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Functional classification of phytoplankton in Kardzhali reservoir (Southeast Bulgaria)

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Abstract

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The study of phytoplankton diversity was carried out in the aquatory of Kardzhali reservoir between July 2015 and November 2016. The divisions Chlorophyta and Cyanoprokaryota, followed by Ochrophyta had the highest frequency of occurrence. We have applied a functional classification of algae based on the Reynolds theory, according to which the plankton algae were classified into nineteen functional groups. We have identified forty-three dominant phytoplankton taxa in the reservoir. The comparison of dominant functional groups indicates that the most common are codon members **F**, **P**, **K**, **H1** and **J**. At the time of the study *Fragilaria crotonensis* Kitton and *Closterium aciculare* T. West of the functional group **P**; *Aphanizomenon flos-aquae* Ralfs ex Bornet & Flahault (**H1**), *Ankyra judayi* (G.M. Smith) Fott (X1*), Coelastrum microporum* Nägeli (**J**), *Oocystis lacustris* Chodat (**F**) and *Aphanocapsa planctonica* (G.M. Smith) Komárek & Anagnostidis (**K**) had the highest abundance. The results of the study confirm the applicability of the functional group approach to better understanding the seasonal changes of phytoplankton communities in different water basin.

Keywords: phytoplankton; functional classification; codon; functional groups; seasonal changes; reservoir

Introduction

The reservoirs often differ from the lakes based on their hydrological and limnological characteristics, but the principles that apply to phytoplankton diversity are the same (Reynolds, 1999). The prediction of the dominant species in lakes and reservoirs and the peak in their development over the year is almost impossible (Reynolds et al., 2005). The phytoplankton has developed various physiological and morphological strategies that allow it to adapt to the changing aquatic environment (Margalef, 1978; Reynolds, 1998). In his classic publications, Reynolds, in order to explain the periodicity of phytoplankton development, describes groups with similar seasonal requirements (Reynolds, 1980; 1984). Initially, fourteen functional groups have been identified in the original study. The phytoplankton has been classified into three main groups based on their susceptibility to disturbance, stress and the use of limited resources: C (invasive-colonists), S (stress-tolerant) and R (ruderals) (Reynolds, 1988). Later, the number of groups of species with similar requirements, called functional groups, was enlarged (Reynolds et al., 2002; Padisák et al., 2006).

They consist of species with similar requirements, but not always affiliated with the same taxonomic groups (Reynolds et al., 2002; Reynolds, 2006). According to a number of authors, this approach is more useful for ecological purposes, rather than the taxonomic distribution of the species (Kruk et al., 2002; Salmaso and Padisak, 2007; Padisak et al., 2009). Functional groups, unlike taxonomic groups, facilitate the analysis and assessment of changes in the aquatic environment (Kruk et al., 2002; Naselli-Flores et al., 2003). The use of such phytoplankton functional classification to assess environmental change has proven its significant effectiveness (Gemelgo et al., 2009). According to Kruk et al. (2002), both types of classification have shown good results, but the one based on functional links has better potential. The definition of functional classification of phytoplankton combines different taxonomic, morphological and functional criteria. Besides these characteristics, other criteria, such as phenology, have shown that species with similar seasonal requirements meet the specific environmental conditions (Salmaso et al., 2015). Reynolds et al. (2002) recommend a list of functional groups based on their tolerance, sensitivity, and appearance in different environments. The researchers have identified 31 functional groups that belong to different taxonomic groups, but with similar survival strategies. The functional classification of phytoplankton today includes more than 40 groups defined by alphanumeric and digital codons according to their habitat, tolerance, and sensitivity (Reynolds, 2006; Padisák et al., 2009).

The same approach was applied for lakes and reservoirs monitoring in Bulgaria for the period 2011-2012 by Stoyneva et al. (2013) and the study results which lead to similar conclusions were published by Belkinova et al. (2014). Stoyneva (2014) and Belkinova et al. (2014) assessed the properties of the application of the functional classification of phytoplankton in Bulgaria. In the last decade algal flora in Kardzhali reservoir has been relatively well studied (e.g. Belkinova et al., 2007; Dochin, 2014, 2015; Dochin and Stoyneva, 2014), but data on the functional classification of phytoplankton are scarce. Therefore, the aim of the presented study was to identify the phytoplankton functional groups in Kardzhali reservoir, thereby improving the understanding of the seasonal dynamics of the dominant species in this large water basin with economic importance.

Materials and Methods

Study area

The study was conducted in the aquatory of Kardzhali reservoir (IBW1668), located in the Rodopi Mountains, Bulgaria (Michev and Stoyneva, 2007). The reservoir has been intensively used for power production and cage farming for over 30 years, with one of the largest cage farms for sturgeon in Europe. The main morphometric characteristics of the reservoir are presented in Table 1.

Table 1. Morphometric characteristics of Kardzhali Reservoir

Reservoir name	Kardzhali (IBW1668)
Average heigh (m.a.s.l.)	280
Volume (m^{-3})	497 235 698
Aquatory (m^{-2})	15 991 735
Maximum length (m^{-1})	22 000
Average width (m^{-1})	1 323
Average depth (m^{-1})	31
Maximum depth (m^{-1})	74,3
Watershed basin (km^{-2})	1 882
Retention time (days)	205
Tributary	Arda river
Sampling sites	GPS coordinates
Site 1	(41°38.367′N) (025°19.166′E)
Site 2	(41°38.454′N) (025°19.257′E)
Site 3	(41°38.564′N) (025°18.887′E)
Site 4	(41°38.481′N) (025°18.713′E)
Site 5	(41°39.643′N) (025°16.394′E)
Site 6	(41°38.949′N) (025°17.400′E)

Sampling and analysis

Six sampling sites were situated across the longitudinal axis of the reservoir (Fig. 1). Forty-one water samples were collected for analysis in the period July to October from the epi-, meta- and hypolimnion in 2015 and from the epilimnion in 2016. The samples for analysis of phytoplankton were collected by Niskin-Type water sampler 5L model (Hydro-Bios Apparatebau GmbH, Germany) and processed by standard methods of fixation with formalin to final concentration 4% and further sedimentation (ISO 5667-1:2006/AC:2007; ISO 5667-3:2003/AC:2007). A Bürker chamber was used for the microscopic analysis. The species composition was determined by light microscopy on Axioscope 2 plus (Carl Zeiss) with magnification 200x and 400x using standard taxonomic literature with the critical use of AlgaeBase (Guiry and Guiry, 2018). Diatoms were identified after Cox (1996). The main counting unit was the cell and biomass was estimated by the method of stereometrical approximations (Rott, 1981; Deisinger, 1984). The counting was carried out individually (cell,

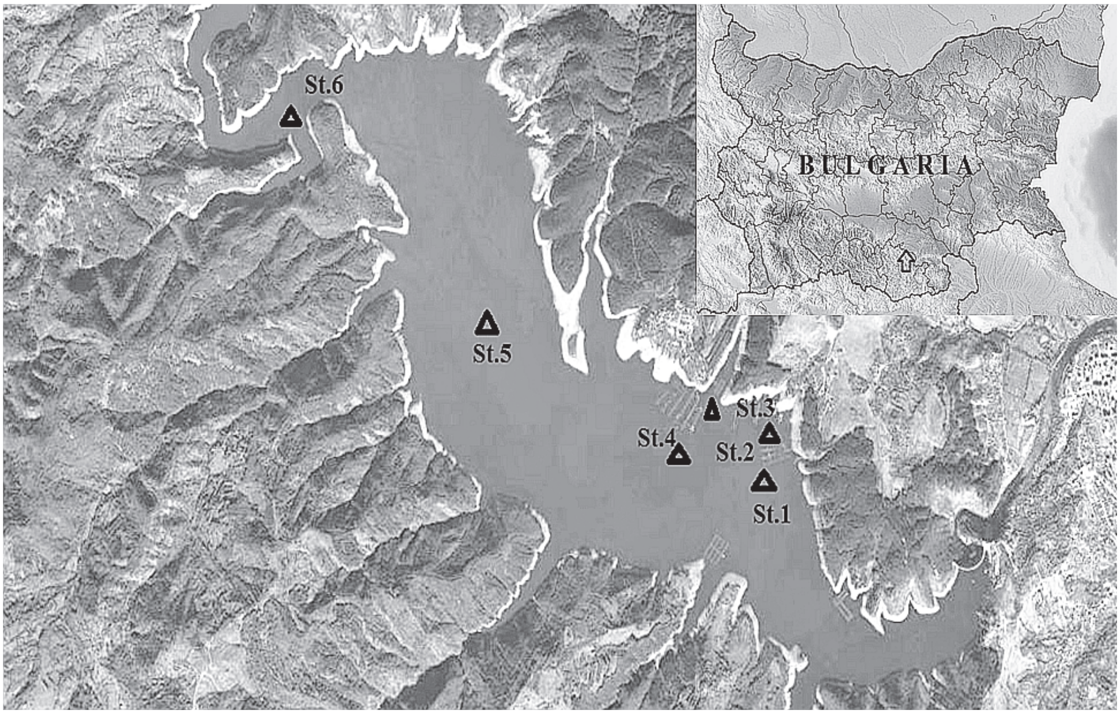

Fig. 1. Map of Kardzhali Reservoir with location of sampling sites

filament or colony). The samples were assessed by the total biomass of each sample, defined as the amount of biomass of all species, summarized in separate taxonomic groups. Water transparency (Z_S) was measured by Secchi-disk of 20 cm^{-1} in diameter. The euphotic zone depth (Z_{EU}) was measured as 2.5 times the Secchi-disc depth (Reynolds, 2006).

Phytoplankton functional groups were identified according to Reynolds et al. (2002), Padisak et al. (2009) and Borics et al. (2016). Functional groups were defined for species that contributed at least 5% of the mean phytoplankton biomass (Reynolds et al., 2002; Reynolds, 2006).

Results

Phytoplankton functional classification

We have identified 110 taxa distributed in seven divisions for the two-year study period: Ochrophyta, 22 (Chrysophyceae, 1; Synurophyceae, 3; Bacillariophyceae, 18); Chlorophyta, 38; Cyanoprokaryota, 24; Euglenophyta, 8; Streptophyta, 14; Pyrrhophyta, 3 and Cryptophyta, 1. In 2015 we have established 88 planktonic algae taxa form seven divisions: Ochrophyta, 20 (Synurophyceae, 3; Bacillariophyceae, 17); Chlorophyta, 25; Cyanoprokaryota, 21; Euglenophyta, 8; Streptophyta, 10; Pyrrhophyta, 3 and Cryptophyta, 1 (Table 2). In 2016 we have identified 69 taxa form six divisions: Ochrophyta, 14 (Synurophyceae, 3; Chrysophyceae, 1; Bacillariophyceae, 10); Chlorophyta, 27; Cyanoprokaryota, 13; Euglenophyta, 2; Streptophyta, 11 and Pyrrhophyta, 2 (Table 2).

The established phytoplankton functional groups in the Kardzhali reservoir are presented in Table 3. We have detected forty-three dominant phytoplankton taxa in the aquatory of Kardzhali reservoir. The identified planktonic algae are distributed in the following nineteen functional groups: **C**, **D**, **E**, **F**, **G**, **H1**, **J**, **K**, $\mathbf{L_O}$, **M**, **MP**, **N**, **P**, **S1**, $\mathbf{T_C}$, **W1**, **W2**, **X1** and **Z**, based on the criteria proposed by Reynolds et al. (2002), Padisak et al. (2009). Species from the **F**, **P**, **K**, **H1** and **J** functional groups dominate in the spring period in Kardzhali reservoir. The highest abundance in the phytoplankton community in the summer (July 2015) at all stations had *Stephanodiscus hantzschii* Grunow (45.8%), classified in group **D**, *Oocystis lacustris* Chodat (75.7%), *Elakatothrix genevensis* (Reverdin) Hindák from **F** (10.9%), *Cocconeis placentula* Ehrenberg from **MP** (58.6%), *Chroococcus turgidus* (Kützing) Nägeli (42.9%) and *Woronichinia naegeliana* (Unger) Elenkin (4.3%) from $\mathbf{L_O}$ functional group and *Ankyra judayi* (G.M.Smith) Fott (100%) form codon **X1**. The diatoms *Fragilaria crotonensis* Kitton from group **P** (93.1%), *Coelastrum microporum* Nägeli (24.3%) from **J**, *Mallomonas caudata* Iwanoff [Ivanov] (6.5%) from **E**, as

Table 2. List of phytoplankton observed in Kardzhali Reservoir

Cyanoprokaryota	2015	2016
Anabaena sp.	*	*
Anabaena sphaerica Bornet & Flahault	*	*
Anathece clathrata (W.West & G.S.West) Komárek, Kastovsky & Jezberová	*	*
Aphanizomenon flos-aquae Ralfs ex Bornet & Flahault	*	*
Aphanocapsa elachista West & G.S.West		*
Aphanocapsa delicatissima West & G.S.West	*	*
Aphanocapsa planktonica (G.M.Smith) Komárek & Anagnostidis		*
Aphanocapsa sp.	*	*
Chroococcus sp.	*	*
Chroococcus turgidus (Kützing) Nägeli	*	
Dolichospermum spiroides (Klebhan) Wacklin, L.Hoffmann & Komárek	*	
Gloethrichia sp.	*	
Limnococcus limneticus (Lemmermann) Komárková, Jezberová, O.Komárek & Zapomelová	*	*
Merismopedia sp.	*	
Microcystis aeruginosa (Kützing) Kützing	*	
Microcystis sp.	*	*
Oscillatoria sp.	*	
Oscillatoria limosa C.Agardh ex Gomont		*
Planktolyngbya limnetica (Lemmermann) Komárková-Legnerová & Cronberg	*	
Pseudanabaena catenata Lauterborn	*	*
Rhabdogloea smithii (Chodat & F.Chodat) Komárek	*	
Snowella lacustris (Chodat) Komárek & Hindák	*	
Synechococcus linearis (Schmidle & Lauterborn) Komárek	*	
Woronichinia naegeliana (Unger) Elenkin	*	
Chlorophyta		
Ankistrodesmus fusiformis Corda	*	
Ankyra judayi (G.M.Smith) Fott	*	*
Carteria simplex Pascher		*
Characium angustum A.Braun	*	*
Coelastrum microporum Nägeli	*	*
Coelastrum sp.		*
Coenococcus sp.	*	
Crucigenia tetrapedia (Kirchner) Kuntze	*	
Crucigeniella pulchra (West & G.S.West) Komárek	*	*
Desmodesmus bicaudatus (Dedusenko) P.M.Tsarenko	*	*
Desmodesmus communis (E.Hegewald) E.Hegewald	*	
Golenkinia radiata Chodat	*	*
Hariotina polychorda (Korshikov) E.Hegewald		*
Hariotina reticulata P.A.Dangeard		*

Table 2. (Continued)

Korshikoviella limnetica (Lemmermann) P.C.Silva	*	*
Lemmermannia triangularis (Chodat) C.Bock & Krienitz	*	
Messastrum gracile (Reinsch) T.S.Garcia		*
Monactinus simplex (Meyen) Corda	*	
Monoraphidium contortum (Thuret) Komárková-Legnerová	*	
Monoraphidium sp.	*	
Mucidosphaerium pulchellum (H.C.Wood) C.Bock, Proschold & Krienitz	*	*
Oocystidium ovale Korshikov	*	*
Oocystis lacustris Chodat	*	*
Pandorina morum (O.F.Müller) Bory	*	*
Paradoxia multiseta Svirenko		*
Pediastrum duplex Meyen	*	*
Planktosphaeria gelatinosa G.M.Smith		*
Pseudodidymocystis planctonica (Korshikov) E.Hegewald & Deason		*
Radiococcus polycoccus (Korshikov) I.Kostikov, T.Darienko, A.Lukesová & L.Hoffmann		*
Scenedesmus sp.		*
Schroederia sp.	*	*
Schroederia spiralis (Printz) Korshikov		*
Tetradesmus obliquus (Turpin) M.J.Wynne		*
Tetraëdron minimum (A.Braun) Hansgirg	*	*
Tetrastrum glabrum (Y.V.Roll) Ahlstrom & Tiffany	*	
Tetrastrum sp.	*	
Tetrastrum staurogeniiforme (Schröder) Lemmermann	*	
Volvox sp.		*
Streptophyta		
Closterium aciculare T.West	*	*
Closterium acutum Brébisson	*	*
Cosmarium margaritiferum Meneghini ex Ralfs	*	*
Cosmarium sp.	*	*
Cosmarium subprotumidum Nordstedt	*	
Costerium pronum Brébisson		*
Elakatothrix gelatinosa Wille	*	*
Elakatothrix genevensis (Reverdin) Hindák	*	*
Elakatothrix lacustris Korshikov	*	
Elakatothrix sp.		*
Elakatothrix spirochroma (Reverdin) Hindák		*
Gonatozygon monataenium De Bary	*	
Staurastrum pingue var. planctonicum (Teiling) Coesel & Meersters	*	*
Staurastum sp.		*
Euglenophyta		

Table 2. (Continued)

Euglena viridis (O.F.Müller) Ehrenberg	*	
Lepocinclis oxyuris (Schmarda) B.Marin & Melkonian	*	
Phacus curvicauda Svirenko	*	
Trachelomonas hispida (Perty) F.Stein	*	*
Trachelomonas oblonga Lemmermann	*	
Trachelomonas planctonica Svirenko	*	
Trachelomonas sp.	*	*
Trachelomonas volvocina (Ehrenberg) Ehrenberg	*	
Pyrrhophyta		
Ceratium hirundinella (O.F.Müller) Dujardin	*	*
Gymnodinium sp.	*	
Peridinium sp.	*	*
Cryptophyta		
Cryptomonas sp.	*	
Ochrophyta		
Chrysophyceae		
Uroglena sp.		*
Synurophyceae		
Mallomonas acaroides Perty	*	*
Mallomonas caudata Iwanoff [Ivanov]	*	*
Mallomonas sp.	*	*
Bacillariophyceae		
Amphora sp.	*	
Asterionella formosa Hassall	*	*
Aulacoseira granulata (Ehrenberg) Simonsen	*	*
Aulacoseira granulata var.angustissima (Otto Müller) Simonsen	*	*
Cocconeis pediculus Ehrenberg	*	
Cocconeis placentula Ehrenberg	*	*
Cocconeis placentula var.euglipta (Ehrenberg) Grunow	*	
Cocconeis sp.	*	
Cymbella cymbiformis C.Agardh	*	*
Diatoma vulgaris Bory		*
Epithemia sp.	*	
Fragilaria acus (Kützing) Lange-Bertalot	*	*
Fragillaria capucina Desmazières	*	
Fragillaria crotonensis Kitton	*	*
Melosira varians C.Agardh	*	
Navicula sp.	*	*
Stephanodiscus hantzschii Grunow	*	*
Ulnaria ulna (Nitzsch) Compère	*	

Table 3. Trait-separated functional groups of phytoplankton in Kardzhali Reservoir (according to Reynolds et al., 2002; Padisak et al., 2009; Borics et al., 2016)

FG	Phytoplankton representatives	Habitat	Tolerances	Sensitivities
C	*Asterionella formosa*	mixed, eutrophic, small - medium lakes	Light, C	Si exhaustion
D	*Stephanodiscus hantzschii*	shallow, enriched turbid waters, including rivers	Flushing	nutrient depletion
	Ulnaria ulna, Fragilaria acus			
E	*Mallomonas caudata*	usually small, oligotrophic, base	low nutrients	CO_2 deficiency
	Mallomonas sp.	poor lakes or heterotrophic ponds	resort to mixotrophy	
F	*Ankistrodesmus fusiformis*	clear epilimnia	low nutrients, high turbidity	CO_2 deficiency
	Coenococcus sp.			
	Oocystis lacustris			
	Elakatothrix gelatinosa			
	Elakatothrix genevensis			
	Elakatothrix lacustris			
	Mucidosphaerium pulchellum			
G	*Pandorina morum*	short, nutrient-rich water columns	high light	nutrient deficiency
H1	*Anabaena* sp.	eutrophic, both stratified and shallow lakes with low nitrogen content	low nitrogen, low carbon	mixing, poor light, low phosphorus
	Anabaena sphaerica			
	Dolichospermum spiroides			
	Aphanizomenon flos-aquae			
J	*Coelastrum microporum*	shallow, enriched lakes, ponds and rivers		settling into low light
	Coelastrum sp.			
	Pediastrum duplex			
K	*Aphanocapsa delicatissima*	short, nutrient-rich water columns		deep mixing
	Aphanocapsa planktonica			
	Aphanocapsa sp.			
	Anathece clathrata			
L_O	*Chroococcus turgidus*	deep and shallow, oligo to eutrophic, medium to large lakes	segregated nutrients	prolonged or deep mixing
	Limnococcus limneticus			
	Woronichinia naegeliana			
	Ceratium hirundinella			
M	*Microcystis aeruginosa*	dielly mixed layers of small eutrophic, low latitude lakes	high insolation	flushing, low total light
MP	*Cocconeis placentula*	frequently stirred up, inorganically turbid shallow lakes		
N	*Cosmarium subprotumidum*	mesotrophic epilimnia	nutrient deficiency	stratification, pH rise
P	*Closterium aciculare*	eutrophic epilimnia	mild light and C deficiency	stratification Si depletion
	Aulacoseira granulata			
	Closterium acutum			
	Fragillaria crotonensis			
	Staurastrum pingue var. planctonicum			
S1	*Planktolyngbya limnetica*	turbid mixed layers	highly light deficient	flushing
T_C	*Pseudanabaena catenata*	shallow, turbid mixed layers	light deficient conditions	flushing
	Oscillatoria limosa			
W1	*Lepocinclis oxyuris*	small organic ponds	high BOD	grazing
W2	*Trachelomonas planctonica*	shallow mesotrophic lakes	?	?
X1	*Ankyra judayi*	shallow mixed layers in enriched conditions	stratification	nutrient deficiency filter feeding
Z	*Synechococcus linearis*	metalimnia or upper hypolimnia of oligotrophic lakes		

well as *Cosmarium subprotumidum* Nordstedt (11.9%) from **N** and *Ulnaria ulna* (7.7%) from codon **D** dominated in the community at all studied stations in the reservoir (Table 3).

In July 2016 the dominant group included *Aphanizomenon flos-aquae* Ralfs ex Bornet & Flahault (50%) from **H1**, the colonial green algae **J** - *Coelastrum microporum* (47.3%), *Mucidosphaerium pulchellum* (H.C.Wood) C.Bock, Proschold & Krienitz (65.2%) classified in the codon **F**, *Ankyra judayi* in **X1** (44.7%) and the diatom *Fragilaria crotonensis* (29%) from functional group **P**. In August 2016, we have detected a significant change in the species composition and the functional groups, respectively. Along with the species from the functional group **P** *Fragilaria crotonensis* (54.3%) and *Mucidosphaerium pulchellum* (**F**, 37.8%), we have also established a high abundance of the blue green algae *Aphanocapsa planctonica* (G.M.Smith) Komárek & Anagnostidis (93.2%), *Aphanocapsa delicatissima* West & G.S.West (79.5%) and *Anathece clathrata* (W.West & G.S.West) Komárek, Kastovsky & Jezberová (39.5%), classified in the functional group **K**. *Aphanizomenon-flosaquae* related to **H1** codon (16.3%), *Oscillatoria limosa* C.Agardh ex Gomont (7.8%) from group $\mathbf{T_C}$ and *Pseudanabaena catenata* Lauterborn (5.4%) from codon **S1** (Table 3). At the beginning of the autumn (September 2015), mostly species from functional group **P** dominated: the diatoms *Aulacoseira granulata* (Ehrenberg) Simonsen (90%), *Fragilaria crotonensis* (89%) and the streptophytes *Closterium aciculate* T.West (32%), *Closterium acutum* Brébisson (30.5%), as well as the *Trachelomonas planctonica* Svirenko (12.3%) from **W2** codon.

In October 2015 the members of the functional group **P** had the highest abundance again – *Fragilaria crotonensis* (70.4%), *Aulacoseira granulata* (24.4%) and *Staurastrum pingue* var. *planctonicum* (Teiling) Coesel & Meersters (53%) and the representative of the codon **H1** – *Aphanizomenon flos-aquae* (32.7%). Among the dominant species for the period are those classified into the following functional groups: **J** – *Coelastrum microporum* (17.3%), **M** – *Microcystis aeruginosa* (Kützing) Kützing (11.3%), **S1** – *Planktolyngbya limnetica* (Lemmermann) Komárková-Legnerová & Cronberg (5.1%), and **W1** – *Lepocinclis oxyuris* (Schmarda) B.Marin & Melkonian (5.8%).

In October, the green algae dominated in the samples at all studied sites, including *Pandorina morum* (O.F.Müller) Bory (56.7%) from codon **G** and *Coelastrum microporum* (29.3%) from group **J**, the pyrrhophyte *Ceratium hirundinella* (O.F.Müller) Dujardin (5.3%) from $\mathbf{L_O}$ and the blue-green algae from group **Z** *Synechococcus linearis* (Schmidle & Lauterborn) Komárek (3.6%). The members of the codon **P** *Closterium aciculate* (58.1%), *Fragilaria crotonensis* (32.4%) and *Staurastrum pingue* var. *planctonicum* (30%), as well as the *Asterionella formosa* Hassall (15.4%) from functional group **C** were identified for the same period (Table 3).

Discussion

During the last decade, the phytoplankton in Kardzhali reservoir is relatively well studied. According to Belkinova et al. (2007), the species, classified into functional groups **P**, **J**, **F**, **D**, **X1**, **H1**, and **Z** have been the most abundant in the aquatory of the reservoir. In 2011, the majority of identified species were distributed to the functional groups **P**, **D**, $\mathbf{L_O}$, **K**, **C**, and **G** (Dochin, 2014). For the period from 2009 to 2012, the most common were the codons: **P**, **E**, **D**, **C**, **G**, **MP**, and others (Dochin, 2015). Our data confirm some of the results from previous studies of the functional classification of phytoplankton in the Bulgarian water basin. The comparison of the identified dominant functional groups with the assessment of the general status in lakes and reservoirs in Bulgaria referred in the legislative group of oligotrophic water bodies (FP1) shows that the most common is the functional group **F** (Stoyneva, 2014). However, in this work the same author and also Stoyneva et al. (2013, 2015) insist on the necessity to change this legislative classification and take it out from defining by trophicity only, which does not reflect their real ecological (and even trophic) status and peculiarities. Sarmento and Descy (2008) define this group as a typical dominant group in mesotrophic basins of Belgium. According to Belkinova et al. (2014), the most common functional groups in Kardzhali reservoir have been **P** and **F**. According to the same researchers, the taxa classified in function group **F** dominate some of the reservoirs in Bulgaria (Studen Kladenets, Kardzhali, and Ivailovgrad). Group **F** has been represented by the colonial green algae *Oocystis lacustris* and *Sphaerocystis planctonica* (Korshikov) Bourrelly in the Kardzhali reservoir (Belkinova et al., 2014). The authors state that the massive abundance of the **P**-species is an indication for a change in the ecological status of the semi-mountain reservoirs.

In the present study, the most common in the Kardzhali reservoir are the members of the functional groups **F**, **P**, **K**, **H1** and **J**. The species *Fragilaria crotonensis*, *Closterium aciculate* and *Aulacoseira granulata,* representatives of the functional group **P**, dominated throughout the whole study period in the water samples. Usually, the members of the functional group **P** inhabit eutrophic waters (Reynolds et al., 2002; Padisak et al., 2009; Belkinova et al., 2014). Sarmento and Descy (2008) define this group as a typical dominant group in mesotrophic basins. Based on our findings Kardzhali reservoir could be characterized as a mesotrophic water basin.

According to Reynolds et al. (2002), the members of the functional group **F** are tolerant to a spring and autumn water overturn, resulting in the homogenization of the water column in mesotrophic and eutrophic lakes. We have established that the group is the most numerous in the summer period, represented by the species O*ocystis lacustris*, *Elakatothrix gelatinosa* and *Mucidosphaerium pulchellum*. The colonial green algae from the functional group **J** have been usually found in shallow lakes, reservoirs and rivers in the summer (Reynolds et al., 2002; Sarmento and Descy, 2008; Becker et al., 2009). We found the species, classified in codon **J** (*Coelastrum microporum* and *Pediastrum duplex*), to be more common during the summer months. A number of researchers describe the presence of the colonial blue-green algae of codon **K** (*Aphanocapsa, Anathece*) in shallow nutrient-rich waters during the summer (Reynolds et al., 2002; Padisak et al., 2009; Belkinova et al., 2014; Celik and Sevindik, 2015). Our results differ from these findings and similar to Becker et al. (2010), show that the members of the functional group **K** (*Aphanocapsa planctonica, Aphanocapsa delicatissima* and *Anathece clathrata*) are also present in a large, deep mesotrophic reservoir.

In addition of the above-mentioned, the following fifteen functional groups were presented in the water samples: **C**, **D**, **E**, **G**, **H1**, $\mathbf{L_O}$, **M**, **MP**, **N**, **S1**, $\mathbf{T_C}$, **W1**, **W2**, **X1**, and **Z**. The members of eleven codons: *Asterionella formosa* (**C**), *Pandorina morum* (**G**), *Ceratium hirundinella* ($\mathbf{L_O}$), *Microcystis aeruginosa* (**M**), *Cocconeis placentula* (**MP**), *Oscillatoria limosa* ($\mathbf{T_C}$), *Lepocinclis oxyuris* (**W1**), *Trachelomonas planctonica* (**W2**), *Ankyra judayi* (**X1**), *Synechococcus linearis* (**Z**) and *Cosmarium subprotumidium* (**N**) were presented by only one taxon. The taxa *Trachelomonas* sp. (**W2**) and *Ankyra judayi* (**X1**) have been reported to inhabit shallow mesotrophic lakes (Reynolds et al., 2002; Reynolds, 2006) and *Synechococcus linearis* (**Z**) has been found in deep oligotrophic lakes. Two taxa were found in two of the functional groups *Stephanodiscus hantzschii* and *Ulnaria ulna* (**D**), *Mallomonas* sp. and *Mallomonas caudata* (**E**). According to Belkinova et al. (2014), *Mallomonas* sp., *Mallomonas caudata* of group **E** and *Asterionella formosa*, classified in the **C** codon, have been among the dominant taxa in the Toshkov Chark reservoir. Padisak et al. (2006) stated that the member of the codon **MP** *Cocconeis placentula* has been often found in muddy and shallow lakes. The members of the $\mathbf{L_O}$ codon *Chroococcus turgidus* and *Woronichinia naegeliana* inhabit deep or shallow oligo- and eutrophic lakes (Reynolds et al., 2002). The same authors associate the presence of **S1** species such as *Planktolyngbya limnetica* with muddy water basins. The codon member **G** *Pandorina morum* inhabits small, eutrophic and nutrient-rich lakes (Reynolds et al., 2002). Similar to our study the species of group **P** have been found to dominate in other reservoirs in Bulgaria such as Krichim (*Fragilaria crotonensis*), Borovitsa, Ovcharitsa and Poroy reservoirs (*Aulacoseira granulata*, Belkinova et al., 2014).

Similar to our study, *Aphanizomenon flos-aquae,* a member of the **H1** group has been found as one of the dominant species in Vacha and Aheloy reservoirs (Belkinova et al., 2014), as well as in the high-mountain Dospat reservoir (Dochin and Stoyneva, 2016). The dominant groups in other Bulgarian reservoirs such as Toshkov chark, Kardzhali, and Belmeken include species, classified in codon **K** (*Anathece clathrata* and *Aphanocapsa delicatissima*). The colonial blue-green algae *Aphanocapsa delicatissima* (**K**) has been established also in subtropical lakes and reservoirs in Brazil (Crossetti et al., 2013; Silva and da Costa, 2015). *Ceratium hirundinella* has been reported by Belkinova et al. (2014) as a member of the $\mathbf{L_O}$ group in Eleshnitza reservoir. The distribution of these species is not geographically constricted, as they have been found in reservoirs in Serbia (Ćirić et al., 2015). Belkinova et al. (2014) detected the presence of *Pandorina morum* (**G**), *Staurastrum* sp. (**P**) and *Cosmarium* sp. (**N**) in their study. In this study, *Pseudoanabaena catenata* (**S1**) is among the abundant species in the Kardzhali dam during the summer. According to Padisák et al. (2009) this species occurs predominantly in turbulent and turbid waters. The dominant complexes in Kardzhali reservoir also include the members of the functional groups **C** and **D** (*Asterionella formosa*, *Ulnaria ulna*). The presence of representatives of groups **C** (*Asterionella formosa*), **D** (*Ulnaria ulna*) and **P** (*Closterium acutum* var. *variabile* (Lemmermann) Willi Kreig) have been also found by Ćirić et al. (2015). *Asterionella formosa* inhabits waters with high trophic status and members of codon **D** *Ulnaria ulna* and *Stephanodiscus hantzschii* associate with the turbid environment (Padisak et al., 2009). Finally, in agreement with the same authors the application of the phytoplankton functional classification approach is an effective tool for understanding seasonal and spatial changes in planktonic communities in water systems, but after careful consideration of whether the division into groups according to the proposed criteria reflects the ecological characteristics and peculiarities of the species.

Conclusions

In conclusion, in the present study we have analyzed the functional classification of the phytoplankton in Kardzhali reservoir for the period July 2015-November 2016. According to our results, the dominant complex planktonic algae was comprised of forty-three taxa, distributed into nineteen functional groups, based on the classic Reynolds study. The most common are members of function groups **F**, **P**, **K**, **H1** and **J**. The data confirm the applicability of this approach to better understanding environmental phytoplankton processes. The present study shows that the proposed model of functional groups can be applied in monitoring programs, seasonal dynamics assessment, and for the collection of more comprehensive information on living strategies, habitats and adaptations of phytoplankton communities in lakes, basins, and reservoirs.

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