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Review Article

Dominance of *Microcystis* spp. in Lake Dojran – a consequence of 30 years of accelerated eutrophication

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ABSTRACT: In the past 30 years, Lake Dojran (Macedonia) has experienced extreme periods of droughts and water removal for irrigation purposes that have resulted in an accelerated process of eutrophication leading to hypertrophy. In the present paper, we document successive changes of the microflora in plankton communities as a result of the prolonged eutrophication impact over this period. The original well established phytoplankton community in the lake, which was rich in species (especially coccoid green forms belonging to the genera *Pediastrum, Scenedesmus, Staurastrum* and *Tetraedon*) and which followed the natural annual succession in the form of diatoms > green algae > cyanobacteria, has been greatly modified over the years. Two episodes of intensive 'water blooms' have been recorded, one involving *Gloeotrichia natans* (in 1993/94) and the other the dinoflagellates *Ceratium hirudinella* and *C. monoceros* (1996/97), events that indicated drastic changes of the ecological conditions. Dominance of *Dolichospermum* aff. *flosaquae* was recorded in 2008. Finally, the phytoplankton in Lake Dojran completed a turnover towards the overall dominance of *Microcystis* spp., with a total of nine co-existing species. The first documented record of *Microcystis protocystis* outside pan- and neotropical regions is here presented. The described successions in phytoplankton species composition and dominance are attributed to gradual and constant changes in the nutrient status of the lake in the direction of hypertrophy, the basic nutritive parameters, total P and N content, having increased more than 40- and eight-fold, respectively, over the years. Measurements of cyanobacterial toxicity have been few, and they were sporadically performed. Nonetheless, the presence of microcystins in the water has been documented, with indications of significant concentration peaks. The paper is intended to be a tribute to all scientific workers who, like Professors Jelena and Živojin Blaženčić, have devoted their expertise and time to the task of revealing forced changes in the lake's biota in the hope of creating a favourable atmosphere for immediate human intervention to save this once very rich and diverse ecosystem.

Keywords: Lake Dojran, eutrophication, phytoplankton changes, *Microcystis* sp. dominance, neo-tropical form

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INTRODUCTION

Located on the south-east border of Macedonia with Greece (Fig. 1), Lake Dojran is a remnant of the once much bigger Paeonic Lake, a member of the former Aegean group of tectonic lakes (most of which are extinct) located around 41° N in the vicinity of the Aegean Sea. This small lake (with an approximate surface area of only 43 km^2) has been the focus of scientific investigations since the beginning of 20th century, mostly due to its famous reputation as the most fish-rich (per unit of surface area) in southeast Europe. The first record of systematic algological research can be found in Schröeder's (1921) work, while Kozarov (1958) listed almost 60 algal taxa in the lake's phytoplankton. These two works report a total of 73 algal taxa for Lake Dojran's phytoplankton, although there are no data on annual cycles or dominance of different algal groups and specific taxa in the detected 'water blooms'.

The first comprehensive investigation of Lake Dojran's phytoplankton can be found in the work of Stojanov

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Figure 1. Map of the Republic of Macedonia and its position in Southern Europe (the location of Lake Dojran is indicated by a red arrow), with aerial photo of the lake's position near the Vardar River and Thessaloniki bay.

(1972). In his research, Professor Stojanov followed the annual phytoplankton cycle and dominance of specific taxa in the overall plankton community. This work increased the known number of algal taxa in the lake's plankton to 133, and also documented the succession of diatoms, blue-green algae and green algae over the year. One of the specific findings was the dominance of *Ceratium hirundinella* (O.F.Müller) Dujardin in winter samples.

Another fundamental study of Lake Dojran's algal flora was later conducted by the same author (Stojanov 1976) in an attempt to resolve the structure and composition of periphyton communities. With this work, the total number of taxa rose to 257, and the lake was labeled as a stable eutrophic system with significant biomass production and dominance of diatoms, green algae and blue-green algae in the periphyton.

The subsequent period (until 1988) produced several scientific papers dealing with the algal flora and periphyton production (Stojanov 1983, 1986), the chironomid fauna (Angelovski 1984) and the dragonfly fauna (Karaman 1981) among other subjects. The existence of stable environmental conditions during this period enabled the natural microflora successions to transpire with the plankton dominance typical throughout the lake's long history. Serious problems for the lake's ecosystem began in 1988 when a huge amount of water (initially more than 21 million m^3) was used for irrigation purposes by Greece. The lake's water level dropped by 60 cm at that time and by more than 7 meters in the years to follow.

This paper aims to present the forced microflora successions caused by the rapid and accelerated eutrophication that was triggered by artificial removal of the surface water column, a prolonged period of dry conditions (1990-1998) and failure to improve the ecological status of the lake by means of control and treatment of communal waste waters. The extensive accumulation of dead organic matter, continuous inflow of unpurified waste waters, wrong infrastructural decisions and misguided construction projects have forced specific dominance of taxa belonging to the genus *Microcystis* Lemmermann (cyanobacteria or blue-green algae) in the plankton as a final consequence of the severe eutrophication pressure. The paper also intends to emphasise the long struggle of scientists to document lethal changes in the lake's ecosystem and initiate relevant actions in order to stop and reverse the deadly consequences of such rapid eutrophication, efforts that have so far proved in vain. Nonetheless, these efforts have produced a wealth of significant data and, as documented in the latest works (Krstić 2011; Krstić *et al.* 2016), have yet again singled out Lake Dojran as an ecosystem unique for the presence of a total of nine *Microcystis* species at the same time, one of which (*M. protocystis* W.B.Crow) has so far been reported only for pan-tropical and neo-tropical regions.

Presentation and analyses of past and current results. Comparative analyses of the basic physicochemical parameters important as indicators of eutrophication processes in the lake reveal a progressive decrease of water quality (Table 1). This is clearly seen in the decrease of dissolved oxygen content and transparency (Secchi depth), while the basic nutritive parameters, total P and N content, increased more than 40- and 8-fold, respectively. In combination with other pollution parameters and decrease of the water level, the lake has been a deeply hypertrophic environment for a prolonged period. The values for these parameters obtained during the 2015 sampling are markedly lower than those recorded in 2004-2005, but the overall ecological status of the lake is still hypertrophic. Such an environment must have had a detrimental influence on the biota, especially on phytoplankton, a fact we will try to document in the following text.

Table 1. Comparison of basic physicochemical parameters of Lake Dojran's water recorded in past research and during the sampling campaign conducted from May to September of 2015 ([1]Stojanov 1972; [2]Stojanov 1976; [3]Lokoska *et al*. 2006; [4]Krstić *et al*. 2016).`

	1971[1]	**1974-75[2]**	**2004-2005[3]**
Maximal depth (m)	10.5	10.4	6.5
Temperature (°C)	4.4 – 27	4.0-25.5	
D.O. (mg/L)	7.0-13.2	8.92-14.02	3.08-11.95
pH	7.60 – 8.85	7.8-8.85	
Secchi depth (m)	0.7-3.6	1.5-6.0	
Total P (µg/L)	12.01	11.3	50-519
Total N (µg/L)	848	811	311-3,245
	May 2015[4]	**July 2015[4]**	**September 2015[4]**
Maximal depth (m)	9	9	9
Temperature (°C)	22.4 – 24.7	24.2 – 25.5	23.4 – 28.7
D.O. (mg/L)	9.2 – 9.4	2.5 – 5.7	6.1 – 10.7
pH	7.23 – 8.04	8.10 – 9.27	8.37 – 9.39
Conductivity (µS)	543 – 662	630 – 750	686 – 761
Secchi depth (m)	3.9 – 4.4	2.0 – 2.7	0.7 – 1.2
Chl. a (µg/L)	0.332 – 2.0	3.8 – 11.88	13.4 – 22.7
Total P (µg/L)	80 – 190	120 – 210	150 – 380
Total N (µg/L)	600 – 1,900	600 – 6,400	730 – 1,320
Ammonia (µg/L)	12 – 50	13 – 60	50 – 180
Nitrites (µg/L)	< 10	< 10	<10 – 19
Nitrates (mg/L)	< 1	< 1	<1 – 2.5
Potassium (mg/L)	4.5 – 9.5	6.3 – 9.5	6 – 11

As pointed out in the paper of Stojanovski & Krstić (1995), Lake Dojran prior to 1988 was occupied by a rich and to some extent endemic biota community (Table 2), with very intensive periphyton and phytoplankton bio-production. However, the vast amount of removed water and subsequent dry period have led to drastic shrinkage of the water column and habitat loss. The lake has become only 1.5 m deep (average depth was 6.5 m), and its fundamental ecological balance shifted as a consequence of the intensive impact and pressures on the biota. The result of this was the loss of almost 110 algal taxa with dominance of only one species in the plankton, the diatom *Aulacoseira granulata* (Ehrenberg) Simonsen, and a very limited number of other taxa still present (Fig. 2a). The authors of the indicated study emphasised extinction of the native microflora and also the appearance of taxa which were never before recorded in the lake system, forms like *Nitzschia angustata* (W.Smith) Grunow, *N. apiculata* (W.Gregory) Grunow, *Hantzschia amphioxys* (Ehrenberg) Grunow and *Navicula (Fallacia) pygmaea* (Kützing) Pantoczek, whose presence is unquestionably indicative of higher levels of trophy and saprobity. Prior to this period and research, an interesting phenomenon was observed in the lake. To be specific, vast proliferation of *Gloeotrichia natans* Rabenhorst ex Bornet & Flahault, a non-planktonic blue-green alga usually found in a very limited number of colonies attached to submerged plants, produced a layer 30 cm deep on the mud surface. This situation led to intensive accumulation of dead organic matter on the lake's bottom, which caused oxygen depletion in the hypolimnion. The very deadly and obvious consequence was the massive extinction of the bottom-dwelling fauna, mostly mussels [*Dreissena polymorpha (presbensis*)].

Table 2 presents changes in the composition of species in the plankton over the investigated period. Figure 2 attempts to give a general impression of the overall dominance of specific taxa or genera. It is quite obvious that the number of planktonic species in 1971 was much higher with especially pronounced occurrence of planktonic representatives of green algae, mainly ones belonging to the genera *Pediastrum* Meyen, *Scenedesmus* Meyen or *Cosmarium* Corda ex Ralfs, and also very marked presence of *Phacus* Dujardin among euglenoids. Cyanobacteria were also present with a fairly good number of genera, but they were

Table 2. Phytoplankton community of Lake Dojran during the selected critical years of intensive ecological changes in comparison with the base planktonic microflora composition prior to those changes (1971) ([1]Stojanov 1972; [2]Stojanovski & Krstić 1995; [3]Krstić *et al*. 2015).

1971[1]	1995[2]	2015[3]
Cyanophyta	**Cyanophyta**	**Cyanophyta**
Aphanizomenon flosaquae Ralfs ex Bornet & Flahault	*Aphanizomenon flosaquae*	*Aphanizomenon gracile Lemmermann*
Cylindrospermum voukii Pevalek	*Dolichospermum (Anabaena) flosaquae*	*Aphanothece stagnina* (Sprengel) A.Braun
Dolichospermum (Anabaena) flosaquae (Brébisson ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J.Komárek	*Dolichospermum (Anabaena) sigmoideum* (Nygaard) Wacklin, L.Hoffmann & Komárek	*Dolichospermum circinale* (Rabenhorst ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J.Komárek
Dolichospermum (Anabaena) scheremetieviae (Elenkin) Wacklin, L.Hoffmann & Komárek	*Gloeotrichia natans* Rabenhorst ex Bornet & Flahault	*Dolichospermum scheremetieviae*
Gloeocapsa minutus (Kützing) Hollerbach	*Merismopedia elegans*	*Gloeothece membranacea* (Rabenhorst) Bornet
Merismopedia elegans A.Braun ex Kützing	*Microcystis aeruginosa*	*Merismopedia glauca*
Merismopedia glauca (Ehrenberg) Kützing	*Microcystis flosaquae*	*Microcystis aeruginosa*
Merismopedia punctata Meyen	*Planktolyngbya contorta*	*Microcystis botrys* Teiling
Microcystis aeruginosa (Kützing) Kützing	**Chrysophyta**	*Microcystis flosaquae*
Microcystis flosaquae (Wittrock) Kirchner	*Dinobryon divergens*	*Microcystis ichthyoblabe* (G.Kunze) Kützing
Oscillatoria limosa C.Agardh ex Gomont	**Dinophyta**	*Microcystis novacekii* (Komárek) Compère
Planktolyngbya contorta (Lemmermann) Anagnostidis & Komárek	*Ceratium hirundinella*	*Microcystis protocystis* W.B.Crow
Chrysophyta	**Bacillariophyta**	*Microcystis smithii* Komárek & Anagnostidis
Dinobryon divergens O.E.Imhof	*Asterionella gracillima*	*Microcystis viridis* (A.Braun) Lemmermann
Dinophyta	*Aulacoseira granulata*	*Microcystis wesenbergii* (Komárek) Komárek ex Komárek
Ceratium hirundinella (O.F.Müller) Dujardin	*Fragilaria capitata*	*Phormidium interruptum* Kützing ex Forti
Ceratium hirundinella var. *silesiacum* (Schroeder) Huber-Pestalozzi	*Fragilaria ulna*	*Phormidium inundatum* Kützing ex Gomont
Glenodinium quadridens (Stein) Schiller	*Tabellaria fenestrata*	*Planktolyngbya contorta* (Lemmermann) Anagnostidis & Komárek
Bacillariophyta	**Chlorophyta**	*Pseudanabaena mucicola* (Naumann & Huber-Pestalozzi) Schwabe
Asterionella gracillima (Hantzsch) Heiberg	*Closterium pronum*	*Snowella lacustris* (Chodat) Komárek & Hindák
Aulacoseira granulata (Ehrenberg) Simonsen	*Cosmarium tenue*	**Dinophyta**
Cyclotella petrowskae (?)	*Oocystis solitaria*	*Ceratium hirundinella*
Fragilaria capitata (Ehrenberg) Lange-Bertalot	*Pediastrum boryanum*	**Bacillariophyta**
Fragilaria ulna (Nitzsch) Lange-Bertalot	*Pediastrum clathratum* var. *punctatum*	*Aulacoseira granulata*
Tabellaria fenestrata (Lyngbye) Kützing	*Pediastrum duplex*	*Cyclotella meneghiniana* Kützing
Chlorophyta	*Pediastrum duplex* var. *reticulatum*	*Encyonema caespitosum* Kützing
Ankistrodesmus falcatus (Corda) Ralfs	*Pediastrum simplex* var. *granulatum*	*Melosira varians* C.Agardh

1971[1]	1995[2]	2015[3]
Closterium pronum Brébisson	*Scenedesmus arcuatus*	*Stephanodiscus hantzschii* Grunow
Cosmarium bioculatum Brébisson ex Ralfs	*Scenedesmus quadricauda*	*Stephanodiscus neoastrea* (Kützing) Grunow
Cosmarium humile Nordstedt ex De Toni	*Scenedesmus quadricauda* var. *longispina*	**Chlorophyta**
Cosmarium tenue W.Archer	*Staurastrum lunatum*	*Volvox aureus* Ehrenberg
Golenkinia radiata Chodat	*Staurastrum paradoxum*	*Eudorina elegans* Ehrenberg
Oocystis solitaria Wittrock	*Tetraedon limneticum*	*Sphaerocystis* sp.
Pediastrum angulosum var. *rugosum* Raciborski	*Tetraedon minimum*	*Cosmarium bioculatum*
Pediastrum bidentulum A.Braun		*Staurastrum paradoxu*
Pediastrum boryanum (Turpin) Meneghini		*Scenedesmus quadricauda*
Pediastrum clathratum var. *microporum* Lemmermann		**Euglenophyta**
Pediastrum clathratum var. *punctatum* Lemmermann		*Euglena viridis* (O.F.Müller) Ehrenberg
Pediastrum duplex Meyen		
Pediastrum duplex var. *reticulatum* Lagerheim		
Pediastrum simplex var. *granulatum* Lemmermann		
Scenedesmus arcuatus (Lemmermann) Lemmermann		
Scenedesmus bicaudatus Dedusenko		
Scenedesmus bijugatus Kützing		
Scenedesmus ecornis (Ehrenberg) Chodat		
Scenedesmus quadricauda (Turpin) Brébisson		
Scenedesmus quadricauda var. *longispina* (Chodat) G.M.Smith		
Staurastrum furcigerum (Brébisson) W.Archer		
Staurastrum lunatum Ralfs		
Staurastrum paradoxum Meyen ex Ralfs		
Staurastrum polymorphum Brébisson		
Tetraedon hastatum Schmidle		
Tetraedon limneticum Borge		
Tetraedon minimum (A.Braun) Hansgirg		
Tetraedon trigonum (Nägeli) Hansgirg		
Euglenophyta		
Phacus brevicaudatus (G.A.Klebs) Lemmermann		
Phacus longicauda (Ehrenberg) Dujardin		
Phacus orbicularis K.Hübner		
Phacus pleuronectes (O.F.Müller) Nitzsch ex Dujardin		

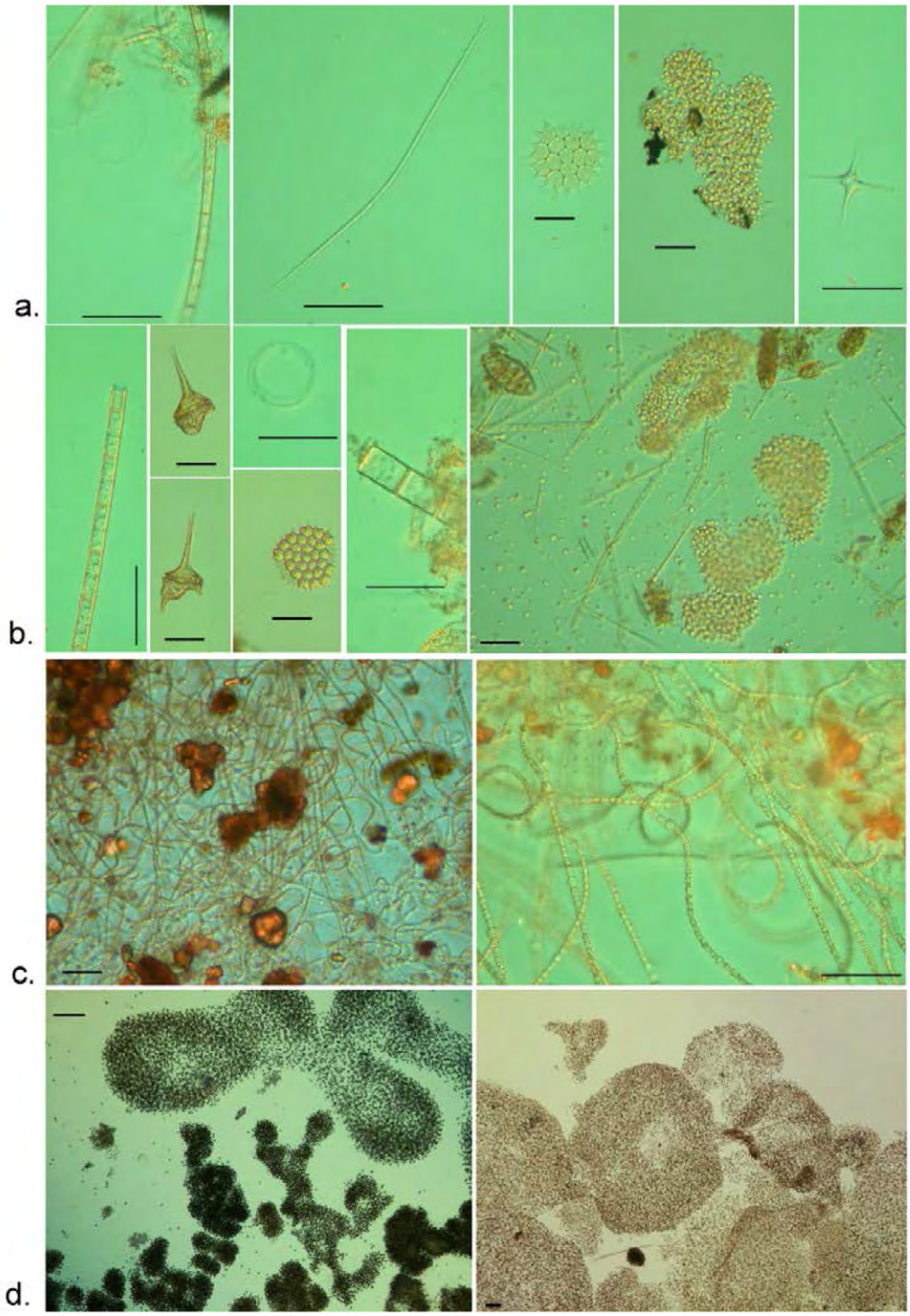

Figure 2. Phytoplankton composition of Lake Dojran in the last 20 years. **a**) 1995: Dominance of *Aulacoseira granulata.* Occasional presence of *Planktolyngbya contorta*, *Raphidiopsis mediterranea*, *Pediastrum boryanum, Microcystis* sp. (poor presence) and *Staurastrum* sp. **b**) 1997: In May, a clear dominance of the zooplankton. Among phytoplankton, three species showed co-dominance: *Planktolyngbya contorta*, *Aulacoseira granulata* and *Ceratium monoceros*. Poor presence of *Microcystis* sp. in association with *Pediastrum boryanum*, *Ceratium hirundinella* and *Melosira varians*. In July, a clear dominance of *Microcystis* spp. with *Aulacoseira granulata* was observed. Presence of *Raphidiopsis mediterranea* and *Planktolyngbya contorta*. **c**). 2008: dominance of *Dolichospermum aff. flosaquae*. **d**). 2015: clear dominance of *Microcystis* spp. (scale bar = 50 μm).

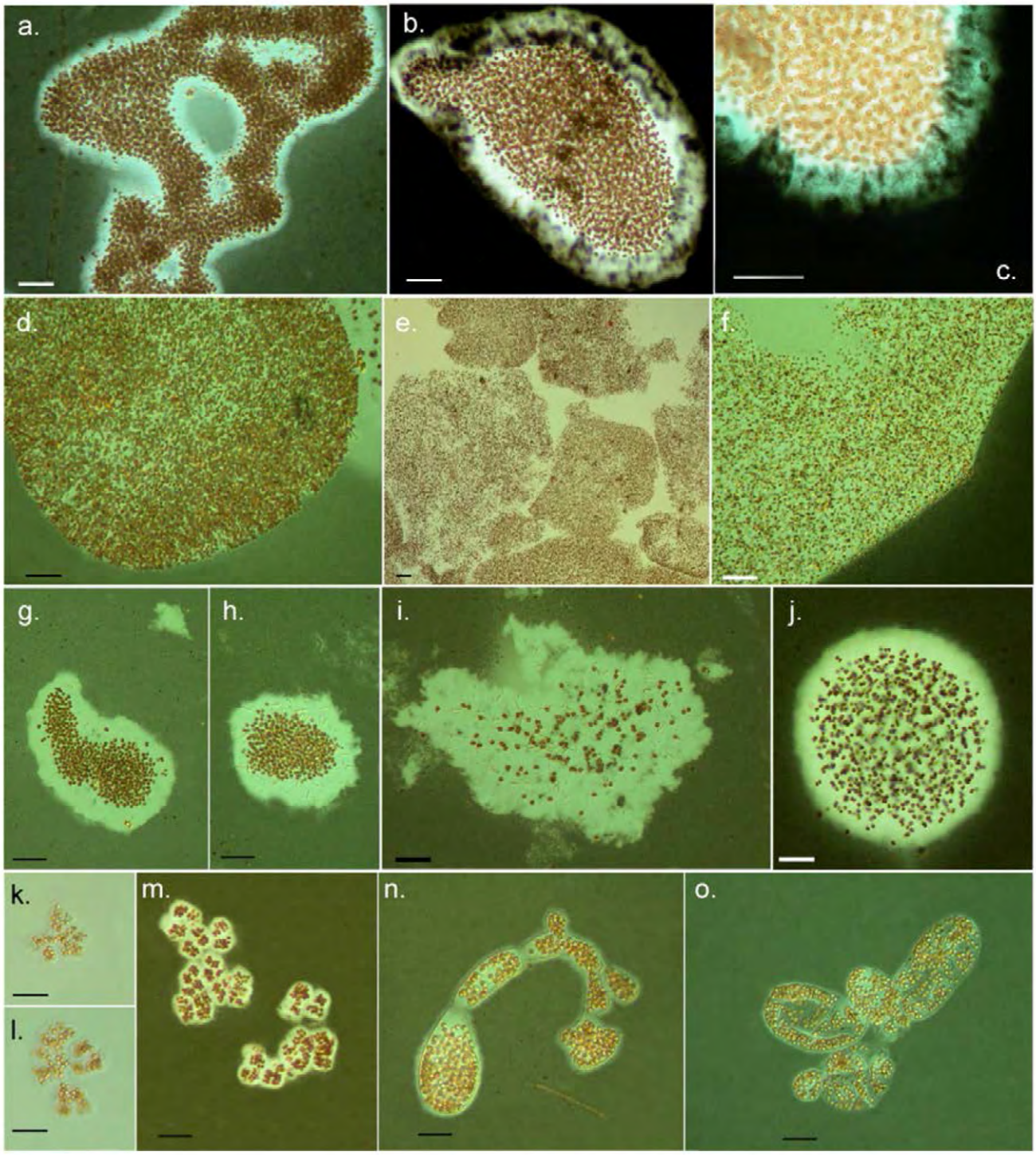

Figure 3. Occurrence of nine *Microcyctis* spp. in Lake Dojran in 2015. **a.** *Microcystis aeruginosa*; **b**. *Microcystis botrys*; **c.** *Microcystis botrys*, detail of mucilage (total magnification of ×1380); **d.** *Microcystis flosaquae*; **e.** *Microcystis ichthyoblabe*, general view of colony (total magnification of ×138); **f.** *Microcystis ichtyoblabe*; **g-h.** *Microcystis novacekii*; **i.** *Microcystis protocystis*; **j.** *Microcystis smithii*; **k-m**. *Microcystis viridis*; **n-o**. *Microcystis wesenbergii*. All microphotographs (except the ones on panel c and panel e, which depict special details of mucilage and colony form) were taken at a total magnification of ×345 and on colonies stained with China ink (exceptions are the microphotographs on panel e and panels k-l because China ink staining masks several critical characters of the types, most notably the refractive margin of *M. viridis*, which is more clearly visible without staining) (modified from Krstić *et al*. 2016) (scale bar = 50 μm).

not as dominant in the plankton as the green algae were. The period of intensive and devastating adverse impact on Lake Dojran (1995) was marked by a severe decrease in the number species, dominance of *Aulacoseira granulata* (Ehrenberg) Simonsen (Fig. 2) and complete absence of *Phacus* spp. In the summer months, intensive dominance of *Microcystis* spp. was also recorded. Intermittently in 2008, yet another shift in cyanobacteria communities was recorded (Fig. 2), in this case a massive proliferation of *Dolichospermum* aff. *flosaquae* (Brébisson ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J.Komárek. The full turnover towards cyanobacterial dominance was finally completed in 2015. At that point, *Microcystis* spp. taxa achieved full development, with *Aulacoseira granulata* in co-dominance and the first records of *Euglena viridis* (O.F.Müller) Ehrenberg in the ecosystem.

The next period in Lake Dojran's hyper-eutrophic 'evolution' was recorded in 1997-1998, when the lake turned red in colour due to massive proliferation of the dinophytes *Ceratium monoceros* Temponeras and *C. hirundinella* (Fig. 2b). The species *Planktolyngbya contorta* (Lemmermann) Anagnostidis & Komárek and *Aulacoseira granulata* were co-dominant, while various *Microcystis* forms were less present than usual. This state of equilibrium of the lake lasted for only several years in a row, a period in which different planktonic forms 'struggled' for survival in the massive presence of toxin-producing dinophyte strains. The lake never turned red again after this period.

During the period following the extensive dominance of dinophytes, the lake's ecological status changed again, but this time in favour of cyanobacteria. Many different species of cyanobacteria, like *Aphanizomenon flosaquae* Ralfs ex Bornet & Flahault, *Jaaginema subtilissimum* (Kützing ex Forti) Anagnostidis & Komárek, *Limnothrix redekei* (Goor) Meffert or *Planktolyngbya limnetica* (Lemmermann) Komárková-Legnerová & Cronberg (Cook *et al.* 2004), competed for dominance over the course of consecutive years, reaching a climax in the massive presence of a toxin-producing strain of *Dolichospermum (Anabaena) flosaquae* (Fig. 2c) in 2008. Measurements of toxicity were not performed in that period, but there are some reports of a continual presence of microcystins (Gkelis *et al.* 2015) from the Greek side of the lake.

Finally, the overall turnover towards hypertrophy of the lake was detected in the monitoring survey performed in 2015, when the massive dominance of different *Microcystis* forms such as *M. aeruginosa* (Kützing) Kützing and *M. ichthyoblabe* (G.Kunze) Kützing (Fig. 2d) was recorded. A total of nine *Microcystis* species (Fig. 3) were recorded in co-existence in the samples from July to September, a scientific result hitherto not reported anywhere else in the world (Krstić *et al.* 2016). These findings can obviously be attributed to intensive changes of the lake's ecology in the direction of accelerated eutrophication (Basi *et al.* 2008; Svirčev *et al.* 2014) (Table 1), such changes supporting the proliferation of this particular cyanobacterial genus and its wide development. Global climate change might be a contributing factor as well, since the occurrence of the pan- or neo-tropical species *Microcystis protocystis* (Fig. 2i) was reported for the first time in a European ecosystem.

In the present study, the focus of research was on taxon successions and dominance rather than on possible toxicity of the dominant cyanobacteria. The values obtained for this period, viz., in the range of 0.5-2.84 μg/L total dissolved microcystins in the water (Krstić *et al.* 2016), are considerably lower than the values reported in a previous study (Krstić 2011), when a maximum value of 270 μg/L was detected. Similar low values were also reported in some previous studies (Papadimitrou *et al.* 2010; Gkelis *et al.* 2015), which underlines the continuous presence of predominantly the microcystin group of toxins in the lake. These discrepancies in the levels of toxins detected in Lake Dojran, (as for any other ecosystem) would appear to be primarily a result of different times of sampling and analyses. In successions of dominance of several *Microcystis* taxa recorded over the past period, the dominance of taxa with low/high toxin production potential alternated, with consequent changes in the final concentration of toxins (microcystins) in the water. Moreover, some of the dominant taxa (like *M. protocystis*) or the sub-dominant species *M. ichthyoblabe* have not been hitherto reported to produce any toxins or else are known to produce toxins other than microcystins, usually neurotoxins. Thus, detection of toxins in any ecosystem has to be a specific scientific task which demands a toxin-orientated sampling frequency. In the light of previous findings, it seems logical to imagine that Lake Dojran experiences several periods of very high toxin presence (peaks) over the year that may last for a couple of days only, after which the ecosystem returns to the base microcystin presence of only a few μg/L. But this prediction needs to be scientifically confirmed in the future.

CONCLUSIONS

The initial aim of this paper was to document successive changes observed in structure of the phytoplankton community over almost 30 years. The base phytoplankton composition (1971) existed in a stable eutrophic environment where the communities were dominated by colonies of coccoid green algae like *Pediastrum, Scenedesmus, Staurastrum* Meyen ex Ralfs and *Tetraedron* Kützing, with a marked presence of the euglenoid genus *Phacus* and natural annual oscillations in dominance of planktonic cyanobacteria and diatoms. Since 1971, several shifts have occurred in structure of the community. In its present stage (recorded in 2015), the phytoplankton of Lake Dojran is dominated by *Microcystis* species with co-dominance of *Aulacoseira granulata*. A total of nine *Microcystis* species were recorded in parallel coexistence, a

situation that has not been reported so far in the scientific literature, and the pan/neo-tropical species *Microcystis protocystis* was observed for the first time in a European ecosystem.

A scientifically challenging question is what has initiated phytoplankton successions of this kind over the years? A brief comparison of available data on water chemistry has been quite informative – the base parameters of eutrophication in Lake Dojran have changed drastically over the years in a process leading to deep hypertrophy of the ecosystem. The observed phytoplankton successions are a consequence of the gradual deterioration of water quality parameters, accumulation of nutrients and pollutants over the years and increase of the 'total tendency' towards hypertrophy, as well as multiple mutual interactions of abiotic and biotic factors in a constantly changing environment. The resulting community has appeared due to the creation of an environment only suitable for the most resilient algal forms, a situation manifested in this case in the overall dominance of *Microcystis* spp. and *Aulacoseira granulata*.

In conclusion, it is very obvious that Lake Dojran has experienced an ecological catastrophe in the past 30 years as a direct consequence of deleterious human influence and negligence. Its prolonged agony has forced many biota changes, extinctions and survival of the fittest, the final result being dominance of the notorious cyanobacterial genus *Microcystis* with a total of nine co-existing species, as well as the continual presence of cyanobacterial toxins. Today, the lake represents a dangerous ecosystem with frequent and still recurring intensive peaks of toxin release in the water and sediment that are an immediate threat to human health and the ecosystem as a whole.

Many scientific workers have joined Professor Panče Stojanovski and his team in the ultimate quest to save this natural and in a lot of ways unique ecosystem, with the focus on protection of human health and immediate application of a number of steps needed to prevent its further deterioration and final turnover to a dead ecosystem. Among them, Professors Jelena and Živojin Blaženčić contributed in many ways and were always ready to work on Lake Dojran. This paper is a tribute to them and all other workers who have unselfishly devoted their time and efforts to obtaining the real truth in an attempt to save Lake Dojran.

Their legacy and the fight for Lake Dojran still continue.

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Botanica SERBICA

REZIME

Dominacija *Microcystis* spp. u Dojranskom jezeru – posledica 30 godina ubrzane eutrofikacije

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Poslednjih 30 godina Dojransko jezero (Makedonija) se suočilo sa periodima ekstremne suše i uklanjanja vode za potrebe navodnjavanja, što je rezultiralo pojačanim procesima eutrofikacije i hipertrofiji. U ovom radu se dokumentuje uspešna promena mikroflore u planktonskim zajednicama kao rezultat produžene eutrofikacije tokom ovog perioda. Prirodno dobro formirane planktonske zajednice u jezeru koje su bogate vrstama, posebno kokoidnim zelenim formama iz rodova *Pediastrum, Scenedesmus, Staurastrum* ili *Tetraedon*, koje prate prirodnu godišnju sukcesiju formi diatomeje > zelene alge > cijanobakterije, tokom godina su izmenjene u velikoj meri. Zabeležene su dve epizode intenzivnog cvetanja vode, događaja koji ukazuju na drastične promene ekoloških uslova, s tim da je jedna epizoda bila vezana za vrstu *Gloeotrichia natans* (1993/94), a druga za dinoflagelate *Ceratium hirudinella* i *C. monoceros* (1996/97). Tokom 2008. godine zabeležena je dominacija *Dolichospermum* aff. *flosaquae*. Konačno, fitoplankton u Dojranskom jezeru je završio svoj preokret ka sveukupnoj dominaciji vrsta roda *Microcystis*, sa ukupno devet vrsta koje koegzistiraju. Zabeležen je i prvi nalaz *Microcystis protocystis* van pan- i neotropskog regiona. Prikazana sukcesija sastava i dominacije fitoplanktonskih vrsta pripisuje se neprekidnim promenama statusa nutrijenata u jezeru koje vode ka hipertrofiji, s tim da su ukupne koncentracije osnovnih nutrijenata, P i N, povećane tokom godina 40, odnosno 8 puta. Merenja toksičnosti cijanobakterija su bila retka i sporadično obavljana. Bez obzira na to, u vodi je dokumentovano prisustvo mikrocistina, sa indikacijom značajnih maksimuma koncentracije. Dodatno, rad je posvećen svim naučnicima kao što su profesori Jelena i Živojin Blaženčić, koji su posvetili svoja naučna istraživanja i vreme otkrivanju indukovanih promena živog sveta u jezeru i kreiranju okruženja za hitne intervencije kako bi se sačuvao ovaj, nekada veoma bogat i raznolik ekosistem.

Ključne reči: Dojransko jezero, eutrofikacija, promene fitoplanktona, dominacija *Microcystis* sp., neotropska forma