-(16-)celled. Marginal cells 8–30 µm long, 8–26 µm wide, polygonal in outline. Incision U-shaped or almost closed O-shaped, deep, dividing cell into two massive lobes. Lobes divided into secondary lobes; the two inner ± radially oriented and sometimes longer, and the two outer ones ± perpendicular to the inner ones. All lobes and processes exactly on plane of coenobium. Inner cells 8–30 µm long, 8–26 µm wide, H-shaped, with four lobes and concave sides, cells connected only by their lobes. Cell wall surface smooth (type 1).

Notes. Comas (1989) examined the morphological variability of the two similar species *P. longecornutum* and *P. biradiatum*, and observed a distinguishing character of *P. longecornutum*. All four secondary lobes of its marginal cells are on the plane of the coenobium and the shorter outer secondary lobes always lie perpendicular to the inner radially oriented secondary lobes.

Molecular studies of the two species are necessary to confirm their taxonomic separation.

Literature data. Few records were given for *P. longecornutum*. Localities include ponds near Rudze in southern Poland (Gutwiński 1896, p. 3, pl. VII, fig. 64 – as synonym *P. biradiatum* var. *longecornutum*; 1897, without documentation), a pond in Cieszyn Silesia (Sosnowska 1956, without documentation), eutrophic Jezioro Maltańskie lake in Poznań (Stefko 1976, without documentation), polluted Jezioro Pątnowskie lake (Burchardt 1977, without documentation), a peat pit near that lake (Socha 1981, without documentation), and the seston of the Vistula river near Warsaw (Tyszka-Mackiewicz 1983, p. 102, pl. V, fig. 9 – as synonym *P. biradiatum* var. *longecornutum*).

****Pediastrum biradiatum*** Meyen 1829, p. 773, pl. XLIII, figs 21 & 22

Figs 29A–F, 31A

Coenobia 35–104 µm in diameter, round or irregular in outline, perforated, 16- or 32-celled. Cells arranged irregularly or concentrically. Marginal cells 9–20 µm long, 9–20 µm wide, trapezoidal, shorter base of trapezoid directed inward. Incision U-shaped or V-shaped, deep, from half to two thirds of cell length, dividing cell into two massive lobes on plane of coenobium. Lobes divided into secondary lobes with narrow or broad incision, U-shaped or V-shaped. Secondary lobes of ± equal length, from one fifth to one third of cell length, oriented obliquely to plane of coenobium, terminating in short processes. Inner cells 6–15 µm long, 8–17 µm wide, H-shaped, with four lobes and concave sides, cells connected only by their lobes. Cell wall surface rugulate with granules (type 6a).

Notes. Cell wall ultrastructure was not observed in every specimen. They could belong to either *P. biradiatum* variety: *biradiatum* having rugulate ornamentation with granules or *glabrum* with a smooth surface. Molecular analysis of the varieties could confirm their separation.

CURRENT RECORDS. *P. biradiatum* occurred at 10 of 71 stations, located on the Southern Baltic Coast and Lakelands, in the Central Polish Lowlands and Polesie, including fish ponds (sampling stations I.6, IV.2, V.1, 3, 6, 7), through-flow ponds (IV.3, 4), a suburban

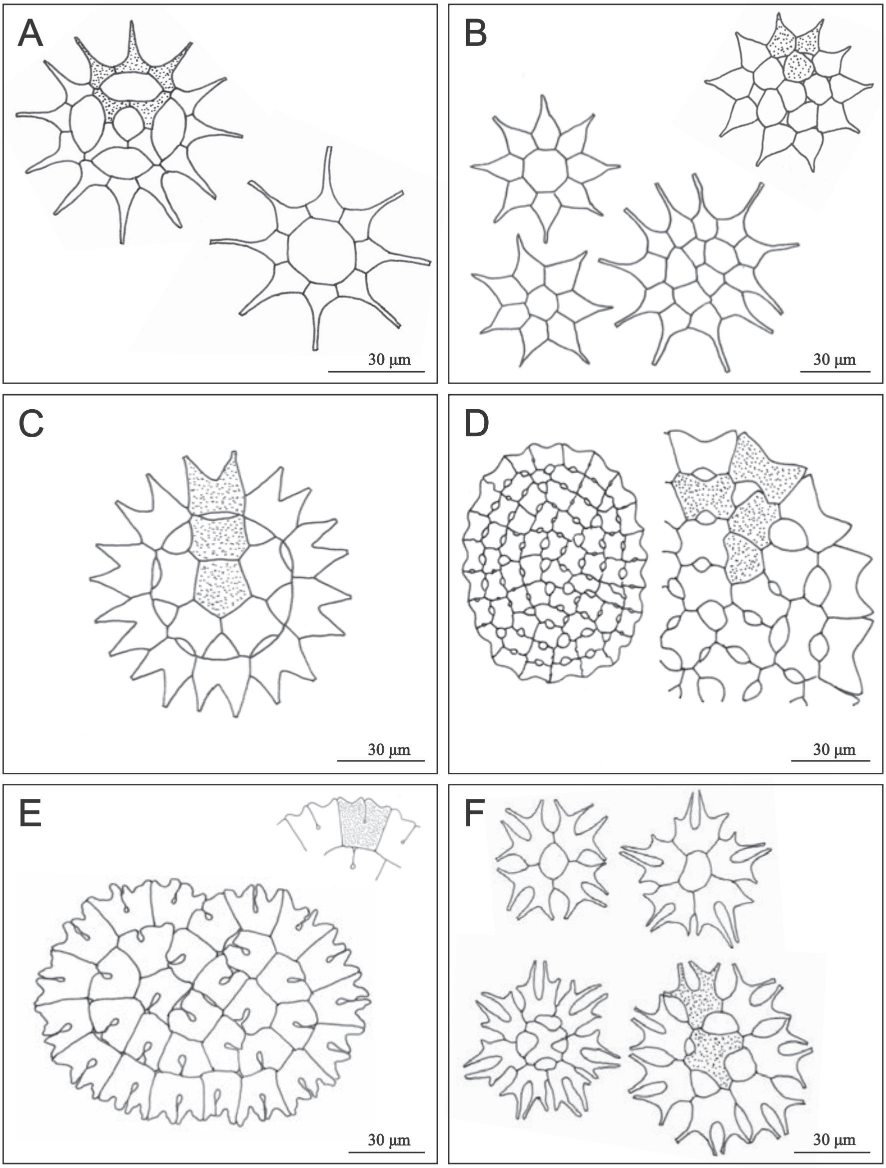

Fig. 30. A – *Pediastrum simplex* var. *clathratum* (Schröter) Chodat. B – *P. simplex* var. *sturmii* (Reinsch) Wolle. C – *P. subgranulatum* (Raciborski) Komárek et Jankovská. D – *P. argentinense* Bourrelly et Tell. E – *P. obtusum* Lucks. F – *P. longecornutum* (Gutwiński) Comas. A–C, E & F – drawings after Komárek & Jankovská (2001). D – Tell (1979).

pond (III.6) and a coastal lake (I.3). The species usually had a share of ≤0.2% (9 sampling stations) or 0.3–3% (1) in the algal communities. The water bodies ranged from meso/eu- to eutrophic, most of them (8) eutrophic; water temperature 17.0–26.3°C, pH 8.3–9.2, conductivity 181–560 µS/cm, total hardness 10.0–11.6°n, carbonate hardness 6.4–8.2°n, nitrates ≤5.0 mg/dm^3 and orthophosphates <0.15–0.25 mg/dm^3. A recent finding in a coastal lake was published by Kowalska & Wołowski (2010b, fig. 24).

Literature data. Very many records were given for *P. biradiatum*. Localities include lakes (Lucks 1906/1907, p. 44, figs 6 & 7; Schulz 1931, pl. III, fig. 8; Malicki 1972, pl. II, fig. a, b & d – as misapplied name *P. tetras*), eutrophic lakes (Kotlińska 1976, pl. XVII, fig. 262) and alkalitrophic lakes (Kowalski 1975, p. 359, fig. 18), ponds (e.g. Kadłubowska 1961, p. 90, pl. XI, fig. 7), fish ponds (e.g. Sosnowska 1956, pl. I, fig. 13; Sitkowska 1992, p. 55, pl. I, fig. 5, pl. II, figs 1–6, pl. III, figs 1–6, pl. IV, figs 1–3 – as misapplied name *P. biradiatum* var. *biradiatum*), a lagoon, including two hypertrophic sampling stations (Luścińska 2005, pl. VIII, fig. 20), dam reservoirs (Bucka & Wilk-Woźniak 2002, p. 166, fig. 190a & b; Wołowski & Grabowska 2007, fig. 61), a settling pond (Humblet-Pawłowska 1939, pl. V, fig. 131 – as misapplied name *P. biradiatum* var. *emarginatum*) and a river (Luer-Jeziorańska 1939, pl. XII, figs 207 & 208 – as misapplied name *P. biradiatum* var. *emarginatum*).

**Pediastrum biradiatum* var. *biradiatum* Fig. 29A–F

Synonyms:

P. biradiatum var. *emarginatum* (Ehrenberg) Brunnthaler 1915, p. 105, fig. 66b;
P. lobatum Nitardy 1914, p. 181, pl. V, fig. 4;
P. rotula (Ehrenberg) Kützing 1845, p.143 (pro parte);
P. rotula fo. *granulatum* Raciborski 1889, p. 31, pl. II, fig. 42.

Coenobia 72–88 µm in diameter, marginal cells 12–20 µm long, 11–19 µm wide, inner cells 12–15 µm long, 12–16 µm wide. Cell wall surface rugulate with granules (type 6a).

Notes. Coenobia (49–100 µm in diameter) and their cells (marginal cells 10–26 µm long, 8–28 µm wide, inner cells 7–18 µm long, 9–23 µm wide) in strain no. 02.040908 had a greater range of dimensions than in the field material; the coenobia in strain no. 05.040908 were smaller (33–74 µm in diameter) but had a greater range of cell dimensions (marginal cells 11–26 µm long, 8–32 µm wide, inner cells 7–20 µm long, 8–25 µm wide) than in the field material. In the first strain 16- and 32-celled coenobia were observed, and in the latter strain 8-, 16- and 32-celled coenobia. Cell shape changed with age in both strains (Fig. 29D–F). The older cells (Fig. 29D & F) were bigger and rounded, the main and secondary incisions were shallower and wider, perforations between cells became smaller, and the wrinkles on the cell surface disappeared. Those differences were also observed in taxonomic studies by Sulek (1969) and Parra (1979). Granules were sometimes not visible on the surface of bigger cells, making them resemble *P. biradiatum* var. *glabrum*. Large irregular thickenings (Fig. 29D & F) together with smaller granules were observed on the surface of large marginal cells. The thickenings could be groups of bacteria or an artefact of sample preparation for SEM.

Current records. *P. biradiatum* var. *biradiatum* occurred at 5 of 71 stations, located in the Southern Baltic Lakelands and Polesie, including eutrophic fish ponds (sampling stations V.1, 3, 6, 7) and a suburban pond (III.6); water temperature 22.8–26.3°C, pH

8.3–9.2, conductivity 307–412 µS/cm, total hardness 11.0°n, carbonate hardness 8.2°n, nitrates <5.0 mg/dm^3 and orthophosphates 0.25 mg/dm^3.

LITERATURE DATA. Some records were given for *P. biradiatum* var. *biradiatum*. Localities include stations in Wola Duchacka and Łęg (Raciborski 1889, p. 31, pl. II, fig. 42 – as synonym *P. rotula* fo. *granulatum*), fish ponds in Gołysz (Krzeczkowska-Wołoszyn 1966, p. 118, fig. 51 – as misapplied name *P. biradiatum*) and near Zator (Bednarz & Nowak 1972, p. 105, fig. 10 – as misapplied name *P. biradiatum*) and others in southern Poland (Bucka & Wilk-Woźniak 2002, p. 166, fig. 190a & b – as misapplied name *P. biradiatum*), the Goczałkowice and Rożnów dam reservoirs, and Puławy reservior in southern Poland (Bucka & Wilk-Woźniak 2002, p. 166, fig. 190a & b – as misapplied name *P. biradiatum*), eutrophic Siemianówka dam reservoir in eastern Poland (Wołowski & Grabowska 2007, fig. 61) and eutrophic Jezioro Sumin lake in the Pojezierze Łęczyńsko-Włodawskie lakeland (Pasztaleniec & Poniewozik 2004, p. 42, fig. 8).

Pediastrum biradiatum var. ***glabrum*** (Raciborski) Parra 1979, p. 56, pl. IV, figs d–k — Fig. 31A

BASIONYM:

P. biradiatum fo. *glabrum* Raciborski 1889, p. 31.

Coenobia up to 82 µm in diameter, marginal cells 11–30 µm long, 8–24 µm wide, inner cells 8–21 µm long, 10–26 µm wide. Cell wall surface smooth (type 1).

LITERATURE DATA. *P. biradiatum* var. *glabrum* was recorded only from a fish pond near Łódź (Sitkowska 1992, p. 55, pl. IV, fig. 4 – as misapplied name *P. biradiatum* var. *biradiatum*).

Pediastrum braunii Wartmann in Wartmann et Schenk 1862, fasc. 1, no. 32 — Fig. 31B

SYNONYMS:

P. tricornutum Borge 1892, p. 4, fig. 3;
P. tricornutum var. *alpinum* Schmidle 1896, p. 5, pl. XIV, figs 2–4;
P. tricornutum var. *alpinum* fo. *evolutum* Schmidle 1896, p. 5, pl. XIV, fig. 4;
P. tricornutum var. *alpinum* fo. *punctatum* Schröder 1898a, p. 21, pl. I, fig. 2.

Coenobia 25–40 µm in diameter, round in outline, without or with small perforations, 4-, 8-, 16-celled. Marginal cells 7–12 µm long, 8–17 µm wide, triangular or trapezoidal, with the longest side directed outward. Each marginal cell with an almost straight outer side, without any incision but with four short conical lobes terminating in small processes. Two of the lobes situated close to the adjacent marginal cells and on plane of coenobium, two others approximately in middle of outer cell margin and oblique to plane of coenobium. Additional small lobes may occur near base of marginal cells. Inner cells 7–12 µm long, 8–17 µm wide, polygonal or rounded, connected by their sides, sometimes with additional lobes and processes oblique to plane of coenobium and morphologically identical to lobes of marginal cells. Cell wall surface rugulate with granules (type 6a) or reticulate with granules (type 7a).

HERBARIUM MATERIAL. Wartmann & Schenk, Schweizerische Kryptogamen, no. 32, leg. Th. Wartmann, July 1860 (B, BM, M, Z).

LITERATURE DATA. Few records were given for *P. braunii*. Localities include a pool near Wielki Staw lake in the Giant Mountains (Schröder 1898a, p. 21, pl. I, fig. 2 – as synonym *P. tricornutum* var. *alpinum* fo. *punctatum*), several lakes in the Tatra Mountains (Wołoszyńska 1925, p. 50, fig. 2 – as synonym *P. tricornutum*) and dystrophic Suchar Wielki lake in Wigry National Park (Ryppowa 1927, without documentation – as synonym *P. tricornutum*). Recently it was noted again from the Tatra Mountains in shallow Wyżni Czerwony Stawek lake (Lenarczyk & Tsarenko 2013, p. 229, fig. 2d & g).

Pediastrum taylori Siemińska 1965, p. 100, pl. I, figs 8–14 Fig. 31C

Coenobia up to 57 µm in diameter, rounded polyhedral or round in outline, discoidal, with small perforations, (2-), 4-, 8-, 16-celled. Marginal cells 9–17 µm long, 9–16 µm wide, triangular, trapezoidal or polygonal in outline, with the longest side directed outward. Each marginal cell with almost straight outer side, without any incision but with four radially oriented, conical, distinct but not very long lobes terminating in small processes. Two of the lobes situated close to adjacent marginal cells and ± on plane of coenobium, two others approximately in middle of outer cell margin and perpendicular to plane of coenobium. One or two more morphologically similar lobes occur at both side walls of marginal cells. Inner cells 9–17 µm long, 9–16 µm wide, rounded polyhedral. Three or four distinct lobes project from flat sides of inner cells on both planes of coenobium. Lobes narrow and conical, morphologically

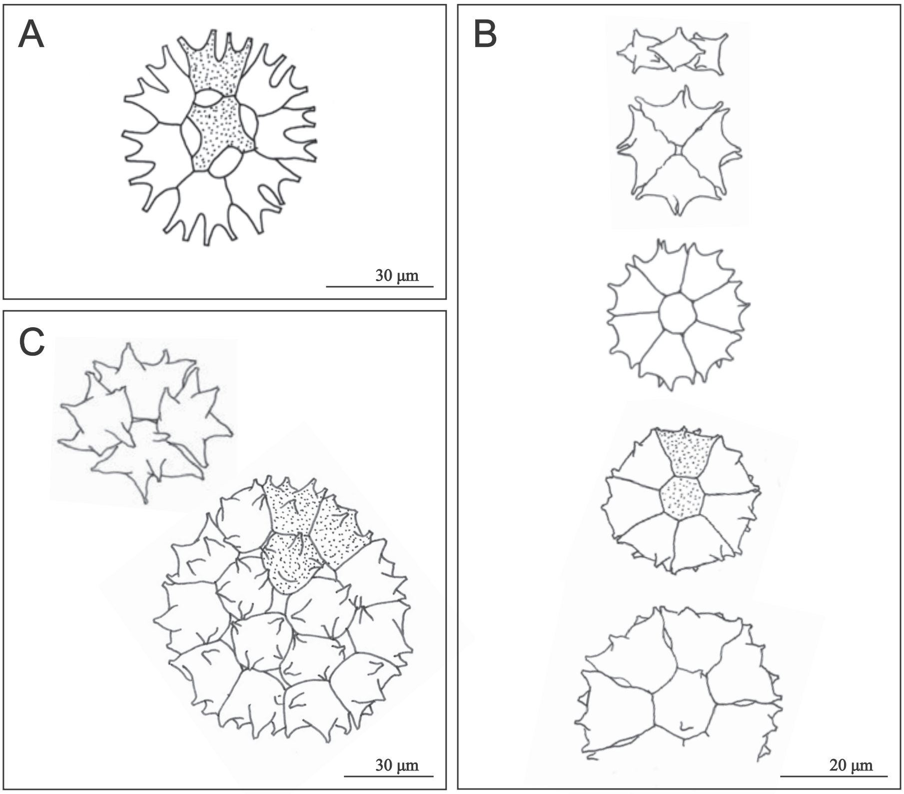

Fig. 31. A – *Pediastrum biradiatum* var. *glabrum* (Raciborski) Parra. B – *P. braunii* Wartmann. C – *P. taylori* Siemińska. A & B – drawings after Komárek & Jankovská (2001). C – Siemińska (1965).

identical to lobes of marginal cells, terminating in small processes. Cell wall surface granulate (type 3?).

NOTES. Morphologically the species closely resembles *P. braunii*. Both species have four processes on the outer margin of marginal cells. However, *P. taylori* has additional distinct lobes on the inner cells and close to the base of marginal cells. Siemińska (1965) noted that the wall of the processes in *P. taylori* is delicately granulate or punctate and that possibly the remainder of the cell wall is likewise granulate. Cell wall ornamentation in this species has not been examined by SEM yet.

LITERATURE DATA. *P. taylori* was recorded (only two coenobia) only from Toporowy Staw Wyżni, a shallow dystrophic lake in the Tatra Mountains (Siemińska 1967, p. 173). Description of the specimens given by Siemińska (1967): "Coenobia 24–26 µm in diameter, 8-celled. Cells 8–9 µm long, 8–10 µm wide. Cell wall punctate".

Discussion

Of the 32 *Pediastrum* taxa known from Poland, 23 were noted in my study. Eight of those are rare on the world scale (Komárek & Jankovská 2001): *P. patagonicum*, *P. musteri*, *P. privum*, *P. kawraiskyi*, *P. orientale*, *P. integrum* var. *integrum*, *P. duplex* var. *asperum* and *P. alternans*. Their distribution is presented below.

P. patagonicum is new for Europe. The species is recorded only from North and South America and the Far East, and its actual distribution is not well known (Tell & Mataloni 1990; Komárek & Jankovská 2001; Tell 2004). *P. musteri*, found at only one sampling station, is new for Central Europe, as given by Kowalska & Wołowski (2010b). The species is recorded from several distant localities including Argentina (Tell & Mataloni 1990; Izaguirre & Vinocur 1994; Tell 2004), Brazil (Comas & Perez 2002), Denmark (Tell & Mataloni 1990) and Japan (Komárek & Jankovská 2001).

The recent finding of *P. privum* is only the second for Poland, as presented by Kowalska & Wołowski (2010a). The previous record was given with no description or iconographic documentation by Pełechaty *et al.* (2007). That record needs revision because under LM the 4-celled coenobium of *P. privum* can be confused with the coccal green alga *Crucigenia tetrapedia* (Kirchner) W. West et G.S. West (Hegewald & Schnepf 1979). The nearest other localities of *P. privum* are in Lithuania (Wołoszyńska 1917, pl. XIV, fig. 39 – as *P. integrum* Nägeli fo.), Slovakia (Hindák & Hindáková 2004) and the Czech Republic (Geriš 2004). The distribution of *P. privum* is restricted to regions with temperate and subarctic climate in the Northern Hemisphere, for example Scandinavia, Asia, North America and Central Europe (Komárek & Jankovská 2001).

Similarly, *P. kawraiskyi* occurs mainly in colder climate, including Scandinavia, Canada and the northern United States. According to Komárek & Jankovská (2001) it has only a few localities in Central Europe, a statement that odds with recent data indicating its frequent occurrence in Poland.

There is conflicting information on the abundance of *P. integrum* var. *integrum*, which was found at only one sampling station in my study but frequently in past studies in Poland. Only three papers give iconographic documentation (Raciborski 1889;

Oleksowicz 1986; Pasztaleniec & Poniewozik 2004), and the data given in other papers cannot be verified. According to Komárek & Jankovská (2001), *P. integrum* var. *integrum* occurs sporadically in Central and Northern Europe, Canada and the northern United States, and on Desolation Island. It is also recorded from warm temperate climate in Argentina (Tell 2004).

P. orientale was somewhat frequently noted in my study. Other localities from Poland were given by Malicki (1972), Sitkowska (1992) and Pasztaleniec & Poniewozik (2004). It is also recorded from Turkey (Skuja 1937), Bear Island, the Andes, Greenland (Nygaard 1977), small reservoirs near the Baltic Sea (Komárek & Jankovská 2001) and Finland (Weckström *et al.* 2009).

Similarly, *P. duplex* var. *asperum* was somewhat frequently noted in my study. The literature data shows a similar frequency of records for this taxon in Poland but most of the data were published before the mid 20th century, and only one paper (Raciborski 1889) includes iconographic documentation. According to Komárek & Jankovská (2001), little is known about the world distribution of *P. duplex* var. *asperum*. There are records from the United States (Dillard 1989), Montenegro (Rakocevic-Nedovic & Rakaj 2001) and Panama (URS Holdings 2004).

The last of the group of rare *Pediastrum* taxa, *P. alternans*, was infrequently noted in this and previous studies in Poland (Wojciechowski 1971; Pasztaleniec & Poniewozik 2004). Outside Poland it is known only from Denmark (Nygaard 1949) and southern Scandinavia (Komárek & Jankovská 2001). It has a restricted geographical distribution.

Besides the several taxa mentioned above, the group of taxa infrequently noted in my study also includes *P. angulosum* var. *angulosum*, *P. biradiatum* var. *biradiatum*, *P. boryanum* var. *brevicorne*, *P. boryanum* var. *cornutum* and *P. duplex* var. *gracillimum*. The two varieties of *P. boryanum* were somewhat frequently noted in previous Polish studies but iconographic documentation is given in only four papers (Raciborski 1889; Lucks 1906/1907; Skalska 1984; Pasztaleniec & Poniewozik 2004). According to Komárek & Jankovská (2001), *P. boryanum* var. *cornutum* is a cosmopolitan taxon, whereas the exact distribution of *P. boryanum* var. *brevicorne* is not known.

The remaining taxa were in the upper three of the four frequency categories in my work. Of these, *P. simplex*, *P. boryanum*, *P. duplex* and *P. tetras* are the most common *Pediastrum* species, distributed throughout the world (Parra 1979; Komárek & Fott 1983; Komárek & Jankovská 2001).

Generally the *Pediastrum* taxa I found were not connected with any particular geographic region of Poland. The exceptions are *P. kawraiskyi*, *P. alternans* and a morphotype of *P. orientale* (coenobia similar to *P. kawraiskyi*), all noted mainly on the Southern Baltic Coast. *P. alternans* and the morphotype of *P. orientale* were noted exclusively in that region. *P. kawraiskyi* was previously recorded from all of Poland (e.g. Wołoszyńska 1913; Humblet-Pawłowska 1939; Sitkowska 1992), *P. alternans* from several localities in south-eastern Poland (Wojciechowski 1971; Pasztaleniec & Poniewozik 2004), and the morphotype of *P. orientale* in central Poland (Sitkowska 1992). *P. braunii* and *P. taylori* are connected mostly with mountain regions (Schröder 1898a; Wołoszyńska 1925; Siemińska 1967; Lenarczyk & Tsarenko 2013). My search for them in the Giant Mountains was unsuccessful.

Representatives of *Pediastrum* were noted in 50 of the 71 localities, in littoral zones, mainly of eutrophic water bodies. According to Parra (1971), the taxa of this genus are especially characteristic of small reservoirs, usually rich in biogenic substances. I did not note *Pediastrum* taxa in oligotrophic lowland peat bogs or in mountain localities including lakes, ponds, peat pools and bogs, nor in a mine effluent settling pond (very high conductivity – 19200 µS/cm) and a flooded quarry where very high carbonate or calcium concentrations probably effectively inhibited *Pediastrum* growth.

The most favourable conditions for many *Pediastrum* taxa were in eutrophic coastal lakes, where the numbers of taxa were highest (ca. 8). Burchardt *et al.* (2003) recorded six taxa from each of two coastal lakes (Jezioro Gardno, Jezioro Dołgie Wielkie). This type of lake is relatively large and shallow; there, water mixing and constant supply of biogens can support many green algae (Reynolds 1984 in: Burchardt *et al.* 2003). Similarly, Malicki (1972), Pasztaleniec & Poniewozik (2004) recorded many *Pediastrum* taxa from shallow lakes in south-eastern Poland, including Jezioro Uściwierz (mean depth 3.1 m) and Jezioro Sumin (2 m). Inflow of saline seawater possibly enriches the coastal lakes with some mineral compounds especially favourable for rare *Pediastrum* species such as *P. alternans* and *P. musteri*. Other rare species, including *P. argentinense* (as synonym *P. duplex* var. *cohaerens*), *P. longecornutum* (as synonym *P. biradiatum* var. *longecornutum*) and *P. obtusum*, were recorded from coastal lakes (Strzelecki & Półtorak 1971; Burchardt *et al.* 2003). I also noted many *Pediastrum* taxa in eutrophic fish ponds (ca. 6 taxa in each pond). This type of pond has been examined exhaustively in Poland in studies that included *Pediastrum* taxa (e.g. Krzeczkowska-Wołoszyn 1963; Bucka & Kyselowa 1967; Sitkowska 1992; Bucka & Wilk-Woźniak 2002).

Conditions for *Pediastrum* apparently were not favourable in the examined lowland lakes having mixed and forest catchments, where two taxa on average occurred. Wojciechowski (1971) recorded ten *Pediastrum* taxa in a paraoligotrophic lake (Jezioro Czarne-Sosnowickie) in south-eastern Poland. The lowland lakes were more often deeper and had lower trophy than the coastal lakes.

The habitat preferences of the *Pediastrum* taxa I noted sometimes differed from those given in the literature. *P. kawraiskyi*, *P. alternans* and *P. musteri* were associated mainly with eutrophic coastal lakes. According to Parra (1979), *P. kawraiskyi* occurs in fresh and brackish water; Komárek & Jankovská (2001) stated that it occurs mainly in oligo- or mesotrophic lakes. However, it was somewhat frequently found in eutrophic water bodies during both the present and previous studies in Poland. According to Komárek & Jankovská (2001), *P. alternans* requires large oligo- to mesotrophic lakes, but it has been noted in Polish water bodies of various trophy. *P. musteri* has been recorded from several localities worldwide, including lakes in dry, moderate and cold climate (Tell & Mataloni 1990; Tell 2004), a lake with high conductivity (Izaguirre & Vinocur 1994), and a lagoon (Comas & Perez 2002). According to Komárek & Jankovská (2001) it occurs sporadically in clear lakes in temperate climate.

In eutrophic fish ponds I observed *P. biradiatum*, *P. simplex* and *P. tetras* more often than other species. Parra (1979) and Komárek & Jankovská (2001) stated that *P. biradiatum* usually occurs in small water bodies. However, previously in Poland it was also observed in larger ones such as dam reservoirs, lakes and a lagoon (e.g. Kowalski 1975;

Bucka & Wilk-Woźniak 2002; Luścińska 2005; Wołowski & Grabowska 2007). Komárek & Jankovská (2001) noted that *P. simplex* and *P. tetras* occur in various water bodies, in agreement with previous Polish data.

The occurrence of most *Pediastrum* representatives was not connected with lowland lakes in the present study, but *P. angulosum* var. *angulosum* was noted only from such lakes, generally of lower trophy. According to Komárek & Fott (1983) it lives in small overgrown water bodies. As mentioned above, in my study the samples were collected from the littoral. Previous Polish localities of the taxon include paraoligo-, eu- and dystrophic stations in lakes, ponds and peat bogs (e.g. Raciborski 1889; Siemińska 1967; Wojciechowski 1971; Pasztaleniec & Poniewozik 2004). According to Weckström *et al.* (2009), however, *P. angulosum* is restricted to more dystrophic water.

Three taxa, *P. patagonicum*, *P. privum* and *P. integrum* var. *integrum*, occurred at single sampling stations. The first one was found in a eutrophic fish pond. Komárek & Jankovská (2001) noted the sparseness of data on the ecology of *P. patagonicum*, which occurs in clear lakes, probably not highly eutrophic. The latter two taxa occurred in a humoeutrophic lowland lake in a forest catchment, thus intermediate between dystrophic and meso- or eutrophic water bodies (Górniak 2006b). *P. privum* was previously observed only in a water body of rather low fertility (Pełechaty *et al.* 2007). World data suggest that it occurs mainly in clear, peaty or dystrophic water (Wołoszyńska 1917; Hegewald & Schnepf 1979; Komárek & Fott 1983; Starmach 1989; Komárek & Jankovská 2001; Geriš 2004), as well as in seawater (Hällfors 2004) and eutrophic ponds (An *et al.* 1999). In Poland, *P. integrum* var. *integrum* is recorded from eutrophic lakes, brackish water and seawater (e.g. Namysłowski 1924; Strzelecki & Półtorak 1971; Oleksowicz 1986; Pasztaleniec & Poniewozik 2004). According to Komárek & Jankovská (2001) and Weckström *et al.* (2009), however, *P. integrum* var. *integrum* usually occurs in oligo- and dystrophic water.

In my study, *P. boryanum* and *P. duplex* were not especially associated with particular types of water bodies but their varieties showed different preferences.

Some varieties of *P. boryanum*, including *boryanum*, *brevicorne*, *forcipatum* and *pseudoglabrum*, were connected mainly with eutrophic ponds and coastal lakes, whereas *cornutum*, *longicorne* and *perforatum* were found in lowland lakes in water with lower trophy more often than the other varieties. In previous Polish (e.g. Malicki 1972; Kotlińska 1976; Sitkowska 1992; Bucka & Wilk-Woźniak 2002; Pasztaleniec & Poniewozik 2004) and world studies (Parra 1979; Komárek & Jankovská 2001; Weckström *et al.* 2009), three varieties of *P. boryanum* (*boryanum*, *forcipatum*, *pseudoglabrum*) occur in various types of oligo- and eutrophic water bodies. According to Komárek & Jankovská (2001) the environmental requirements of *P. boryanum* var. *brevicorne* are not clear because many of its determinations in the literature are incorrect. Only two Polish records were verified from iconography as *P. boryanum* var. *brevicorne*, from a lake (Lucks 1906/1907) and a dam reservoir (Skalska 1984). Among the second group of *P. boryanum* varieties, var. *longicorne* is well documented in Polish papers referring it to various oligo-, eu- and dystrophic water bodies as well as brackish ones (e.g. Wołoszyńska 1925; Stefko 1976; Oleksowicz 1986; Picińska-Fałtynowicz 1997; Wołowski & Grabowska 2007). That information accords with my findings but differs from those of Komárek & Jankovská

(2001), who stated that *P. boryanum* var. *longicorne* is restricted to peaty water. They also maintained that var. *cornutum* is cosmopolitan and lives in eutrophic lakes and ponds, whereas var. *perforatum* is restricted to clear lakes and ponds of the northern temperate zone. The ecological requirements of *P. boryanum* var. *cornutum* and *P. boryanum* var. *perforatum* in Poland are poorly known.

All varieties of *P. duplex* were connected mainly with eutrophic and meso/eutrophic water bodies in my study. *P. duplex* var. *asperum* showed the clearest requirements with regard to water bodies; it was connected mostly with fish ponds. According to literature data, var. *asperum* occurs in plankton of small water bodies and swamps, *rugulosum* in various waters (Komárek & Fott 1983), *gracillimum* in large, not highly eutrophic lakes, and *duplex* is a typical plankton algal variety (Komárek & Jankovská 2001).

I observed *P. orientale* only in coastal lakes and ponds. Its recent and previous Polish localities are the first eutrophic ones; previously it was known only from a mountain brook (Skuja 1937) and a tarn (Nygaard 1977), as well as oligotrophic lakes in cold climate (Weckström *et al.* 2009).

Some of the *Pediastrum* taxa had a narrower ecological spectrum, and others were more adaptable to various environmental conditions. *P. boryanum* had the widest ecological spectrum, matching that of the whole genus with regard to all measured physical and chemical water parameters. Parra (1979) also mentioned that it can adapt to various conditions.

In my study the genus showed a general preference for water of higher conductivity and total hardness. However, 11 *Pediastrum* taxa (*P. alternans*, *P. boryanum* var. *boryanum*, *P. boryanum* var. *forcipatum*, *P. boryanum* var. *pseudoglabrum*, *P. duplex* var. *duplex*, *P. duplex* var. *rugulosum*, *P. kawraiskyi*, *P. orientale*, *P. simplex* var. *simplex*, *P. simplex* var. *echinulatum*, *P. tetras*) occurred over a wide spectrum of conductivity, 200–1700 µS/cm. Some taxa, including *P. angulosum* var. *angulosum*, *P. boryanum* var. *cornutum* and *P. tetras*, were found in water with lower conductivity, 46 µS/cm. Studies of *Pediastrum* taxa from subarctic water bodies showed that *Pediastrum* can occur in water of very low conductivity, 10–40 µS/cm (Weckström *et al.* 2009). Pasztaleniec & Poniewozik (2004) observed *Pediastrum* taxa in Polish waters at 400–700 µS/cm, and Bucka & Wilk-Woźniak (2002) found them at 200–900 µS/cm.

I recorded *Pediastrum* taxa from a wide range of total hardness, from very soft to hard (1.8–27.8°n) (Dojlido 1987). *P. angulosum* var. *angulosum*, *P. boryanum* var. *cornutum*, *P. integrum* and *P. privum* were associated with soft and very soft water. The taxa did not occur under high concentrations of calcium and magnesium, the main elements causing water hardness (Dojlido 1987). Many *Pediastrum* taxa (e.g. *P. alternans*, *P. boryanum* var. *pseudoglabrum*, *P. boryanum* var. *longicorne*) occurred under moderate carbonate hardness, 5–11°n. This suggests that the levels of calcium and magnesium carbonates and bicarbonates are important determinants of their occurrence. Further studies on the influence of various ions on *Pediastrum* growth are needed.

I recorded *Pediastrum* over a wide range of nitrate (<5.0–20.0 mg/dm^3) and orthophosphate (<0.15–1.50 mg/dm^3) concentrations. *P. angulosum* var. *angulosum*, *P. biradiatum* and its variety *biradiatum*, *P. integrum* var. *integrum*, *P. privum* and two varieties of *P. boryanum* (*cornutum*, *longicorne*) and *P. duplex* (*rugulosum*, *asperum*) were connected with lower values of nitrate (≤5.0 mg/dm^3) and orthophosphate (≤0.25 mg/dm^3) concentrations. Some taxa were found at high concentrations of nitrates (20.0 mg/dm^3: *P. boryanum* var. *boryanum*) or orthophosphates (1.50 mg/dm^3: *P. simplex* var. *simplex*, *P. boryanum* var. *boryanum*, *P. boryanum* var. *pseudoglabrum*, *P. boryanum* var. *forcipatum*, *P. duplex*, *P. tetras*). Many of the *Pediastrum* taxa I found were pollution-tolerant. A sampling station in a coastal lake (Jezioro Jamnno) near a sewer outlet, where the orthophosphate concentration was rather high (0.75 mg/dm^3), yielded 8 *Pediastrum* taxa. Komárek & Jankovská (2001) listed several taxa occurring only in clear water. Among them are *P. kawraiskyi*, *P. orientale* and *P. boryanum* var. *perforatum*, which I observed living under higher concentrations of nitrates (≥10.0 mg/dm^3) or orthophosphates (≥0.75 mg/dm^3). Luścińska (2005) noted *P. kawraiskyi* at a hypertrophic sampling station in Zalew Szczeciński lagoon, and Burchardt (1977) recorded *P. boryanum* var. *perforatum* from Jezioro Pątnowskie, a polluted lake. More studies on trophy requirements and pollution tolerance in *Pediastrum* are needed.

I observed *Pediastrum* taxa in water having neutral to basic pH (7.4–9.6). Matuła (1995) recorded *P. boryanum* and *P. tetras* from peaty water having pH 6 and pH 4, respectively. *P. integrum* var. *integrum*, *P. privum* and *P. angulosum* var. *angulosum* occurred at lower pH (ca. 8) than other *Pediastrum* taxa, but never in acidic water. Weckström *et al.* (2009) also found that *P. angulosum* was connected with lower pH (ca. 6). According to Komárek & Jankovská (2001) it is rather basiphilic and does not occur in peaty water, unlike *P. privum* which can be found in such water. Parra (1979) observed *P. integrum* and *P. angulosum* in acidic to neutral water. In the present study, *P. alternans*, *P. kawraiskyi* and *P. boryanum* var. *brevicorne* were the taxa most associated with higher pH (ca. 9). Pasztaleniec & Poniewozik (2004) observed *P. alternans* and *P. kawraiskyi* at pH 8.4–8.8, and Weckström *et al.* (2009) recorded *P. kawraiskyi* from water with higher pH.

My field studies were done only during summer seasons. Because of this it is impossible to verify the influence of water temperature on the growth of the *Pediastrum* taxa. The range of temperature at which I noted them was 15.7–26.3°C. According to Socha (1993), several common taxa (e.g. *P. boryanum*, *P. simplex*) occur even at a few degrees above 0°C. According to Komárek & Jankovská (2001), *P. simplex*, *P. boryanum* var. *forcipatum* and *P. boryanum* var. *brevicorne* are thermophilic, whereas *P. kawraiskyi* and *P. orientale* prefer cold water. Very useful in this regard would be long-term studies on the influence of temperature on *Pediastrum* growth in different climate zones.

The relative shares of *Pediastrum* and its representatives in the algal communities generally were low, under 3%. *Pediastrum* taxa had 4–10% shares at only five of my sampling stations: three in coastal lakes, one in a suburban pond and one in a fish pond. Only once was a 11–25% share noted, in an oxbow lake. Most of the taxa usually had ≤0.2% or 0.3–3% shares in the algal communities. *P. boryanum* had a 4–10% share in Jezioro Łebsko coastal lake and *P. simplex* had an 11–25% share in an oxbow of the Vistula river near Cracow. The higher shares mean that the two taxa have good conditions for growth in those water bodies, which are relatively shallow, have basic pH and high conductivity (1500–1700 µS/cm). Burchardt *et al.* (2003) reported a high share of

P. boryanum in the same coastal lake. More work is needed to determine whether other *Pediastrum* taxa achieve higher shares in the algal communities.

For a complete understanding of the conditions in which *Pediastrum* taxa live we need to know which groups of algal taxa accompany them. Various species of Cyanophyta (cyanoprokaryotes), Bacillariophyceae (diatoms) and Chrysophyceae (chrysophytes) often dominated in the water bodies I studied. *Pediastrum* co-existed mainly with Chlorophyta (green algae) of the orders Chlorococcales, Volvocales and Ulotrichales, as well as centric Bacillariophyceae and Cyanophyta, including Chroococcales, Oscillatoriales and Nostocales. According to Pasztaleniec & Poniewozik (2004), *Pediastrum* taxa are accompanied mainly by green algae and cyanoprokaryotes. Kowalski (1975) observed the genus together with diatoms and other green algae, Kowalska & Luścińska (2006) found them in algal communities dominated by cyanoprokaryotes and dinophytes, and Stefko (1976) reported them accompanied by cyanoprokaryotes. Besides the *Pediastrum* taxa, I identified 89 representatives of other groups of algae (Table 2). More detailed studies of the co-existence of *Pediastrum* with particular algal species are needed.

Nine taxa were not confirmed in my study: *P. simplex* var. *clathratum*, *P. simplex* var. *sturmii*, *P. subgranulatum*, *P. argentinense*, *P. obtusum*, *P. longecornutum*, *P. biradiatum* var. *glabrum*, *P. braunii* and *P. taylori*. Four of these, *P. subgranulatum*, *P. argentinense*, *P. longecornutum* and *P. braunii*, had been given only under invalid names. They were verified and synonymised in this work. All the taxa except *P. argentinense* were infrequently noted from Poland. According to Komárek & Jankovská (2001), all the taxa except *P. argentinense* are known from temperate climate.

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