Marcin Pliński
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Ilona Złoch

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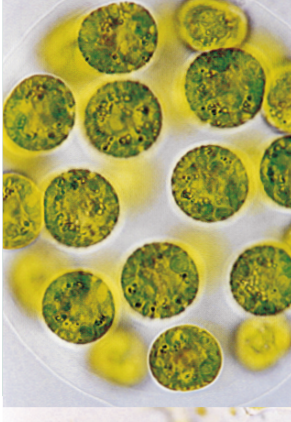
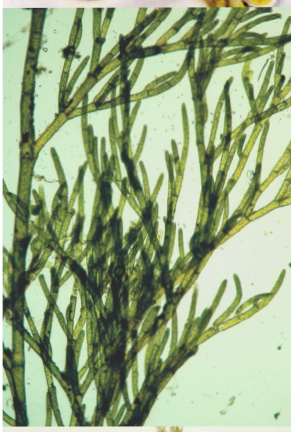
A key to the identification of the species





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Introduction

This book covers species from two divisions of algae that were formerly known as green algae. Thus, the contemporary taxonomy distinguishes two separate divisions: chlorophytes (Chlorophyta) and charophytes (Charophyta). The green algae is a very numerous group of algae, commonly present in various types of water bodies. Most species are typical of freshwater, but some are found only in the seas. Many of both groups live in brackish water. Hence, their large representation in the waters of the Gulf of Gdańsk. Due to the low salinity of this body of water, there are also many freshwater species with a significant tolerance range for salt concentration. Green algae species are characterized by a large morphological diversity. Among them there are monads, moreover rhizopodial, capsal, coccal, trychal and siphon forms. Coccal and monad forms usually occur in plankton, sometimes causing water blooms, while filamentous forms usually live attached to the ground with rhizoids, or float forming wadded clusters on the water surface. There are also forms that live in the tissues of plants and animals and others show adaptations to life on the ground.

This book lists the species of green algae recorded in the waters of the southern Baltic, the Gulf of Gdańsk and Puck Bay (Lakowitz 1907, 1929; Heitzmanówna 1923; Namysłowski 1924; Marchewianka 1925; Rumek 1948; Bursa 1935, 1937, 1938; Bursa et al. 1939; Kornaś et al. 1960; Biernacka 1967, 1968, 1970; Pliński 1975, 1979, 1982; Pliński & Giebułtowska-Mindak 1976; Ringer 1985; Pliński & Florczyk 1990; Pliński et al. 1992, 1996; Modzelewski & Pliński 1992; Pankow 1971, 1976, 1990; Kruk-Dowgiałło 1998; Kruk-Dowgiałło & Opioła 2001; Andrulewicz et al. 2004; Pliński & Jóźwiak 2004) and in offshore, brackish-water reservoirs, such as the Vistula and Szczecin Lagoons (Szarejko-Łukaszewicz 1957; Zembrzuska 1962; Pliński 1979). The list includes benthic and plankton species and epi- and endolithic and -phytic forms as well. Species occurring in the other Baltic parts (Nielsen et al. 1995; Hällfors 2004), especially those of the north-east regions, have been considered as a potentially for the algal flora in the southern Baltic.

The editorial scheme used in this book is typical for this type of publication and consists of several parts. The first part – the introduction – presents the thematic scope of the content of the book and indicates the items of literature in which individual species from the area that is the subject of this book are

described. The second detailed part is written in the form of identification keys for individual taxonomic units, starting from the most general ones, i.e. classes, through orders, families, genera and finally species. All essential diagnostic features are included in the keys relevant to a given taxonomic level, while the identification key for species provides data on size measurements for given species. These data are presented in two blocks and refer to the individual two groups of algae: chlorophytes and charophytes respectively. Each block begins with an introduction on the characteristics of a given group of algae with a description of views on the taxonomic system of this group and the taxonomic system for the genera included in this book is presented below. The most important part of this handbook is the tables with drawings and images of species. The work is provided with original photographs of selected taxa from samples collected in the Gulf of Gdańsk and adjacent regions of the Baltic Sea.

The authors express their gratitude to Prof. František Hindák, Prof. Mariusz Pełechaty, Dr Justyna Kobos and Mgr Grzegorz Kozłowski for original colour photographs of selected species of green algae and stoneworts, and to Prof. Joanna Żelazna-Wieczorek for verifying diagnostic descriptions for species belonging to the genus Vaucheria.

Chlorophytes

Division Chlorophyta is a large group of algae, very diverse in terms of morphology. Green algae most often have a grassy color, because they have the same photosynthetic pigments and in similar proportions as in higher plants. These are chlorophyll *a*, chlorophyll *b*, *β*-carotene, *α*-carotene, lutein and other xanthophylls. In some species, these pigments are masked by hematochrome. It is a specific mixture of carotenoids, distributed on the outer side of the chloroplasts, thanks to which it turns the entire cell red. In the cells of green algae, chloroplasts occur singly or are numerous. They have different shapes. When they are located near the cell wall, they are called wall chloroplasts, and when they are located in the center of the cell, they are called axial chloroplasts. Typically, the wall chloroplast is cup-shaped, i.e. it is thicker at the bottom of the cell. The storage product is starch. The cell wall is usually made of cellulose. Many green algae contain pectins in the outer layers of the cell wall. Chlorophytes are characterized by a great variety of types of reproduction. They show the ability of normal vegetative reproduction through cell division and fragmentation of the thallus. In addition, there is asexual reproduction with isomorphic and isodynamic zoospores and immobile aplanospores, and they reproduce sexually by isogamy, heterogamy and oogamy.

The basic morphological characteristics of green algae are: the ability to move in the vegetative stage, the morphological differentiation of the cell, the number of flagella in relation to the monad forms, the ability to form aggregated forms, the structure and form of colonies, the morphology of filaments, which can be single, branched or bladder-like and tube-shaped.

Monads form (Pedinophyceae, Mamiellophyceae, Nephroselmidiophyceae, Chlorodendrophyceae, Pyramimonadophyceae) are characterized by the fact that the cells are quadrangular or biconverse flattened, often with a depression where the flagella originate and are usually covered with organic scales. The number of flagella varies: one, two, four, eight, sometimes sixteen; the flagella are covered with delicate scales or short hairs, which give the impression that they are stiff and relatively thick; they are hetero- or homodynamic. Light olive green chloroplasts, one, less often two, straight or patchy; in the phycoma stage, they are numerous and disc-shaped. Often an eyespot is present.

The storage product is starch in the form of discoid-round pyrenoids or dispersed in chloroplasts.

Green algae belonging to the Chlorophyceae class are characterized by the fact that the cells are usually round or ovoid, sometimes with horns of various shapes (e.g., of the genus Brachiomonas), rarely naked, usually surrounded by a cellulose cell wall. They can appear singly or form clusters (colonies) or coenobia. The shape and size of the coenobium are characteristic of a given species. Cells in the coenobium do not divide and their number is fixed at the time of formation and does not increase with growth. The flagella are: one or two, four or sometimes eight, smooth, homodynamic. Bright green chloroplasts; in monad forms, usually one wall-like, cup-shaped, patchy, or mesh-like, with an eyespot mostly present. The storage product is starch in circular pyrenoids or dispersed in chloroplasts.

Chlorophytes of the class Ulvophyceae have a filamentous, lamellar or tubular structure. The order Ulotrichales which belongs to this class, includes species that form single-row, unbranched filaments composed of mononuclear cells. Cells are equipped with one wall chloroplast with one or more pyrenoids. Sometimes pyrenoids are missing. The cell walls are homogeneous or composed of H-shaped sections (as in the genus Microspora). Asexual reproduction is achieved by the fragmentation of filaments and by means of akinetes (= thickly covered vegetative cells) germinating directly or after a resting period, aplanospores (= non-motile zoospores) formed in parental cells usually in greater numbers, and micro- and macrozoospores, with 2 or 4 flagella. Sexual reproduction takes place by the copulation of double-filamented gametes or through oogamy.

Representatives of the order of Ulvales are characterized by the presence of a regular alternation of generations. The asexual generation – sporophyte and sexual generation – gametophyte are similar to each other or morphologically different. The sporophyte sometimes takes the form of a single-celled thallus, but usually, the sporophyte and gametophyte form a multi-celled thallus. They are macroscopic, tubular or flat, ribbon-shaped or leafy thalli. They can be branched or unbranched. Branches can be normal or prolificated (= new twigs or thalli developing on older filaments or thalli). The thalli are sessile at a young age, attached to the ground with a foot, sometimes reinforced with rhizoids, or a basal plate from which one or more erect shoots grow. Cells have one nucleus and one lamellar or cup-shaped chloroplast with one or more pyrenoids. Asexual reproduction is carried out with the help of 4-flagellated zoospores or aplanospores, and sexual reproduction is carried out by copulation of iso- or heterogametes with two flagellates.

Representatives of the order Prasiolales have filamentous, flat cylindrical or leafy thalli; they differ from the previous order by the presence of a centrally

located stellate chloroplast. Cells have one eccentric nucleus, tiny vacuoles and one chloroplast with a pyrenoid. Reproduction takes place by fragmentation of the thalli with akinetes and aplanospores, and by heterogamy (2-flagellated gametes present) and oogamy.

The order Chaetophorales includes filamentous, branched algae forming parenchymatous or pseudoparenchymatous thalli, spherical or flattened, sometimes in the form of cubic bundles. Cells contain one nucleus and one chloroplast. Reproduction occurs vegetatively by cell division, thallus fragmentation and the presence of akinetes, asexually with 2- or 4-flagellated zoospores, and sexually through isogamy, heterogamy and oogamy.

The order Oedogoniales includes filamentous algae, branched or unbranched, usually attached to the substrate by rhizoids produced by the basal cell. The cells are mononuclear, they contain one wall, reticular chloroplast, in which there are numerous pyrenoids and starch grains. A characteristic feature of this order is the presence of the apical rings or so-called collars, formed as a result of a specific division of vegetative cells as a remnant of the cell wall of the paternal cell. Asexual reproduction is carried out with the help of zoospores surrounded in the upper part of the flagellum wreath, and by the production of thick-walled akinetes. Sexual reproduction takes place by way of oogamy. Sexual reproductive organs, female, oogonium and male, antheridium, may occur on the same filament (monoecious individuals) or separate filament (dioecious individuals). In dioecious species, antheridial cells are produced on male filaments, which are either analogous to female filaments or strongly reduced. Antheridial cells are easily distinguishable. They are much shorter than vegetative cells and appear singly, but more often in series consisting of a certain number of cells, characteristic of a given species. Some species in the oogonium produce sperm cells that are unable to fertilize an egg, called androspores. Androspores usually settle down next to the oogonium and produce a short male filament composed of several cells. These creations are called dwarf-males. Androsporangial cells can exist singly or in series. They are formed either directly on the female filament or special androsporangial filaments. After the egg is fertilized, a spore zygote (oospore) is formed, which surrounds itself in three layers. The walls of the oospore can be smooth or structured in the form of spines, warts or dimples. This sculptation is a constant feature for individual species.

The order of Cladophorales includes algae with thalli composed of single, unbranched or branched filaments The thalli are usually large, visible to the naked eye, sometimes tiny, microscopic. The filaments may be rarely or profusely branched, but then there is no clear distinction between the main shoot and side branches. In terms of morphology, thalli in this order show great diversity and sometimes even the identification of genus is a difficult task. There are three types of morphological organization: 1. acropetal – thalli grow by

dividing the apical cells and then elongating them; 2. acropetal-basipetal – the upper part of the thallus grows at the top, and the lower one, by intercalary divisions downwards; 3. intercalar – the thallus only grows thanks to cell division in the middle parts of the filaments. The cells are mononuclear or multinucleated, they have a wall-like reticular chloroplast (which breaks up into tiny plates) with numerous pyrenoids. Reproduction takes place by the breakdown of filaments, proliferation of older wintering cells, formation of runners and with the help of akinetes, 2- or 4-flagellated zoospores, or by the copulation of double-flagellated iso- or heterogametes. Zoospores and gametes are formed in unchanged or only slightly swollen cells of the thallus.

A characteristic feature of the species included in the order Siphonales is the siphonous structure of the thallus, so their body is formed by a single coenocyte. They are single-celled, multi-nuclear algae, often richly branched and morphologically diverse. Chloroplasts are located along the wall and there are numerous nuclei closer to the interior of the cell. Only in the top, growing parts of the thallus, the arrangement of these two elements is reversed. Reproduction consists of the fragmentation of the thalli, the production of akinetes, aplanospores, zoospores and iso- or heterogametes. Some genera go through a change of generations. Algae included in this order are typically marine species, they are essentially absent in the flora of the Baltic Sea. The only genus that inhabits this environment is Vaucheria, which by some authors is included in the Xanthophyceae group. This is supported by the lack of chlorophyll *b* and a large number of carotenoids, the lack of starch as a storage product, and the formation and structure of the flagella in antheridium. These arguments are, however, open to debate. The prevalence of xanthophylls in the thallus is variable and depends on ecological conditions. Also, the lack of starch is not an important parameter, as some authors found the presence of starch, especially in constantly lit filaments. On the other hand, the production of synzoospores and oogons and antheridia of the genus Vaucheria have no equivalent in the Xanthophyceae class, but is present in filamentous green algae. For practical reasons, especially related to the anatomy of the thallus, i.e. the cellular structure, after Starmach (1972), the Vaucheriaceae family was included in this handbook.

The taxonomic system of green algae is still far from being ordered. This primarily applies to higher-level taxonomic units. The systematics in green algae is traditionally based on the morphology of cells and thalli, and on the types of reproduction (Brunnthaler 1915; Komárek & Fott 1983; Hindák 1977, 1980, 1984, 1988, 1990; Ettl 1983; Ettl & Gärtner 1988; John et al. eds. 2002). Thus, on the basis of the similarity of these features, Fritsch (1965) distinguished 9 orders, of which 3 related to non-filamentous green algae, and 6 refer to broadly understood filamentous green algae. Chadefaud (1960) divided the Chlorophyta type into 3 subtypes: Zygophyceae, Euchlorophyceae and Charophyceae.

A modification of this system is one proposed by Bourrelly (1966) and adopted by Starmach (1972), where 4 classes are distinguished: Euchlorophyceae, including unicellular or colony forms, but not thallious and non-filamentous; Ulotrichophyceae, including thalli and filamentous algae; Zygophyceae, are forms that reproduce by conjugation with non-flagellated gametes; Charophyceae, group together forms with large, varied thalli and helically twisted spermatozoids with two flagella. Contemporary taxonomic research on green algae conducted by Lewis & McCourt (2004) did not cause significant changes in the structure of the systematic system. They do indeed produce an independent, new Charophyta division, which includes, in addition to charaleans, also zygnemataleans and desmids. The species included in these units in each of the systems were distinguished from green algae at high levels of the system due to their biological specificity. Modern systems are supplemented with cell ultrastructure studies and molecular techniques are used, thanks to which additional taxonomic criteria were adopted, which led to the modification and many adjustments of the old systems. The new system based on the concept of a polyphasic approach, using molecular, ultrastructural, phenotypic and ecological studies, creates the foundations for the modern taxonomy of green algae. The taxonomic system used in this manual is based on the assumptions described by: Lewis & McCourt (2004), Brodie & Lewis (2007), Tsarenko et al. (2011), Leliaert et al. (2012), Fučiková et al. (2014), Archibald et al. (2017), Guiry & Guiry (2022).

Note to the users of this key: due to the advances in molecular research, some species have acquired a new taxonomic status, which has been highlighted in the key by underlining these new species names that are gradually coming into common use.

Division: Chlorophyta
- Class: Pedinophyceae
  - Order: Pedinomonadales
    - Family: Pedinomonadaceae
      - Genus: Pedinomonas, Resultomonas
  - Order: Scourfieldales
    - Family: Scourfieldaceae
      - Genus: Scourfieldia
- Class: Mamiellophyceae
  - Order: Mamiellales
    - Family: Mamiellaceae
      - Genus: Micromonas, Mantoniella
  - Order: Monomastigales
    - Family: Monomastigaceae

Genus: Monomastix
Class: Nephroselmidophyceae
Order: Nephroselmidales
Family: Nephroselmidaceae
Genus: Nephroselmis
Class: Chlorodendrophyceae
Order: Chlorodendrales
Family: Chlorodendraceae
Genus: Tetraselmis
Class: Pyramimonadophyceae
Order: Pyramimonadales
Family: Pyramimonadaceae
Genus: Pyramimonas
Family: Halosphaeraceae
Genus: Halosphaera, Pachysphaera
Family: Pterospermataceae
Genus: Pterosperma
Order: Pseudoscourfieldiales
Family: Pycnococcaceae
Genus: Pseudoscourfieldia
Class: Trebouxiophyceae
Order: Trebouxiales
Family: Botryococcaceae
Genus: Botryococcus
Order: Chlorellales
Family: Chlorellaceae
Genus: Chlorella, Closteriopsis, Dictyosphaerium, Dicellula, Actinastrum, Siderocelis, Micractinium, Acanthosphaera
Family: Oocystaceae
Genus: Quadricoccus, Eremosphaera, Oocystis, Granulocystis, Granulocystopsis, Siderocystopsis, Lagerheimia, Franceia, Trochiscia, Nephrocytium, Nephrochlamys, Tetrachlorella, Crucigeniella, Rayssiella, Planctonema
Order: Prasiolales
Family: Prasiolaceae
Genus: Prasiola, Rosenvingiella
Class: Chlorophyceae
Order: Chlamydomonadales
Family: Dunaliellacee
Genus: Dunaliella, Spermatozopsis
Family: Phacotaceae

Genus: Dysmorphococcus, Hemitoma, Phacotus, Pteromonas
Family: Chlamydomonadaceae
Genus: Carteria, Chlamydomonas, Lobomonas, Brachiomonas
Family: Haematococcaceae
Genus: Chlorogonium, Haematococcus
Family: Goniaceae
Genus: Gonium
Family: Volvocaceae
Genus: Pandorina, Eudorina, Volvox
Family: Tetrasporaceae
Genus: Tetraspora, Askenasyella
Family: Chlorangiellaceae
Genus: Chlorangiella
Family: Palmellopsidaceae
Genus: Pseudosphaerocystis, Chlamydocapsa
Family: Sphaerocystidaceae
Genus: Planctococcus
Order: Sphaeropleales
Family: Radiococcaceae
Genus: Eutetramorus, Coenocystis
Family: Schizochlamydacea
Genus: Schizochlamys, Planktosphaeria
Family: Treubariaceae
Genus: Treubaria
Family: Selenastraceae
Genus: Chlorolobion, Monoraphidium, Quadrigula, Kirchneriella, Ankistrodesmus, Selenastrum
Family: Cylindrocapsaceae
Genus: Fusola
Family: Schroederiaceae
Genus: Schroederia
Family: Characiaceae
Genus: Ankyra, Korshikoviella, Characium
Family: Hydrodictiaceae
Genus: Tetraëdron, Hydrodictyon, Pediastrum, Sorastrum
Family: Scenedesmaceae
Genus: Westella, Dimorphococcus, Coelastrum, Tetradesmus, Enallax, Scenedesmus, Desmodesmus, Tetrastrum, Pseudotetrastrum, Hofmania, Willea
Family: Neochloridaceae
Genus: Golenkinia, Botryosphaerella

Family: Mychonastaceae
Genus: Mychonastes
Order: Chaetophorales
Family: Chaetophoraceae
Genus: Chaetophora, Stigeoclonium
Family: Aphanochaetaceae
Genus: Aphanochaete
Order: Oedogoniales
Family: Oedogoniaceae
Genus: Oedogonium, Bulbochaete
Class: Ulvophyceae
Order: Ulotrichales
Family: Ulotrichaceae
Genus: Capsosiphon, Ulothrix, Urospora, Spongomorpha, Acrosiphonia
Family: Monostromaceae
Genus: Monostroma
Family: Gomontiaceae
Genus: Gomontia, Eugomontia
Family: Planophilacae
Genus: Planophila
Order: Ulvales
Family: Ulvaceae
Genus: Percursaria, Ulva, Ochlochaete, Epicladia
Family: Kornmanniaceae
Genus: Blidingia, Pseudendoclonium
Family: Bolbocoleonaceae
Genus: Bolbocoleon
Family: Phaeophillaceae
Genus: Phaeophila
Family: Ulvellaceae
Genus: Ulvella
Order: Cladophorales
Family: Cladophoraceae
Genus: Rhizoclonium, Chaetomorpha, Cladophora

This handbook is an important item in the taxonomic literature for green algae. As the latest taxonomy is adopted here, it is a valuable source of systematics of this group of algae. It covers the species that have so far been recorded in the waters of the Gulf of Gdańsk and the neighbouring waters of the Southern Baltic Sea. The low salinity of the Baltic Sea causes a unique composition of the algae flora, including both marine and limnetic species with a wide range of salinity tolerance. This handbook comprises this variety of species occurring in brackish waters and may be useful to a wide audience not only in the Baltic Sea but also in other brackish waters of the temperate and boreal zones. It fills the gap between identification books dealing solely with either marine or fresh-water species. Moreover, it comprises all types of chlorophytes, which are highly different in shape and complexity, reaching from unicellular or colonial planktonic forms to filamentous or leaf-shaped benthonic organisms. Chlorophytes and charophytes are important bioindicators of environmental changes. This publication is a valuable tool for species identification that is needed by specialized students and researchers, dealing with multi-faceted ecological research such as environmental monitoring, biodiversity, food web interactions and aquatic ecosystem management, which is especially important in controlling changes related to climate instability.

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