





PHYTOPLANKTON DIVERSITY IN THE LAKES OF THE DRAWIEŃSKI NATIONAL PARK

RYSZARD GOŁDYN, ELŻBIETA SZELĄG-WASIELEWSKA

R. Gołdyn, E. Szeląg-Wasielewska, Department of Water Protection, Faculty of Biology, Adam Mickiewicz University in Poznań, Uniwersytetu Poznańskiego 6, 61-614 Poznań, Poland, e-mail: rgold@amu.edu.pl, eszelag@amu.edu.pl; RG  <https://orcid.org/0000-0001-8325-5161>, ES-W  <https://orcid.org/0000-0002-7542-6490>

ABSTRACT. This is the first comprehensive analysis of the taxonomic composition of phytoplankton in 16 lakes in the Drawieński National Park. It covers phytoplankton from the spring and summer, mainly of 1997, taking into account its dominance structure in individual lakes. Taxonomic similarities in the phytoplankton of the studied lakes, the Shannon-Wiener Diversity Index, and the Pielou Evenness Index were calculated. A total of 439 taxa belonging to 10 phyla were found. The most taxa belonged to the Chlorophyta (151), while Heterokontophyta (134) also exhibited high species richness. This high taxonomic diversity resulted from the considerable diversity of the lakes, in terms of trophic, hydrological, morphological, morphometric and catchment characteristics. Most lakes were characterised by high values of Shannon-Wiener Diversity Index (above 2) and Pielou Evenness Index (above 0.5), indicating the high naturalness of the habitats in the studied lakes.

KEYWORDS: algae, cyanobacteria, postglacial lakes, dystrophic lakes, meromictic lake, rare species

INTRODUCTION

The lakes of the Drawieński National Park (DNP) are a highly diverse group of lakes, both in terms of morphometry and trophic state. Their diversity and the unique characteristics of some of them are a valuable feature and asset of the Park, which aims to protect a wide variety of ecosystems (Kraska 1997). There are 20 lakes within the Park, and their diversity is particularly evident in their catchment area and water table, water volume, depth, lake basin shape, water mixing patterns, and the state of aquatic biocenoses, including macrophytes and microphytes. The latter, freely and passively floating in the water column and called phytoplankton, have so far been the subject of few publications on DNP lakes (Szeląg-Wasielewska et al. 2000, Gołdyn & Szeląg-Wasielewska 2004, Joniak & Kraska 2006), in contrast to vascular plants and macroscopic algae from charophytes, as well as the chemical composition of water and hydrological regime (e.g. Kraska 1997, Szyper & Kraska 1999, Kraska et al. 2000, Szeląg-Wasielewska et al. 2000, Kraska et al. 2001, 2002, Piotrowicz et al. 2006, Czerniawski et al. 2010, Grześkowiak et al. 2010, Jasnowska & Wróbel 2010, Klimaszuk et al. 2010,

Ławniczak et al. 2012, Piątkowska & Ziarnek 2024). These articles analysed the physicochemical characteristics of waters, the specificity of the catchment area, macrophytes, and the assessment of external load on lakes. One of these publications concerned phytoplankton versus trophic state of sixteen DNP lakes, but it focused on the relationships between phytoplankton biomass (expressed as chlorophyll-a concentration) and several habitat parameters, including nutrients (Szeląg-Wasielewska et al. 2000). Some publications present several lakes within the Park (Kraska et al. 2001, Gołdyn & Szeląg-Wasielewska 2004, Joniak & Kraska 2006), and sometimes only a single selected lake (Szeląg-Wasielewska 2004, Kuczyńska-Kippen et al. 2006). Moreover, the water quality of some DNP lakes was monitored by the state environmental protection services, and their results were published in the Polish Environmental Monitoring Library (Cydzik et al. 1995, Stan czystości... 1998), however, they contain little information on phytoplankton communities in the pelagic zone of the lakes.

As the first link in the trophic chains of aquatic ecosystems, the phytoplankton community plays a key role in the pelagic zone of lakes. It is the primary

producer of organic matter, provides food for many invertebrates, and interacts with aquatic bacteria and fungi. From a functional perspective, phytoplankton primarily includes photoautotrophic cells, sometimes also mixotrophic and heterotrophic (Kajak 1998, Lampert & Sommer 2001). Taxonomically, phytoplankton communities can be composed of organisms belonging to multiple phyla, which in turn contributes to its high taxonomic diversity, thus ensuring the stable functioning of the pelagic zone of lakes (Kawecka & Eloranta 1994, Reynolds 2009).

Most of the lakes in the Drawieński National Park are located in its eastern part. These include the flow-through lakes Sitno, Płociczno, the northern part of Lake Ostrowiec, and Lake Jamno. Most of the lakes in the Park are endorheic. These are primarily harmonic lakes, namely Lakes Marta, Płociowe, Piaseczno Duże, Zdroje, Kocie, Perkoz, and Pustelnia. There are also dystrophic lakes: Lake Piaseczno Małe, Lake Głodne 2, and Lake Głodne 3, whose phytoplankton was also studied in 1999–2002 and 2004 (Joniak & Kraska 2006, Kuczyńska-Kippen et al. 2006, Joniak et al. 2010). Lake Czarne proved to be an exceptional water body in terms of water mixing, where meromixis was observed (Kraska 1997, Kraska et al. 2002, Klimaszuk et al. 2010). Furthermore, due to the presence of specific microbial communities, the size structure of its phytoplankton, including picoplankton, was analysed in depth, with the study repeated in 1998 (Szelaż-Wasielewska 2005a, b). In the second, western part of the Park, there are only a few lakes, of which Lake Moczele was included in this phytoplankton studies.

The aim of this publication is to present the taxonomic structure of phytoplankton in 16 lakes located within the DNP. The results of phytoplankton studies mainly from 1997, previously unpublished in their full scope, are presented. Furthermore, the lakes are assessed and compared using biodiversity indicators,

with attention also paid to the spatial variability of phytoplankton within the lakes. This article is the first comprehensive study of the phytoplankton of the lakes of the Drawieński National Park. It covers a large number of lakes studied simultaneously, during spring and summer, the two most important seasons for their functioning. It also enriches knowledge on the taxonomic composition of algae and cyanobacteria in lakes in Polish national parks (Burchardt et al. 2004, Messyasz et al. 2011, Ławniczak et al. 2016). These results may also be useful for assessing changes in the lake ecosystems of the DNP in subsequent studies conducted years later, using the same research methods.

METHODS

Samples for analysis of phytoplankton species composition and abundance were collected from 16 lakes at 20 stations (Table 1). In most lakes, water samples were collected at a single station in the deepest part of the lake. In Lake Ostrowiec, samples were collected at four stations, and in Lake Marta, at two stations (Fig. 1).

Samples for study from 15 lakes were collected in 1997, once in spring (between April 7 and 12) and once in summer (between July 15 and 25). Furthermore, in 1998, one sample was collected from Lake Moczele on March 20 and July 28. Samples were collected every 1 m in the water column using a Toń sampler and then integrated within each thermal layer of the lake, depending on the summer stratification profile. In spring, during water mixing, one integrated sample was collected from each shallow lake, and two integrated samples were collected from the deep lakes: the first from the 5 m thick water layer, and the second from the remaining layer. The samples were fixed with Lugol's solution acidified with sodium acetate (Starmach 1963). In the laboratory,

Table 1. Morphometric data of the studied lakes (acc. to Kraska et al. 2002, changed)

Name of the lake	Abbreviation	Surface area (ha)	Max. depth (m)	Mean depth (m)	Volume (10 ³ m ³)
Ostrowiec	OsL	387.6	28.5	9.4	36433.1
Sitno	SiL	67.2	7.0	4.0	2666.7
Marta	MaL	66.1	25.0	7.7	5111.4
Piaseczno Duże	PDL	58.7	25.9	7.6	4519.2
Płociczno	PL	56.1	5.2	2.7	1530.9
Płociowe	PiL	35.3	25.0	10.3	3620.0
Jamno	JaL	27.6	9.2	3.5	967.9
Zdroje	ZdL	21.3	4.8	2.9	612.1
Czarne	CzL	19.1	29.0	11.5	2196.5
Piaseczno Małe	PML	8.0	6.8	3.2	258.4
Pustelnia	PuL	2.7	5.1	2.4	65.8
Moczele	MoL	2.5	1.5	0.7	17.5
Kocie	KoL	2.4	2.9	1.3	30.2
Perkoz	PeL	1.34	4.6	2.1	27.7
Głodne 3	G3L	0.65	6.8	3.1	19.9
Głodne 2	G2L	0.64	6.8	3.1	19.6

Taxon name	OsL	SiL	MaL	PDL	PL	PiL	JaL	ZdL	CzL	PML	PuL	MoL	KoL	PeL	G3L	G2L	Frequency
<i>Dolichospermum mendotae</i> (W.Trelease) Wacklin, L. Hoffmann & Komárek	*	1
<i>Dolichospermum solitarium</i> (Klebahn) Wacklin, L. Hoffmann & Komárek	*	*	2
<i>Dolichospermum spiroides</i> (Klebahn) Wacklin, L. Hoffmann & Komárek	*	.	*	.	.	.	*	*	.	.	4
<i>Dolichospermum</i> sp.	*	*	2
<i>Eucapsis minima</i> (Keissler) Pliński & Komárek	*	*	*	.	.	.	3
<i>Gleocapsa</i> sp.	*	1
<i>Gomphosphaeria</i> sp.	*	*	2
<i>Jaaginema geminatum</i> (Schwabe ex Gomont) Anagnostidis & Komárek	*	1
<i>Johanseninema constrictum</i> (Szafer) Hasler, Dvorák & Poulícková	*	*	2
<i>Komvophoron minutum</i> (Skuja) Anagnostidis & Komárek	*	.	*	.	.	*	***	4
<i>Limnothrix planctonica</i> (Woloszyńska) Meffert	*	1
<i>Limnothrix redekei</i> (Goor) Meffert	*	.	.	.	*	***	.	.	*	.	.	4
<i>Lyngbya</i> sp.	*	**	.	.	2
<i>Merismopedia tenuissima</i> Lemmermann	*	.	.	.	**	.	**	.	.	.	***	4
<i>Merismopedia tranquilla</i> (Ehrenberg) Trevisan	.	*	1
<i>Microcystis aeruginosa</i> (Kützing) Kützing	*	*	*	*	.	*	.	*	.	.	6
<i>Microcystis wesenbergii</i> (Komárek) Komárek ex Komárek	*	.	.	*	.	.	2
<i>Oscillatoria obliquaeacuminata</i> Skuja	**	.	.	.	1
<i>Oscillatoria tenuis</i> C. Agardh ex Gomont	*	1
<i>Oscillatoria</i> sp.	*	*	*	3
<i>Phormidium granulatum</i> (N.L. Gardner) Anagnostidis	.	*	1
<i>Phormidium</i> sp.	*	1
<i>Planktolyngbya limnetica</i> (Lemmermann) Komárková- Legnerová & Cronberg	.	.	*	1
<i>Planktothrix agardhii</i> (Gomont) Anagnostidis & Komárek	*	*	.	.	*	*	***	.	.	.	*	.	.	*	.	.	7
<i>Pseudanabaena limnetica</i> (Lemmermann) Komárek	.	.	*	.	.	*	2
<i>Pseudanabaena</i> sp.	*	.	.	.	1
<i>Radiocystis geminata</i> Skuja	.	.	.	*	**	.	.	*	*	.	.	4
<i>Rhabdoderma lineare</i> Schmidle & Lauterborn	.	.	*	*	2
<i>Snowella lacustris</i> (Chodat) Komárek & Hindák	.	.	*	.	.	**	2
<i>Snowella rosea</i> (J.W. Snow) Elenkin	.	*	1
<i>Synechocystis aquatilis</i> Sauvageau	.	*	1
<i>Synechocystis salina</i> Wisłouch	***	1
<i>Synechocystis</i> sp.	**	.	.	1
<i>Trichodesmium lacustre</i> Klebahn	*	.	.	.	1
Euglenophyta																	
Euglenophyceae																	
<i>Colacium vesiculosum</i> Ehrenberg	*	1
<i>Euglena</i> sp. 1	*	*	.	.	*	*	*	*	.	.	.	*	7
<i>Euglena</i> sp. 2	*	1
<i>Euglenaformis proxima</i> (P.A. Dangeard) M.S. Bennett & Triemer	*	.	*	.	.	2
<i>Lepocinclis acus</i> (O.F. Müller) B. Marin & Melkonian	*	*	*	*	*	*	.	.	6
<i>Lepocinclis oxyuris</i> (Schmarda) B. Marin & Melkonian	*	.	.	*	*	.	.	3
<i>Monomorphina pyrum</i> (Ehrenberg) Mereschkowsky	*	.	.	.	*	.	*	.	.	.	*	.	.	*	.	.	5
<i>Phacus</i> sp.	*	*	2
<i>Phacus acuminatus</i> A. Stokes	*	*	.	.	*	*	.	.	3
<i>Phacus longicauda</i> (Ehrenberg) Dujardin	*	.	.	.	*	*	*	.	*	*	.	.	5
<i>Phacus orbicularis</i> Hübner	*	1

Taxon name	OsL	SiL	MaL	PDL	PL	PiL	JaL	ZdL	CzL	PML	PuL	MoL	KoL	PeL	G3L	G2L	Frequency
<i>Strombomonas acuminata</i> (Schmarda) Deflandre	.	.	*	1
<i>Trachelomonas dybowskii</i> Dreżepolski	.	*	.	.	*	*	*	4
<i>Trachelomonas hispida</i> (Perty) F. Stein	*	*	.	.	*	.	*	*	.	.	.	5
<i>Trachelomonas lukowiensis</i> Dreżepolski	*	1
<i>Trachelomonas rotunda</i> var. <i>collaris</i> (Skvortzov) T.G. Popova	*	1
<i>Trachelomonas volvocina</i> (Ehrenberg) Ehrenberg	*	*	*	.	*	*	.	*	.	.	*	7
<i>Trachelomonas volvocinopsis</i> Svirenko	.	*	*	2
<i>Trachelomonas</i> sp. 1	*	*	2
<i>Trachelomonas</i> sp. 2	*	*	.	*	.	.	.	3
Anisonemea																	
<i>Distigma curvatum</i> E.G. Pringsheim	*	.	.	.	*	*	3
<i>Distigma</i> sp.	*	1
<i>Menoidium tortuosum</i> (A. Stokes) Lemmermann	*	1
Cryptista, Cryptophyceae																	
<i>Chroomonas</i> sp.	.	.	.	*	**	2
<i>Cryptomonas curvata</i> Ehrenberg	*	**	*	.	*	*	*	*	*	*	*	*	*	*	.	*	14
<i>Cryptomonas gracilis</i> Skuja	.	.	*	1
<i>Cryptomonas marssonii</i> Skuja	**	**	*	*	*	*	**	*	*	**	*	*	**	**	*	*	16
<i>Cryptomonas obovata</i> Skuja	.	**	*	.	.	*	*	.	.	**	*	.	*	.	.	*	8
<i>Cryptomonas ovata</i> Ehrenberg	*	**	*	.	*	*	*	*	*	*	**	*	*	*	*	*	15
<i>Cryptomonas paramaecium</i> (Ehrenberg) Hoef-Emden & Melkonian	*	*	2
<i>Cryptomonas phaseolus</i> Skuja	**	**	*	.	**	*	***	.	.	**	**	.	.	*	.	*	10
<i>Cryptomonas pyrenoidifera</i> Geitler	*	**	*	.	*	*	*	*	*	*	*	**	*	*	**	*	15
<i>Cryptomonas tenuis</i> Pascher	**	1
<i>Cryptomonas tetrapyrenoidosa</i> Skuja	.	*	1
<i>Cryptomonas woloszynskae</i> J. Czosnowski	*	*	2
<i>Cryptomonas</i> sp. 1	*	.	.	*	*	*	.	.	.	*	.	.	5
<i>Cryptomonas</i> sp. 2	.	.	.	*	*	.	.	2
<i>Komma caudata</i> (L. Geitler) D.R.A. Hill	*	.	.	1
<i>Plagioselmis lacustris</i> (Pascher & Ruttner) Javornicky	**	**	**	**	**	**	**	**	**	*	*	.	**	***	.	*	14
<i>Rhodomonas lens</i> Pascher & Ruttner	***	***	.	.	**	**	.	.	*	**	.	.	6
<i>Rhodomonas tenuis</i> Skuja	*	*	.	.	2
Dinoflagellata, Dinophyceae																	
<i>Amphidinium</i> sp.	*	*	.	.	2
<i>Ceratium cornutum</i> (Ehrenberg) Claparède & J. Lachmann	*	*	.	.	2
<i>Ceratium furcoides</i> (Levander) Langhans	*	.	*	.	.	.	*	*	.	.	4
<i>Ceratium hirundinella</i> (O.F. Müller) Dujardin	*	.	.	*	*	.	.	*	*	*	*	*	.	*	.	.	9
<i>Ceratium hirundinella</i> f. <i>austriacum</i> (Zederbauer) Bachmann	*	.	*	.	.	*	*	.	.	4
<i>Glennodinium uliginosa</i> (A.J. Schilling) Wołoszyńska	*	1
<i>Gymnodinium fuscum</i> (Ehrenberg) F. Stein	*	*	*	*	*	*	6
<i>Gymnodinium simile</i> Skuja	*	1
<i>Gymnodinium</i> sp. 1	*	*	.	*	*	*	*	*	*	*	*	**	*	*	.	.	13
<i>Gymnodinium</i> sp. 2	*	*	.	*	*	*	.	.	.	5
<i>Gymnodinium</i> sp. 3	*	1
<i>Parvodinium inconspicuum</i> (Lemmermann) Carty	*	*	*	.	**	*	*	*	**	.	8
<i>Parvodinium umbonatum</i> (F. Stein) Carty	**	.	1
<i>Peridiniopsis</i> sp.	*	1
<i>Peridinium cinctum</i> (O.F. Müller) Ehrenberg	.	.	.	*	1
<i>Peridinium williei</i> Huitfeldt-Kaas	.	*	*	.	.	*	3
<i>Peridinium</i> sp. 1	*	.	.	*	*	.	*	.	.	*	*	*	*	.	.	.	8
<i>Peridinium</i> sp. 2	*	1

Taxon name	OsL	SIL	MaL	PDL	PL	PiL	JaL	ZdL	CzL	PML	PuL	MoL	KoL	PeL	G3L	G2L	Frequency
Choanozoa, Choanpflagellata																	
<i>Monosiga ovata</i> Kent	**	.	*	.	.	.	*	3
<i>Salpingoeca ruttneri</i> (Bourrelly) Bourrelly	*	*	.	.	.	*	3
<i>Salpingoeca skujae</i> Tikhonenkov & Mazei	*	1
<i>Salpingoeca</i> sp.	*	1
Bigyra, Bicosoecophyceae																	
<i>Bicosoeca planctonica</i> Kisselev	*	.	.	.	*	*	*	.	.	.	*	5
<i>Bicosoeca</i> sp.	*	.	.	*	*	3
Haptophyta, Coccolithophyceae																	
<i>Chrysochromulina parva</i> Lackey	***	***	**	**	**	**	***	**	**	.	.	*	.	**	.	.	11
Heterokontophyta																	
Raphidophyceae																	
<i>Gonyostomum semen</i> (Ehrenberg) Diesing	*	*	*	3
Chrysophyceae																	
<i>Chromulina</i> sp.	*	**	.	**	*	***	**	.	6
<i>Chrysococcus punctiformis</i> Pascher	*	.	.	.	1
<i>Chrysococcus rufescens</i> G.A. Klebs	*	**	.	.	**	.	*	4
<i>Chrysococcus skujae</i> Heynig	*	1
<i>Chrysococcus triporus</i> B. Mack	***	***	*	.	***	*	*	*	*	*	.	.	9
<i>Chrysococcus</i> sp. 1	*	*	.	*	**	.	*	*	.	.	6
<i>Chrysococcus</i> sp. 2	*	.	.	*	.	.	2
<i>Chrysolykos planctonicus</i> B. Mack	*	.	.	.	*	2
<i>Chrysolykos</i> sp.	.	.	.	*	1
<i>Chrysopora fenestrata</i> Pascher	.	.	.	*	1
<i>Dinobryon bavaricum</i> Imhof	.	*	*	**	.	*	**	*	.	.	6
<i>Dinobryon borgei</i> Lemmermann	*	1
<i>Dinobryon crenulatum</i> West & G.S. West	*	.	*	.	.	.	*	**	**	.	**	.	*	.	.	.	7
<i>Dinobryon cylindricum</i> O.E. Imhof	.	.	**	**	.	.	*	*	*	5
<i>Dinobryon cylindricum</i> var. <i>palustre</i> Lemmermann	*	1
<i>Dinobryon divergens</i> O.E. Imhof	**	**	*	*	*	*	**	*	*	.	***	**	.	*	.	.	11
<i>Dinobryon divergens</i> var. <i>schauinslandii</i> (Lemmermann) Brunthaler	*	*	2
<i>Dinobryon faculiferum</i> Willén	**	1
<i>Dinobryon pediforme</i> (Lemmermann) Steinecke	**	***	2
<i>Dinobryon sertularia</i> Ehrenberg	*	.	***	*	3
<i>Dinobryon sociale</i> (Ehrenberg) Ehrenberg	*	.	*	.	*	**	.	*	.	.	*	***	*	*	.	.	9
<i>Dinobryon sociale</i> var. <i>americanum</i> (Brunnthaler) Bachmann	**	*	**	.	.	*	4
<i>Dinobryon spirale</i> Iwanoff	.	*	.	.	*	.	*	3
<i>Dinobryon stipitatum</i> Stein	*	*	*	3
<i>Dinobryon suecicum</i> Lemmermann	*	1
<i>Dinobryon</i> sp.	*	1
<i>Epipyxis polymorpha</i> (J.W.G. Lund) D.K. Hilliard & Asmund	.	.	*	1
<i>Epipyxis tabellariae</i> (Lemmermann) G.M. Smith	.	.	*	1
<i>Kephyrion densatum</i> (Gerlinde Schmid) Bourrelly	*	1
<i>Kephyrion inconstans</i> (Gerlinde Schmid) Bourrelly	*	1
<i>Kephyrion littorale</i> J.W.G. Lund	.	*	*	.	.	*	3
<i>Kephyrion moniliferum</i> (Gerlinde Schmid) Bourrelly	*	.	*	*	.	*	*	5
<i>Kephyrion ovale</i> (Lackey) Huber-Pestalozzi	*	1
<i>Kephyrion petasatum</i> Conrad	*	*	*	.	.	.	*	.	.	.	4
<i>Kephyrion rubri-claustri</i> Conrad	*	1
<i>Kephyrion spirale</i> (Lackey) Conrad	.	.	*	*	2
<i>Kephyrion valkanovii</i> Huber-Pestalozzi	*	**	.	.	*	*	*	*	.	.	**	.	.	*	.	.	8
<i>Kephyrion</i> sp.	*	.	.	*	**	.	.	*	*	.	.	.	5

Taxon name	OsL	SIL	MaL	PDL	PL	PiL	JaL	ZdL	CzL	PML	PuL	MoL	KoL	PeL	G3L	G2L	Frequency
<i>Gogorevia exilis</i> (Kützing) Kulikovskiy & Kociolek	*	1
<i>Gomphonella olivacea</i> (Hornemann) Rabenhorst	*	.	*	*	3
<i>Gomphonema constrictum</i> Ehrenberg	.	*	1
<i>Gomphonema coronatum</i> Ehrenberg	*	1
<i>Gomphonema parvulum</i> (Kützing) Kützing	*	1
<i>Gomphonema</i> sp.	.	.	*	.	*	.	*	*	.	.	.	*	.	*	.	.	6
<i>Hippodonta capitata</i> (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski	.	*	*	*	.	*	4
<i>Meridion circulare</i> (Greville) C. Agardh	.	*	.	.	*	2
<i>Navicula cryptocephala</i> Kützing	.	*	*	.	.	*	3
<i>Navicula radiosa</i> Kützing	*	*	.	.	*	*	.	*	.	*	.	.	*	*	.	.	8
<i>Navicula rhynchocephala</i> Kützing	.	.	*	*	2
<i>Navicula tripunctata</i> (O.F. Müller) Bory	.	*	*	.	*	.	*	*	5
<i>Navicula viridula</i> (Kützing) Ehrenberg	.	.	*	1
<i>Navicula</i> sp.	*	.	*	.	*	*	.	.	.	4
<i>Nitzschia acicularis</i> (Kützing) W. Smith	**	**	.	.	**	*	.	*	.	.	*	.	*	.	*	.	8
<i>Nitzschia acicularis</i> var. <i>closterioides</i> Grunow	*	***	.	.	**	.	.	*	4
<i>Nitzschia dissipata</i> (Kützing) Rabenhorst	.	*	*	2
<i>Nitzschia holsatica</i> Hustedt	**	**	.	.	*	3
<i>Nitzschia recta</i> Hantzsch	.	.	*	1
<i>Nitzschia</i> sp.	*	*	*	*	*	.	.	.	*	*	.	.	7
<i>Odontidium elongatum</i> var. <i>actinastroides</i> (Willi Krieger) R.M. Patrick	*	1
<i>Planothidium lanceolatum</i> (Brébisson ex Kützing) Lange-Bertalot	*	*	2
<i>Rhoicosphenia abbreviata</i> (C. Agardh) Lange-Bertalot	.	*	.	.	*	2
<i>Stausosira construens</i> Ehrenberg	**	*	*	*	.	*	5
<i>Stausosira venter</i> (Ehrenberg) Cleve & J.D. Möller	.	**	.	.	*	2
<i>Stausosirella martyi</i> (Héribaud) Morales & Manoylov	.	.	*	.	.	*	2
<i>Surirella librile</i> (Ehrenberg) Ehrenberg	*	1
<i>Synedra bipes</i> Roll	*	1
<i>Synedra</i> sp.	*	***	*	.	.	***	*	.	.	.	5
<i>Tabellaria flocculosa</i> (Roth) Kützing	*	.	*	2
<i>Tabellaria flocculosa</i> var. <i>asterionelloides</i> (Grunow) Knudson	*	1
<i>Tabularia tabulata</i> (C. Agardh) Snoeijs	*	1
<i>Ulnaria acus</i> (Kützing) Aboal	*	**	*	.	*	*	**	.	*	.	*	**	*	*	.	.	11
<i>Ulnaria biceps</i> (Kützing) Compère	*	.	.	.	1
<i>Ulnaria capitata</i> (Ehrenberg) Compère	*	1
<i>Ulnaria danica</i> (Kützing) Compère & Bukhtiyarova	*	1
<i>Ulnaria delicatissima</i> var. <i>angustissima</i> (Grunow) Aboal & P.C. Silva	*	*	*	.	*	*	*	*	.	.	*	.	.	*	.	.	9
<i>Ulnaria ulna</i> (Nitzsch) Compère	*	*	.	.	*	.	*	4
<i>Tabellaria</i> sp.	*	1
Xanthophyceae																	
<i>Botrydiopsis arhiza</i> Borzi	.	*	**	**	3
<i>Centrtractus ellipsoideus</i> Starmach	.	.	*	*	.	*	*	*	*	*	**	8
<i>Pseudogoniochloris tripus</i> (Pascher) Krienitz, E. Hegewald, Reymond & Peschke	*	*	2
<i>Ophiocytium capitatum</i> Wolle	*	1
Eustigmatophyceae																	
<i>Chloridella cystiformis</i> Pascher	.	.	*	***	***	3
<i>Goniochloris mutica</i> (A. Braun) Fott	.	*	1
<i>Goniochloris</i> sp.	*	.	.	1
<i>Tetraëdriella jovetii</i> (Bourrelly) Bourrelly	*	.	*	.	.	.	*	.	.	3

Taxon name	OsL	SIL	MaL	PDL	PL	PiL	JaL	ZdL	CzL	PML	PuL	MoL	KoL	PeL	G3L	G2L	Frequency
Phaeothamniophyceae																	
<i>Phaeoschizochlamys delicatula</i> (West) R.A. Andersen	.	.	**	1
Chlorophyta																	
Pedinophyceae																	
<i>Scourfieldia cordiformis</i> H.Takeda	*	***	2
Pyramimonadophyceae																	
<i>Pyramimonas denticulata</i> Pascher	*	.	.	.	1
Chlorodendrophyceae																	
<i>Tetraselmis</i> sp.	*	1
Chlorophyceae																	
<i>Ankistrodesmus arcuatus</i> Korshikov	.	*	*	*	.	.	3
<i>Ankistrodesmus densus</i> Korshikov	**	1
<i>Ankistrodesmus fusiformis</i> Corda	.	*	*	2
<i>Ankistrodesmus spiralis</i> (W.B. Turner) Lemmermann	*	.	**	**	*	.	.	.	4
<i>Chlamydomonas dinobryonis</i> G.M. Smith	*	1
<i>Chlamydomonas epibiotica</i> Ettl	*	1
<i>Chlamydomonas</i> sp. 1	**	**	*	.	*	*	*	.	*	*	*	.	*	*	**	*	13
<i>Chlamydomonas</i> sp. 2	**	.	.	.	*	*	.	.	*	.	.	4
<i>Chlamydomonas</i> sp. 3	*	1
<i>Chloromonas</i> sp.	*	*	.	*	*	.	*	.	.	.	5
<i>Chlorotetraedron incus</i> (Teiling) Komárek & Kovácik	.	*	.	.	*	2
<i>Coelastrum astroideum</i> De Notaris	*	**	*	.	*	*	.	.	.	5
<i>Coelastrum cruciatum</i> Schmidle	.	.	*	1
<i>Coelastrum microporum</i> Nägeli	*	**	*	.	*	*	**	6
<i>Coelastrum pseudomicroporum</i> Korshikov	*	*	*	3
<i>Coelastrum</i> sp.	*	*	.	.	2
<i>Coenochloris fottii</i> (Hindák) P.M. Tsarenko	**	**	.	**	**	.	.	*	.	**	6
<i>Coenochloris</i> sp.	*	*	**	*	*	.	.	5
<i>Coenococcus planctonicus</i> Korshikov	*	1
<i>Coenococcus</i> sp.	*	1
<i>Coenocystis planctonica</i> Korshikov	*	*	.	.	2
<i>Crucigenia quadrata</i> Morren	*	1
<i>Desmatractum indutum</i> (Geitler) Pascher	*	1
<i>Desmodesmus abundans</i> (Kirchner) E.H. Hegewald	*	**	*	.	.	3
<i>Desmodesmus armatus</i> (Chodat) E.H. Hegewald	*	**	.	.	*	.	*	.	.	*	*	.	.	**	.	.	7
<i>Desmodesmus bicaudatus</i> (Dedusenko) P.M. Tsarenko	*	.	.	.	*	*	.	.	*	.	.	4
<i>Desmodesmus bicellularis</i> (Chodat) S.S. An, T. Friedl & E. Hegewald	**	1
<i>Desmodesmus brasiliensis</i> (Bohlin) E. Hegewald	.	*	.	.	*	.	.	*	.	.	*	*	*	*	.	.	7
<i>Desmodesmus denticulatus</i> (Lagerheim) S.S. An, T. Friedl & E. Hegewald	*	.	.	1
<i>Desmodesmus dispar</i> (Brébisson) E. Hegewald	*	1
<i>Desmodesmus intermedius</i> (Chodat) E. Hegewald	*	.	.	.	1
<i>Desmodesmus opoliensis</i> (P.G. Richter) E. Hegewald	*	*	*	.	.	.	3
<i>Desmodesmus spinosus</i> (Chodat) E. Hegewald	*	**	.	.	*	*	*	*	5
<i>Didymocystis</i> sp.	*	*	*	*	***	**	*	*	.	.	8
<i>Dimorphococcus lunatus</i> A. Braun	.	*	1
<i>Drepanochloris nannoselene</i> (Skuja) Marvan, Komárek & Comas	**	.	.	.	1
<i>Euastropsis richteri</i> (Schmidle) Lagerheim	.	.	*	*	.	.	.	2
<i>Eudorina</i> sp.	*	1
<i>Eutetramorus globosus</i> Walton	*	**	*	.	*	*	5
<i>Golenkinia radiata</i> Chodat	.	*	.	.	*	2
<i>Hariotina reticulata</i> P.A. Dangeard	*	*	*	*	4
<i>Kirchneriella irregularis</i> (G.M. Smith) Korshikov	***	1

Taxon name	OsL	SIL	MaL	PDL	PL	PLL	JaL	ZdL	CzL	PML	PuL	MoL	KoL	PeL	G3L	G2L	Frequency
<i>Kirchneriella irregularis</i> var. <i>spiralis</i> Korshikov	*	1
<i>Kirchneriella obesa</i> (West) West & G.S. West	*	*	.	.	2
<i>Kirchneriella</i> sp.	*	1
<i>Korschpalmella mucosa</i> (Korshikov) Hindák	.	**	*	.	.	**	.	.	.	*	4
<i>Lanceola spatulifera</i> (Korshikov) Hindák	**	.	.	1
<i>Messastrum gracile</i> (Reinsch) T.S. Garcia	*	*	.	*	.	.	3
<i>Monoraphidium capricornutum</i> (Printz) Nygaard	.	*	1
<i>Monoraphidium circinale</i> (Nygaard) Nygaard	*	*	**	.	*	.	.	*	.	.	5
<i>Monoraphidium contortum</i> (Thuret) Komárková-Legnerová	*	*	*	.	*	.	*	**	**	*	.	.	8
<i>Monoraphidium dybowskii</i> (Wołoszyńska) Hindák & Komárková-Legnerová	*	.	*	*	.	.	.	*	.	*	.	.	*	*	.	.	7
<i>Monoraphidium griffithii</i> (Berkeley) Komárková-Legnerová	.	*	.	.	*	*	*	.	.	*	.	.	5
<i>Monoraphidium komarkovae</i> Nygaard	*	1
<i>Monoraphidium minutum</i> (Nägeli) Komárková-Legnerová	.	**	.	.	*	*	.	.	.	**	**	.	.	*	.	.	6
<i>Monoraphidium tortile</i> (West & G.S. West) Komárková-Legnerová	*	*	*	.	.	*	*	*	*	.	.	7
<i>Monoraphidium</i> sp. 1	**	.	.	*	**	.	.	*	**	.	*	.	*	**	.	.	8
<i>Monoraphidium</i> sp. 2	**	1
<i>Monoraphidium</i> sp. 3	*	1
<i>Mychonastes jurisii</i> (Hindák) Krienitz, C. Bock, Dadheech & Proschold	.	**	*	**	**	.	.	4
<i>Nephrocytium agardhianum</i> Nägeli	.	.	.	*	1
<i>Pandorina morum</i> (O.F. Müller) Bory	*	1
<i>Pediastrum duplex</i> Meyen	*	*	.	.	*	*	*	.	*	.	.	6
<i>Phacotus lenticularis</i> (Ehrenberg) Diesing	**	**	*	.	**	*	**	*	**	8
<i>Planktosphaeria gelatinosa</i> G.M. Smith	*	.	.	.	1
<i>Pseudodidymocystis inconspicua</i> (Korshikov) Hindák	.	**	.	.	*	*	*	.	.	.	*	.	*	.	.	.	6
<i>Pseudodidymocystis planctonica</i> (Korshikov) E. Hegewald & Deason	*	.	*	.	.	.	2
<i>Pseudopediastrum boryanum</i> (Turpin) E. Hegewald	*	*	*	*	*	.	.	.	*	.	*	*	8
<i>Pseudoschroederia robusta</i> (Korshikov) E. Hegewald & E. Schnepf	*	.	*	.	.	.	*	*	.	.	4
<i>Quadrigula korsikovii</i> Komárek	*	1
<i>Quadrigula pfitzeri</i> (Schröder) G.M. Smith	*	.	.	*	.	*	.	.	3
<i>Quadrigula</i> sp.	.	.	.	*	.	.	.	*	.	*	3
<i>Radiococcus nimbatus</i> (De Wildeman) Schmidle	.	.	.	*	1
<i>Raphidocelis danubiana</i> (Hindák) Marvan, Komárek & Comas	***	.	.	.	1
<i>Scenedesmus ecornis</i> (Ehrenberg) Chodat	*	.	*	.	.	*	.	.	.	*	*	.	*	*	.	.	7
<i>Scenedesmus obtusus</i> f. <i>disciformis</i> (Chodat) Compère	.	.	*	.	*	.	*	*	.	.	.	4
<i>Scenedesmus obtusus</i> Meyen	*	*	*	.	.	.	3
<i>Scenedesmus quadricauda</i> (Turpin) Brébisson	*	*	*	**	4
<i>Scenedesmus semipulcher</i> Hortobágyi	*	**	.	.	*	.	*	.	.	.	*	5
<i>Scenedesmus</i> sp.	*	.	.	*	*	*	*	.	.	5
<i>Schroederia setigera</i> (Schröder) Lemmermann	*	*	2
<i>Selenastrum bibraianum</i> Reinsch	**	*	*	.	.	3
<i>Spermatozopsis exsultans</i> Korshikov	*	1
<i>Sphaerocystis planctonica</i> (Korshikov) Bourrelly	*	.	.	1
<i>Stauridium tetras</i> (Ehrenberg) E. Hegewald	*	*	.	.	*	.	*	*	.	.	*	.	*	*	.	.	8
<i>Tetradesmus dimorphus</i> (Turpin) M.J. Wynne	*	1
<i>Tetradesmus lagerheimii</i> M.J. Wynne & Guiry	.	*	.	.	*	*	3
<i>Tetradesmus obliquus</i> (Turpin) M.J. Wynne	*	*	.	.	.	2
<i>Tetraëdron caudatum</i> (Corda) Hansgirg	*	*	.	.	*	*	*	.	.	**	.	.	6

Taxon name	OsL	SiL	MaL	PdL	PL	PiL	JaL	ZdL	CzL	PML	PuL	MoL	KoL	PeL	G3L	G2L	Frequency
<i>Siderocelis ornata</i> (Fott) Fott	*	*	.	*	*	.	.	4
<i>Stichococcus bacillaris</i> Nägeli	**	***	.	.	2
<i>Stichococcus minutissimus</i> Skuja	*	1
<i>Stichococcus</i> sp.	***	.	.	*	**	**	.	.	4
<i>Tetrachlorella incerta</i> Hindák	*	1
<i>Willea apiculata</i> (Lemmermann) D.M. John, M.J. Wynne & P.M. Tsarenko	**	*	2
<i>Willea irregularis</i> (Wille) Schmidle	*	.	*	*	3
<i>Willea rectangularis</i> (A. Braun) D.M. John, M.J. Wynne & P.M. Tsarenko	.	.	*	*	2
Ulvophyceae																	
<i>Ulothrix</i> sp.	*	*	2
Charophyta																	
Klebsormidiophyceae																	
<i>Elakatothrix acuta</i> Pascher	*	*	.	.	*	3
<i>Elakatothrix biplex</i> (Nygaard) Hindák	*	*	2
<i>Elakatothrix gelatinosa</i> Wille	.	**	*	.	.	*	*	4
<i>Elakatothrix genevensis</i> (Reverdin) Hindák	*	*	.	.	2
<i>Elakatothrix pseudogelatinosa</i> Korshikov	*	.	.	*	2
<i>Elakatothrix</i> sp.	*	.	.	*	.	.	.	*	*	**	*	*	.	*	.	.	8
Zygnematophyceae																	
<i>Closterium acutum</i> Brébisson	*	.	*	.	.	.	2
<i>Closterium acutum</i> var. <i>variabile</i> (Lemmermann) Willi Krieger	*	*	.	*	*	*	*	*	**	.	**	.	.	*	.	.	10
<i>Closterium gracile</i> Brébisson ex Ralfs	*	*	.	.	2
<i>Closterium limneticum</i> Lemmermann	.	*	1
<i>Cosmarium bioculatum</i> Brébisson ex Ralfs	.	*	.	*	*	*	*	.	.	.	5
<i>Cosmarium botrytis</i> Meneghini ex Ralfs	*	.	.	.	1
<i>Cosmarium humile</i> Nordstedt ex De Toni	.	.	.	*	*	.	.	.	2
<i>Cosmarium margaritifera</i> Meneghini ex Ralfs	*	.	.	.	1
<i>Cosmarium phaseolus</i> Brébisson ex Ralfs	*	.	.	.	1
<i>Cosmarium pygmaeum</i> W. Archer	.	.	*	1
<i>Cosmarium subprotumidum</i> Nordstedt	.	.	.	*	1
<i>Cosmarium</i> sp. 1	.	.	.	*	.	*	.	*	*	*	*	.	*	**	.	*	9
<i>Cosmarium</i> sp. 2	*	.	.	1
<i>Heimansia pusilla</i> (L. Hilse) Coesel	*	.	.	.	1
<i>Mougeotia</i> sp.	*	*	*	3
<i>Spirogyra</i> sp.	*	1
<i>Spondylosium papillosum</i> West & G.S. West	*	.	.	.	1
<i>Staurodesmus cuspidatus</i> (Brébisson) Teiling	*	1
<i>Staurastrum gracile</i> Ralfs ex Ralfs	*	**	.	.	.	2
<i>Staurastrum laeve</i> Ralfs	**	.	.	.	1
<i>Staurastrum paradoxum</i> Meyen ex Ralfs	*	*	.	*	*	*	*	6
<i>Staurastrum pseudopelagicum</i> West & G.S. West	*	1
<i>Staurastrum tetracerum</i> Ralfs ex Ralfs	.	*	.	.	*	*	*	.	*	*	.	.	6
<i>Staurastrum</i> sp.	*	*	*	*	3
<i>Staurodesmus cuspidatus</i> (Brébisson) Teiling	*	.	.	.	1
<i>Staurodesmus dejectus</i> var. <i>apiculatus</i> (Brébisson) Croasdale	*	1
<i>Staurodesmus glaber</i> (Ralfs) Teiling	*	.	.	.	1
<i>Staurodesmus triangularis</i> (Lagerheim) Teiling	*	1
<i>Staurodesmus</i> sp.	*	1
<i>Teilingia granulata</i> (J. Roy & Bisset) Bourrelly	*	.	.	.	1

present in at least one analysis at numbers between 100 and 999 individuals/ml, it was marked with two asterisks. If the number of individuals/ml was 1,000 or more, the taxon was marked with three asterisks. Based on the data in Table 2, the taxonomic similarity of the lake phytoplankton was calculated using cluster analysis in the PAST program.

Data from each quantitative phytoplankton analysis from the epilimnion in spring and the epilimnion and metalimnion in summer were used to calculate the Shannon-Wiener Diversity Index and the Pielou Evenness Index (Kawecka & Eloranta 1994). The indices were calculated using the PAST program.

RESULTS

During phytoplankton analysis of 16 DNP lakes, a total of 439 taxa were identified. The vast majority, 359, were assigned to species or variety, with the remainder assigned to genus or higher taxonomic units (Table 2). The most taxa were identified in the phylum Chlorophyta (151), followed by slightly fewer in the phylum Heterokontophyta (134). The remaining phyla contained significantly fewer taxa (Table 3). Species richness varied significantly between lakes. The most taxa were identified in Lake Ostrowiec (191), with slightly fewer in Lakes Sitno (138) and Płociczno (131). The lowest number of taxa was found in the phytoplankton of Lakes Głodne 2 (25) and Głodne 3 (23) (Table 3).

The taxonomic similarity of the lake phytoplankton, calculated using cluster analysis, revealed the separation of several groups. Lake Ostrowiec clearly differed from the others. The taxonomic composition of Lake Sitno and Lake Płociczno was most similar to it. The next group consisted of Lakes Jamno, Płociowe, and Marta. The remaining 10 lakes formed a single, albeit very heterogeneous, group. Within this group, Lakes Perkoz and Pustelnia occurred close together, Lake Kocie separately, and a heterogeneous group of the remaining seven lakes. Among these, a clearly distinct group of two lakes, Głodne 2 and

Głodne 3, with the smallest Euclidean distances, was distinguished (Fig. 2).

Most of the identified taxa (174) occurred at low abundances, ranging from 1 to 99 individuals/ml. 120 taxa were slightly more abundant (from 100 to 999 individuals/ml), and only 39 reached abundances of 1000 or more individuals/ml in at least one sample (Table 2). Of the most abundant taxa, 11 belonged to green algae, 9 to golden algae, 8 to diatoms, 6 to cyanobacteria, 3 to cryptophytes, 1 to haptophytes, and 1 to Eustigmatophyceae. As many as 174 taxa were recorded in only one of the lakes (Fig. 3). Several dozen taxa occurred in several lakes, and from 1 to 5 taxa were found with a frequency of occurrence in 10–16 lakes (Fig. 3). Only one species (*Cryptomonas marssonii*) was present in all 16 lakes. Other cryptophytes were also quite common, for example *C. ovata* and *C. pyrenoidifera* were found in 15 lakes, and *C. curvata* and *Plagioselmis lacustris* in 14 lakes.

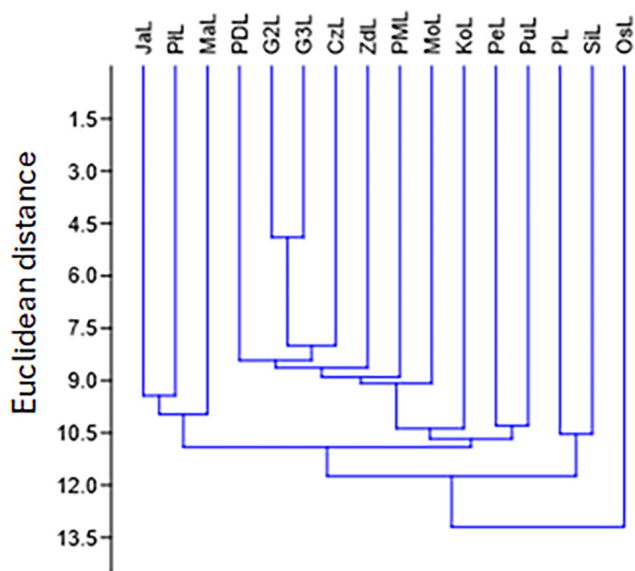


Fig. 2. Taxonomic similarity of phytoplankton in the studied lakes (abbreviations of the lake names are explained in Table 1)

Table 3. Number of taxa in the phytoplankton of sixteen lakes in the Drawieński National Park (abbreviations of the lake names are explained in Table 1)

Phylum	Name of the lake																Total
	OsL	SiL	MaL	PDL	PL	PiL	JaL	ZdL	CzL	PML	PuL	MoL	KoL	PeL	G3L	G2L	
Cyanobacteriophyta	26	9	11	4	7	8	7	2	3	4	7	2	8	11	0	2	52
Euglenophyta	8	5	2	0	12	3	4	2	0	6	9	6	3	6	0	1	23
Cryptista	9	10	8	5	8	8	7	5	6	8	7	6	7	11	4	8	18
Dinoflagellata	10	4	4	5	4	7	3	2	3	5	4	6	4	8	2	0	18
Choanozoa	4	0	1	0	0	0	3	0	0	0	1	0	0	0	0	0	4
Bigyra	2	0	0	1	2	1	1	0	0	0	1	0	0	0	0	0	2
Haptophyta	1	1	1	1	1	1	1	1	1	0	0	1	0	1	0	0	1
Heterokontophyta	58	51	51	10	44	35	36	25	21	18	25	15	26	28	10	8	134
Chlorophyta	63	50	28	18	46	23	23	26	14	21	41	21	35	44	6	3	151
Charophyta	10	8	2	8	7	5	3	3	4	5	7	2	13	7	1	3	36
Sum	191	138	108	52	131	91	88	66	52	67	102	59	96	116	23	25	439

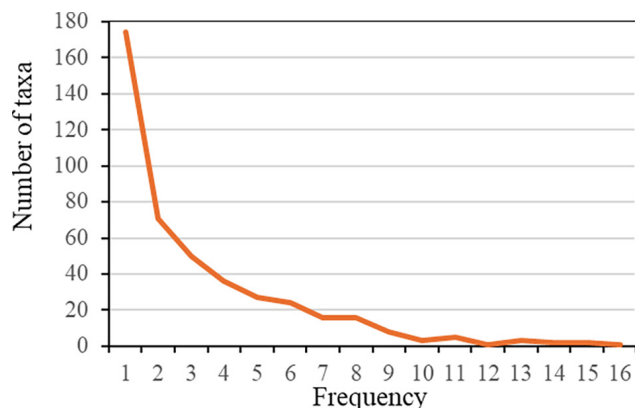


Fig. 3. Frequency of taxa in the studied lakes

Among other taxonomic groups, a large number of lakes contained representatives of golden algae (e.g. *Pseudokephyrion entzii* in 13 lakes, *Dinobryon divergens* in 11 lakes), some dinophyte taxa (e.g. *Gymnodinium* sp. in 13 lakes), haptophytes (*Chrysochromulina parva* in 11 lakes), diatoms (e.g. *Fragilaria crotonensis* and *Ulnaria acus* in 11 lakes) and green algae (e.g. *Chlamydomonas* sp. in 13 lakes, *Tetraëdron minimum* in 12 lakes and *Tetraëdron minimum* var. *tetralobulatum* in 11 lakes) (Table 2).

The Shannon-Wiener Diversity Index for phytoplankton varied significantly between lakes, from 0.45 (Lakes Pustelnia and Głodne 2) to 3.89 (Lake Sitno). In most lakes, this index was higher in summer than in spring. Only in a few cases it was higher in spring, namely in Lake Płociczno, Ostrowiec III,

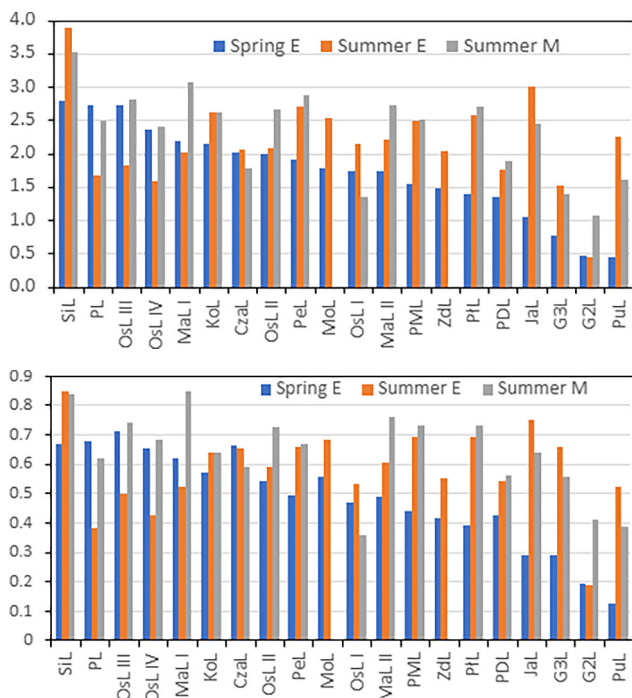


Fig. 4. Shannon-Wiener Diversity Index H (A) and Pielou Evenness Index J (B), calculated for stations at individual lakes in spring and in summer, divided in summer into epi- (Summer E) and metalimnion (Summer M)

Ostrowiec IV and Marta I (Fig. 4A). The diversity index calculated separately for samples collected from the metalimnion was higher than for samples from the epilimnion in as many as 12 cases.

The Pielou Evenness Index showed very similar variation to the Shannon-Wiener index, both with respect to individual lakes, seasons, and thermal layers (Fig. 4B). Its highest value was found in the epilimnion of Lake Sitno in summer (0.85), the lowest in Lake Pustelnia in spring (0.12). In most lakes in summer, and especially in their metalimnion, it was quite even, falling within the range of 0.6–0.7. Only the Pielou index values for the epilimnion of lakes Płociczno, Ostrowiec III, Ostrowiec IV, and Głodne 2, and the metalimnion of Lake Ostrowiec I, were clearly lower than the above range.

DISCUSSION

The relatively large number of taxa identified during phytoplankton studies in DNP lakes is undoubtedly due to the great diversity of these lakes in many respects. These include lakes with various trophic levels, from eutrophic (Sitno, Płociczno, Ostrowiec, Jamno, Perkoz, Pustelnia, Moczele), through mesotrophic (Marta, Płociwe, Piaseczno Duże, Zdroje, Kocie), to oligotrophic (Czarne Lake). Three of the studied lakes should be considered dystrophic (Głodne 2, Głodne 3, and Piaseczno Małe). The lakes also differed in their type of thermal stratification. Most were dimictic lakes with complete or partial thermal stratification, possessing three or two thermal layers in summer. Small and shallow lakes were polymictic, mixing multiple times throughout the year (Moczele Lake and Zdroje Lake). One lake turned out to be meromictic, with limited depth of water mixing (Lake Czarne). The lakes also differed in their hydrological regime. Most were endorheic. Only four were flow-through lakes: Lake Sitno, Lake Płociczno, Lake Ostrowiec, and Lake Jamno, and they differed significantly in water exchange rates. The least stable was Lake Płociczno (flashing rate 46 times per year), while the most stable was Lake Ostrowiec (flashing rate 1.5 times per year). The studied lakes also differed significantly in surface area, ranging from 0.6 ha to 387.5 ha, and water volume, ranging from 17,500 m³ to 36.4 million m³ (Kraska et al. 2002).

The highest taxonomic richness was found in three flow-through lakes located along the Płociczna River. This was primarily due to the presence of several lakes along this river and its tributaries, located outside the DNP. Numerous plankton species typical for lakes flowed with the river water, enabling their proliferation in Lake Sitno (Gołdyn & Szelaż-Wasielewska 2004). This included many taxa from almost all classes. Phytoplankton from Lake Sitno flowed with the Płociczna River waters, first to Lake

Płociczno, and then to Lake Ostrowiec, where the quantitative composition of individual taxa changed. As water flowed through the individual lakes, the trophic level of the water decreased as a result of nutrient uptake by phytoplankton and deposition in the bottom sediments. Therefore, species typical of high trophic levels began to decline in abundance already in Lake Sitno. This process continued in the next two lakes, causing the appearance of new species typical of lower trophic waters.

The richest phytoplankton taxonomic composition was observed in Lake Ostrowiec, which is due, on the one hand, to the inflow of species typical of higher trophy via the river, and, on the other hand, to the development of new species typical of lower trophy in the lake. This was facilitated by the low water exchange in the lake, which occurred mainly in the northern, flow-through part of the lake. Analysis of its composition at four study sites also contributed to the finding of greater taxonomic richness of phytoplankton in Lake Ostrowiec. At individual study sites, 96–146 taxa (average 116) were identified. This is likely why Lake Ostrowiec was not included in the same cluster as Lakes Sitno and Płociczno, but its taxonomic composition nevertheless shows the greatest similarity to them (Fig. 2). Significantly fewer taxa (88) were found in Lake Jamno, even though it is also a flow-through lake. However, the inflow to this lake is small, so planktonic species likely disappear in the flow path from Lake Zdroje. Therefore, its phytoplankton is not found in the same cluster as the other flow-through lakes, but in a cluster encompassing the phytoplankton of the nearby endorheic lakes Płociowe and Marta, despite their lack of hydraulic connection and differences in trophic status.

The highest species richness typically occurs in mesotrophic lakes (Kawecka & Eloranta 1994, Reynolds 2009). In the case of DNP lakes, this relationship was not confirmed, as the total number of taxa ranged in mesotrophic lakes from 52 to 108. The highest number was found in Lake Marta, which is mainly due to the analysis of phytoplankton composition at two stations. At each of them, it was significantly lower, amounting to 79 and 88 taxa. The lower phytoplankton species richness in these mesotrophic lakes is most likely related to the allelopathic effect of stonewots (Mulderij et al. 2003, Mohamed 2017, Złoch et al. 2018), which occupied almost the entire phytolittoral. This was reflected not only in species richness, but also in the abundance of phytoplankton, thanks to which the Secchi depth was relatively high, ranging from 2.6 to 6.0 m (Kraska et al. 2002).

Low taxonomic richness was also observed in the eutrophic Lake Moczele. Its entire surface was dominated by *Nuphar lutea*, *Nymphaea alba*, and *Stratiotes aloides* (Piotrowicz et al. 2006). These species strongly shade the water surface, limiting light access for phytoplankton. *S. aloides* is also known to secrete

allelopathic compounds. Furthermore, it produces a large biomass, thus posing a serious competition for phytoplankton for nutrients available in the water column (Mulderij et al. 2007).

The smallest number of taxa was found in dystrophic lakes, namely Lake Głodne 2 and Lake Głodne 3 (25 and 23 taxa, respectively). The low number of taxa is often found in polyhumic lakes and results from the low pH of water and a high content of humic compounds, which limit light penetration in the water (Szeląg-Wasielewska & Gołdyn 1994). The taxonomic composition of these two lakes was very similar, and at the same time the most different from that of the other DNP lakes (Fig. 2). The closest similarity was found in the phytoplankton of the meromictic Lake Czarne, but twice as many species were found there (52). The phytoplankton composition of Lake Piaseczno Duże differed significantly from that of Lake Głodne 2 and Lake Głodne 3, even though it is also a dystrophic lake. This was undoubtedly due to the low content of humic compounds, which allowed better access of light to the water column. This lake was considered to be dystrophic oligohumic (Joniak et al. 2010).

The wide variety of habitats found in individual lakes contributed to the high taxonomic diversity of phytoplankton. Many of taxa (174) were found only in a single lake. They belonged to almost all identified phyla. This may indicate their narrow ecological scale or the presence of a favorable habitat in only one lake. Some of them were very rare, known from only a few locations. Only 18 of them were found with abundance exceeding 100 individuals/ml. The lack of dominance in the phytoplankton of most of them may indicate their accidental presence in the plankton. However, few taxa occurred in a large number of lakes. These taxa had a wide ecological range, which allowed them to occur in such diverse habitats. Most of them were flagellates, belonging to cryptophytes, chrysophytes, dinophytes, and haptophytes, which can feed mixotrophically (Reynolds 2009). In unfavorable environmental conditions, they can feed on smaller organisms or even dead organic matter suspended in the water column. The small number of taxa (39) occurring in high numbers (1000 or more individuals/ml) and the large number of lakes (13) with a Shannon-Wiener Diversity Index above 2 in at least one analysis indicates the existence of natural habitats in the studied lakes (Ye et al. 2025). This is due to the low human impact on the lakes, as they are located in the protected area of the National Park. Climatic conditions may also have had some influence on the lack of strong algal blooms in the lakes in summer. In summer of 1997, heavy precipitation occurred, which could have contributed to poor light conditions, higher water levels, and more intense mixing of water in the lakes. Only in three lakes was the Shannon-Wiener Diversity Index

consistently low (Głodne 2, Głodne 3, and Piaseczno Duże), which indicates a strong influence of some environmental drivers. In the case of Lakes Głodne 2 and Głodne 3, these were undoubtedly humic compounds. In such conditions, only a few species, mainly mixotrophs, could grow in large numbers. Joniak and Kraska (2006), during their later studies in the polyhumic Lake Głodne 3, also found a small number of taxa, dominated by mixotrophic flagellates (82%).

A low Pielou Evenness Index (value below 0.5), indicating a clear dominance of one or two taxa, was found only in Lake Głodne 2. In spring, it was *Chloridella cystiformis*, and in summer, *Dinobryon pediforme* and *Scourfieldia cordiformis*. The latter two species are flagellates, capable of actively moving through the water column and feeding mixotrophically under specific polyhumic conditions (Reynolds 2009). An index higher than 0.5 in the other lakes indicates no pollution or light pollution, and favorable conditions for the even proliferation of various species in the phytoplankton (Ye et al. 2025).

CONCLUSIONS

The high taxonomic diversity observed in the studied Drawieński National Park (DNP) lakes resulted from their considerable diversity. The flow capacity of some of them was significant, thanks to the inflow of planktonic species from other lakes outside the National Park via river waters. The low taxonomic composition of phytoplankton in the polyhumic dystrophic lakes differed significantly from the other lakes, resulting primarily from light scattering by humic compounds. The large number of taxa found in only single lake (174) indicates their narrow ecological scale or the presence of a favorable habitat in only one lake. Since the vast majority of them were characterised by low numbers (less than 100 individuals/ml), this may also indicate their accidental presence in the pelagic plankton. In contrast, few taxa occurred in a significant number of lakes. Most of them were cryptophytes, chrysophytes, dinophytes, and haptophytes, which can feed mixotrophically under unfavorable environmental conditions. High Shannon-Wiener Diversity Index and Pielou Evenness Index indicate the presence of natural habitats in the studied lakes. The obtained results contribute to a better understanding of the biodiversity of the DNP, enrich our knowledge of the algae and cyanobacteria of lakes in Polish national parks, and may also be useful in assessing changes in the ecosystems of the studied lakes after repeating the study using the same research methods.

REFERENCES

Burchardt L., Gąbka M., Kuczyńska-Kippen N., Mesyasz B., Nagengast B., Owsiany P.M., Pełechata

- A., Stefaniak K., Wieścicka I., Picińska-Fałtynowicz J., Szyper H. (2004): Ekosystemy wodne Słowińskiego Parku Narodowego. In: L. Burchardt (ed.). Seria Biologia 71, Wydawnictwo Naukowe Uniwersytetu Adama Mickiewicza, Poznań.
- Cydzik D., Kudelska D., Soszka H. (1995): Atlas stanu czystości jezior Polski badanych w latach 1989–1993. Państwowa Inspekcja Ochrony Środowiska, Biblioteka Monitoringu Środowiska, Warszawa.
- Czerniawski R., Pilecka-Rapacz M., Domagała J. (2010): Ocena statusu troficznego jezior przepływowych zlewni Drawy w odniesieniu do warunków środowiskowych terenu. In: A. Grześkowiak, B. Nowak (eds). Dynamika procesów przyrodniczych w zlewni Drawy i Drawieńskim Parku Narodowym. Polskie Towarzystwo Geofizyczne i Instytut Meteorologii i Gospodarki Wodnej, Poznań: 27–37.
- Gołdyn R., Szelaż-Wasielewska E. (2004): Changes in the phytoseston of a river-lake system in Drawieński National Park. *Oceanological and Hydrobiological Studies* 33(2): 17–28.
- Grześkowiak A., Jańczak J., Sziwa R. (2010): Hydrologia i jakość wody jeziora Ostrowiec w Drawieńskim Parku Narodowym. In: A. Grześkowiak, B. Nowak (eds). Dynamika procesów przyrodniczych w zlewni Drawy i Drawieńskim Parku Narodowym. Polskie Towarzystwo Geofizyczne i Instytut Meteorologii i Gospodarki Wodnej, Poznań: 55–64.
- Guiry M.D. in Guiry M.D., Guiry G.M. (2016): Algae-Base. World-wide electronic publication. National University of Ireland, Galway. <https://www.algae-base.org>; searched on 10 December 2025.
- Jasnowska J., Wróbel M. (2010): Ochrona czynna „kłoci ostrowieckich” w Drawieńskim Parku Narodowym. In: A. Grześkowiak, B. Nowak (eds). Dynamika procesów przyrodniczych w zlewni Drawy i Drawieńskim Parku Narodowym. Polskie Towarzystwo Geofizyczne i Instytut Meteorologii i Gospodarki Wodnej, Poznań: 173–179.
- Joniak T., Klimaszyk P., Kraska M. (2010): Diel dynamics of vertical changes of chlorophyll and bacteriochlorophyll in small humic lakes. *Oceanological and Hydrobiological Studies* 39 (3): 103–111.
- Joniak T., Kraska M. (2006): Biodiversity of phytoplankton in hydrochemically different types of humic lakes in the Drawieński National Park. *Acta Agrophysica* 7 (2): 369–374.
- Kajak Z. (1998): *Hydrobiologia-limnologia: ekosystemy wód śródlądowych*. Państwowe Wydawnictwo Naukowe, Warszawa.
- Kawecka B., Eloranta P.V. (1994): *Zarys ekologii glonów wód słodkich i środowisk lądowych*. Państwowe Wydawnictwo Naukowe, Warszawa.
- Klimaszyk P., Kraska M., Joniak T., Piotrowicz R. (2010): Jezioro meromiktyczne, unikatowy eko-

- system wodny w Drawieńskim Parku Narodowym – funkcjonowanie i ochrona. In: A. Grześkowiak, B. Nowak (eds). Dynamika procesów przyrodniczych w zlewni Drawy i Drawieńskim Parku Narodowym. Polskie Towarzystwo Geofizyczne i Instytut Meteorologii i Gospodarki Wodnej, Poznań: 47–53.
- Kraska M. (1997): Jeziora w Drawieńskim Parku Narodowym. *Aura* 8: 14–16.
- Kraska M., Borysiak J., Danielak K., Domek P., Gołdyn R., Joniak T., Klimaszyk P., Kujawa-Pawlaczyk J., Piotrowicz R., Radziszewska R., Romanowicz W., Szelaż-Wasielewska E., Szyper H. (2001): Jeziora dystroficzne i jezioro meromiktyczne w Drawieńskim Parku Narodowym. In: M. Wojterska (ed.). Szata roślinna Wielkopolski i Pojezierza Południowopomorskiego. Przewodnik sesji terenowych 52. Zjazdu Polskiego Towarzystwa Botanicznego, 24–28 września 2001: 369–400.
- Kraska M., Piotrowicz R., Radziszewska R., Borysiak J., Rakowski W., Stachnowicz W. (2000): Diversity of vegetation versus trophic state of lakes in the Drawieński National Park. In: H. Gurgul (ed.). Physicochemical Problems of Natural Waters Ecology 2: 129–140. Wydawnictwo Naukowe Uniwersytetu Szczecińskiego, Szczecin.
- Kraska M., Piotrowicz R., Szyper H., Szelaż-Wasielewska E., Goldyn R., Klimaszyk P. (2002): Variability of trophic state and vegetation in lakes of Drawieński National Park (Northern Poland). *Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen* 28(2): 900–904.
- Kuczyńska-Kippen N., Klimaszyk P., Szelaż-Wasielewska E. (2006): Diel changes in the plankton communities of the ecotone zone of a peat mat of the dystrophic lake „Głodne Jezioro” (Drawieński National Park). *Acta Agrophysica* 7(2): 423–431.
- Lampert W., Sommer U. (2001): *Ekologia wód śródlądowych*. Państwowe Wydawnictwo Naukowe.
- Ławniczak A.E., Pełechata A., Czerniawska-Kusza I., Kuczyńska-Kippen N., Kokociński M., Golski J. (2016): *Wody powierzchniowe Wielkopolskiego Parku Narodowego i jego otuliny*. Tom 1. Jeziora. Bogucki Wydawnictwo Naukowe, Poznań.
- Ławniczak A.E., Strzelczak A., Choiński A. (2012): Drawieński Park Narodowy. In: R. Bogdanowicz, P. Jokieli, J. Pociask-Karteczka (eds). *Wody w parkach narodowych Polski*. Instytut Geografii i Gospodarki Przestrzennej Uniwersytetu Jagiellońskiego, Komisja Hydrologiczna Polskiego Towarzystwa Geograficznego: 74–91.
- Messyasz B., Pełechata A., Burchardt L. (2011): Różnorodność glonów i sinic w jeziorach Wielkopolskiego Parku Narodowego. In: A. Kostrzewski (ed.). *Zróżnicowanie krajobrazowe Wielkopolskiego Parku Narodowego*. Morena, Prace i Materiały Wielkopolskiego Parku Narodowego 15, Jezioro: 37–81.
- Mohamed Z.A. (2017): Macrophytes-cyanobacteria allelopathic interactions and their implications for water resources management – A review. *Limnologia* 63: 122–132.
- Mulderij G., van Donk E., Roelofs J.G.M. (2003): Differential sensitivity of green algae to allelopathic substances from *Chara*. *Hydrobiologia* 491: 261–271.
- Mulderij G., Mau B., van Donk E., Gross E.M. (2007): Allelopathic activity of *Stratiotes aloides* on phytoplankton – towards identification of allelopathic substances. *Hydrobiologia* 584(1): 89–100.
- Piątkowska D., Ziarnik M. (2024): *Wodny świat. Ekosystemy zależne od wody – mokradła, torfowiska, łąki*. Publisher: Drawieński Park Narodowy, Drawno.
- Piotrowicz R., Kraska M., Klimaszyk P., Szyper H., Joniak T. (2006): Vegetation richness and nutrient loads in 16 lakes of Drawieński National Park (northern Poland). *Polish Journal of Environmental Studies* 15(3): 467–478.
- Reynolds C.S. (2009): *The Ecology of Phytoplankton*. Cambridge University Press, Cambridge.
- Stan czystości jezior w województwie pilińskim (1998). Na podstawie badań monitoringowych w latach 1992–1997. Biblioteka Monitoringu Środowiska, Państwowa Inspekcja Ochrony Środowiska, Wojewódzka Inspekcja Ochrony Środowiska w Pile, Piła.
- Starmach K. (1963): *Rośliny słodkowodne. Wstęp ogólny i zarys metod badania*. Flora słodkowodna Polski. Vol. 1. Państwowe Wydawnictwo Naukowe, Warszawa.
- Szelaż-Wasielewska E. (2004): Pelagic pico-, nano- and microphytoplankton in a meromictic lake: a preliminary study. In: A. Jankowski, M. Rzętała (eds). *Lakes and artificial water reservoirs – functioning, revitalization and protection*. University of Silesia, Faculty of Earth Sciences. Polish Limnological Society, Polish Geographical Society – Branch Katowice, Sosnowiec: 205–213.
- Szelaż-Wasielewska E. (2005a): Autotroficzny piko-plankton podczas letniej stratyfikacji wód: rozmieszczenie w pelagialu i udział w fitoplanktonie. In: A. Jankowski, M. Rzętała (eds). *Jeziora i sztuczne zbiorniki wodne – procesy przyrodnicze oraz znaczenie społeczno-gospodarcze*. Uniwersytet Śląski, Wydział Nauk o Ziemi, Polskie Towarzystwo Limnologiczne, Polskie Towarzystwo Geograficzne – Oddział Katowicki, Sosnowiec: 231–240.
- Szelaż-Wasielewska E. (2005b): Distribution du picoplankton autotrophe dans la zone pélagique d'un lac méromictique (Lac Czarne, Pologne). *Revue des Sciences de l'Eau* 18: 1–11.

- Szelaż-Wasielewska E., Gołdyn R. (1994): Zbiorowiska glonów w pelagialu jezior lobeliowych. In: M. Kraska (ed.). Jeziora lobeliowe. Charakterystyka, funkcjonowanie i ochrona. Part 1. Idee Ekologiczne 6, Seria Szkice nr 4: 37–65.
- Szelaż-Wasielewska E., Gołdyn R., Kraska M., Piotrowicz R. (2000): Phytoplankton versus trophic state of lakes in the Drawieński National Park. In: H. Gurgul (ed.). Physicochemical Problems of Natural Waters Ecology 2: 103–117. Wydawnictwo Naukowe Uniwersytetu Szczecińskiego, Szczecin.
- Szyper H., Kraska M. (1999): Ocena zewnętrznego obciążenia związkami biogennymi jezior Drawieńskiego Parku Narodowego. In: A. Choiński, J. Jańczak (eds). Naturalne i antropogeniczne przemiany jezior. Instytut Meteorologii i Gospodarki Wodnej Oddział w Poznaniu, Uniwersytet im. A. Mickiewicza w Poznaniu, Zakład Hydrologii i Gospodarki Wodnej Instytutu Geografii Fizycznej. Konferencja Limnologiczna, Radzyń k. Sławy: 255–264.
- Wetzel R.G., Likens G.E. (1991): Limnological analyses. 2nd ed. Springer, New York.
- Ye Z., Zhang Q., Li C. Ye C., Wang Y. (2025): Environmental drivers of aquatic community structures in a shallow eutrophic lake of the Taihu Lake Basin. *Water* 17(16), 2372.
- Złoch I., Śliwińska-Wilczewska S., Kucharska M., Kozłowska W. (2018): Allelopathic effects of *Chara* species (*C. aspera*, *C. baltica*, and *C. canescens*) on the bloom-forming picocyanobacterium *Synechococcus* sp. *Environmental Science and Pollution Research* 25(36): 36403–36411.