ПРИЛОЗИ, Одделение за природно-математички и биотехнички науки, МАНУ, том **44**, бр. 1–2, стр. 303–314 (2023)
CONTRIBUTIONS, Section of Natural, Mathematical and Biotechnical Sciences, MASA, Vol. **44,** No. 1–2, pp. 303–314 (2023)

Received: September 14, 2024
Accepted: November 22, 2024

ISSN 1857–9027
e-ISSN 1857–9949
UDC:
DOI: 10.20903/masa/nmbsci.2023.44.31

Original scientific paper

EUTROPHICATION – A NEED FOR UNDERSTANDING THE DANGERS OF AN OLD NEMESIS

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Nutrient enrichment of aquatic environments, or eutrophication in modern terms, is a fundamental primordial planetary process that enables the proliferation of life in otherwise "sterile" ecosystems. It strongly supports the rapid expansion of primary producers, most of all – the algae, which initiates the formation of sequenced food chains, leading to life boosts in specific areas. This so-called ‘natural’ eutrophication has been a driving force for living forms throughout the history of our planet, and may even have been depicted in the Bible. However, the development of human society, including agriculture, industrial and technological expansion, and waste generation, has been the starting point of so-called ‘cultural’ or accelerated eutrophication that poses numerous problems for both the environment and humans. Based on selected natural and manmade ecosystems in North Macedonia, this paper points out the necessity of understanding and combating the deleterious effect of accelerated eutrophication in all water bodies.

Key words: Eutrophication; accelerated eutrophication; causes; consequences; management

INTRODUCTION

Nutrients are essential for all living organisms on our planet. The formation of specific food chains in both aquatic and terrestrial environments greatly depends on energy from the Sun, nutrients, and favorable conditions. Recently discovered [1], ‘hydrothermal vents’ in almost all oceans [2] differ only in terms of their energy source, which comes from geothermal activity rather than the Sun. However, the complexity of life and food chains discovered in these extreme locations is astonishing. Both terrestrial and aquatic environments can become rich in nutrients, or eutrophic, the main difference being that aquatic ecosystems are more dynamic and express consequent changes in biota and overall ecosystem deterioration much more rapidly.

Water environments remain in ecological equilibrium as long as favorable conditions, including nutrients, support primary production that is roughly equal to decomposition processes, thus preventing an excess of nutrients in the system. The so-called ‘total capacity’ of an ecosystem [3] is defined as "a chain of parameters whose combination will guide the course of eutrophication". Essential elements of ecosystem functionality, such as total capacity, primary production, and the decomposition of organic matter, define the intensity of trophy and saprobity. When an ecosystem has a primary organic production that corresponds in the intensity to decomposition of the total biomass, the trophy is about the same as saprobity. In these systems, there is no additional organic load, and the aging process corresponds to *natural eutrophication*. Water ecosystems, especially freshwater ones, age naturally over a very long period (even spanning millions of years) unless a catastrophic event or human activity does not change the essential elements of the ecosystem. Disturbance or the absence of any of these elements may lead to the prevention of primary production and, therefore, represent the limiting factors for that particular ecosystem. However, it is more probable today that disturbances will add excess nutrient elements to the ecosystem, thereby altering its total capacity and primary production, leading to intensive eutrophication or ‘accelerated eutrophication’, which greatly shortens the ecosystem’s lifespan.

Excess inputs of organic and mineral matter (from natural or human processes) lead to a direct increase in an ecosystem’s total capacity, which is reflected in an increase in total organic production. In this case, every member of the food chain, primary producers, decomposers, and consumers, increases its biomass, resulting in disturbances in the decomposition processes that cannot compensate for the excessive production of matter. This process called ‘self-purification’, or better auto-recovery, of the ecosystems that combat the overload of nutrients is a biologically limited process that will never reverse the input levels prior to organic loads. Therefore, with the continual input of organic material, the water body cannot recover and experiences intensive (or accelerated) eutrophication and rapid aging, typically occurring over a few decades. Accelerated eutrophication is already evident in the majority of ecosystems today, largely due to adverse human impacts. As dimly stated [4] "*In many countries, both developing and developed, current pathways for water use are often not sustainable… The world faces a worsening series of local and regional water quantity and quality problems… Water resource constraints and water degradation are weakening one of the resource bases on which human society is built*".

So, why is the accelerated eutrophication of freshwater ecosystems so devastating to the environment, as well as to human and animal health? The continual excess input of nutrients into aquatic environments triggers a series of sequential responses of biota, ultimately leading to the total extinction of autochthonous flora and fauna. This results in an almost lifeless ecosystem dominated primarily by bacteria. Namely, being mixotrophic [5], algae, as primary producers in waters, first react to excess nutrients (usually N and P compounds, but also other nutrients like Fe that are also important for marine ecosystems [6]) and use it for a rapid proliferation of cell numbers. Both planktonic and benthic algae respond to the newly enriched environment, causing their biomass to rapidly increase throughout the water column. The types of algae that predominate in the ecosystem depend on their overall capacity, but the general rule for almost all environments (except polar ones) is a seasonal or prolonged, permanent microflora succession from chrysophytes and diatoms, toward green algae and, ultimately, blue-green algae (Fig. 1).

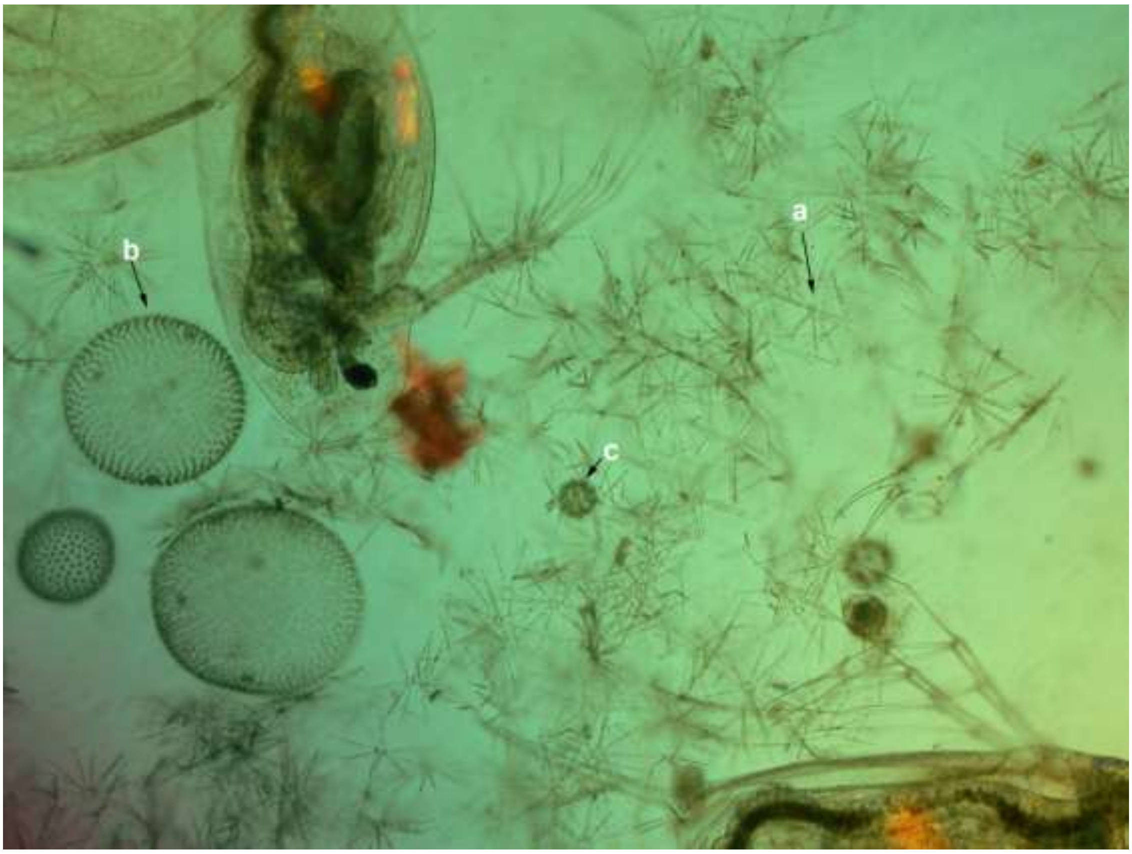

Figure 1. *Asterionella formosa* (a diatom, pointed out with letter a), *Volvox aureus* (b) and *Eudorina elegans* (green algae, c) in plankton of the Knezevo reservoir, July 2013 (zooplanktonic *Daphnia* sp. also present) (photo S. Krstić).

The rapid and intensive increase of algal biomass represents serious deterioration of ecological circumstances purely by production of excess organic matter in the system that will inevitably end up at the bottom as organic biomass subjected to an intensive bacterial decomposition. From this point onwards, if the excess nutrient supply is not stopped, freshwater ecosystems enter a spiral of deterioration, leading to murky waters (low transparency), oxygen depletion (especially at the bottom), extinctions of biota (mainly bottom-dwelling fauna and fish), and the accumulation of anaerobic mud sediments that further proliferate the excess nutrients in the system.

Furthermore, there is another very important aspect of algal dominance in a particular ecosystem. Of the more than 72.000 known algal species [7], only about a hundred are capable of mass proliferation and bloom formation visible at the surface of the water body. Some of these species, no more than a few dozen (although scientific evidence of new taxa is mounting up) are capable of producing toxins as an evolutionary adaptation to restrictive environmental conditions, including allelopathy. There are only a few known algal groups capable of toxin production: cyanobacteria (blue-green algae), dinoflagellates (formerly known as Pyrrophyta – fire algae), chrysophytes (golden algae), diatoms (silicate algae) and xanthophytes (yellow-green algae). The production of toxins in algae is still not well understood. Produced toxins surely influence other organisms, including grazers, and thus promote the proliferation of toxin-producing algae [8]. Algal toxins are usually secondary metabolites that are toxic to other organisms by chance. Their primary roles are in processes such as storing nitrogen reserves, biosynthesis of nucleic acids, bioluminescence, structural organization of chromosomes, ion transport through channels, bacterial endosymbiosis or induction of sexual reproduction during bloom senescence [9]. The mass proliferation of toxic algae in water environments is termed Harmful Algal Blooms (HABs).

All water environments are susceptible to massive algal proliferation and HABs. However, considering the importance of freshwater ecosystems for the environment and human activities, such as being sources of drinking water and irrigation for food production, the deleterious effects of accelerated eutrophication are much more pronounced and life-threatening. The sheer volume of marine environments masks the obvious trends and spatial-temporal impacts of eutrophication. In freshwater environments, many different algal groups become dominant during the eutrophication process. Filamentous benthic forms, such as *Cladophora*, *Stigeoclonium*, *Spirogyra*, or *Oedogonium*, increase their presence, become buoyant, and appear at the surface of water bodies as scum. In plankton, different algal groups also interchange in dominance depending on the total capacity of the water body, usually represented by diatoms, green, yellow-green, golden, and fire algae. However, the most prominent water blooms are caused by blue-green algae. While any mass proliferation of algae is regarded as a nuisance and harmful to the water body, only a very limited number of algae are considered truly harmful in freshwater environments, such as *Primnesium parvum* (Haptophyta, formerly golden algae) and the diatom *Didymosphenia geminata*. The real threat to freshwater environments comes from the massive dominance of blue-green algae or cyanobacteria, many of which are known toxin producers, and the number of these species continually rises.

The occurrence of blue-green algae (cyanobacteria) in different trophic statuses of freshwaters is depicted by Chorus and Welker [10] as:

- In oligotrophic waterbodies, planktonic cyanobacteria are unlikely to attain cell densities that cause hazardous cyanotoxin concentrations. However, benthic or epiphytic cyanobacteria may be present and cover littoral sediments.

- In mesotrophic waterbodies, cyanobacterial blooms occur rarely; exceptions include metalimnetic accumulations of *Planktothrix rubescens* (which may be at depths of drinking-water offtakes or come to the surface, increasing risk of exposure), detached mats of benthic cyanobacteria and – in large waterbodies – recruitment of cyanobacteria (particularly of *Dolichospermum*) from low cell density but very large water volumes and surface areas to visible scums along a downwind shoreline.

- In eutrophic and particularly hypertrophic waterbodies, cyanobacteria occur frequently and abundantly, often constituting a major share of the total phytoplankton biomass for extended parts of the year.

It is estimated that as much as 75% of all water ecosystems containing cyanobacteria also contain toxic cyanobacterial metabolites [11]. These secondary metabolites, some of which are called cyanotoxins, have different biological effects. Cyanotoxins differ in their chemical structure and toxicity. Considering which human (animal) organ they express their toxicity to, cyanotoxins are divided as **hepatotoxins** (*microcystins, nodularin, cylindrospermopsin*), **neurotoxins** (*saxitoxins, anatoxin-a, anatoxin-a(s)*, *homoanatoxin-a*), **cytotoxins** (*aplysiatoxin, debromoaplysiatoxin, lyngybatoxin, lipopolysaccharide endotoxins*) and **skin irritants** (almost all cyanotoxins) [12].

Cyanotoxins may cause many deleterious harmful effects on humans, terrestrial and aquatic animals, as well as the environment as a whole [13]. The color and odor produced by the mass development of cyanobacteria, along with documented poisonings of animals (mammals, birds, fish), have undoubtedly attracted human attention in the past. There are various written documents, long before the invention of the microscope, that clearly point out the mass proliferation of algae in waters. For example, the allusion to "swamp fungus" on the surface of waters is mentioned in Shakespeare's drama "Venetian Merchant" [14]. Over time, people began to connect animal poisonings and different human incidents with the mass development of blue-green algae in freshwater environments. The oldest known record of possible human poisoning from cyanotoxins dates 1,000 years ago by General Liang when soldiers died after drinking green water in Southern China [15]. The first mass human poisoning (5.000–8.000 people) might have been recorded in Charleston (West Virginia) in 1931 when the activities for purification of drinking water were not effective against blue-green algal bloom [16]. In Australia, 149 people were hospitalized in 1979, while in Brazil, out of 2.000 cases, 88 people died when water contaminated with cyanotoxins was used for dialysis [17].

Finally, as vividly described in the Bible [18], even God might have used the horrors of algal (cyanobacterial) blooms to punish the Egyptians for their disobedience, turning the waters of the River Nile red, killing fish, and rendering the water unusable for people. On the other hand, could this have been just an episode of old Nemesis? Nonetheless, Mays et al. [19] argue that harmful algal and bacterial blooms, linked to deforestation, soil loss, and global warming, are becoming increasingly frequent in lakes and rivers. They demonstrate that climate changes and deforestation can drive recurrent microbial blooms, inhibiting the recovery of freshwater ecosystems for hundreds of millennia. Furthermore, fossil, sedimentary, and geochemical data suggest that bloom events occurred following the collapse of forest ecosystems during the most severe mass extinction in Earth's history, the end-Permian event (EPE, c. 252.2 Ma). Microbial communities proliferated in lowland fresh and brackish water bodies, with algal concentrations typical of modern blooms.

Recognizing the severity of the impact and dangers coming from cyanobacterial toxins, the World Health Organization (WHO) [20] derived a tolerable daily intake (TDI) value for microcystin-LR for human health risk assessment purposes. The TDI of 0.04 μg/kg bw/day was used for the calculation of guidance value for the maximal acceptable concentration of microcystin-LR in drinking water (1 μg/L). It was also used in human health risk assessments for microcystins resulting from other exposure routes, such as recreational exposure, consumption of contaminated food, or blue-green algal food supplements [21]. However, microcystin-LR is not the only common structural variant of microcystin, and experts recommend using the guideline value for total microcystins instead [22].

In the Republic of North Macedonia, there is no continuous, scientifically based, reliable monitoring of eutrophication in any of its freshwater environments. Consequently, there is no database where eutrophication parameters, trends, algal blooms, and their impacts are recorded, including possible cases of adverse effects of algal toxins on humans, animals, and the environment. The hydrobiological team at the Faculty of Natural Sciences and Mathematics within Ss Cyril and Methodius University in Skopje is the only scientific group addressing this issue and gathering data in different water bodies across the country over the years. Based on selected natural and manmade ecosystems in North Macedonia, this paper aims to present case studies and highlight the necessity of understanding and combating the harmful effects of accelerated eutrophication in all water bodies, including marine environments.

MATERIAL AND METHODS

Regular monitoring of eutrophication is relatively straightforward and does not require extensive expenses if conducted by experts. It involves regular measurements of basic nutrients, metals, algal biomass, algal composition, abundance, and algal toxins in a given water body. Since there is no regular monitoring system in place, the results presented in this paper are based on occasional efforts by the authors over the years, focusing on different water ecosystems that were in focus at a particular time. Generally, the following methods were used, although not for every ecosystem presented in the results. Field measurements included basic physicochemical parameters (temperature, pH, dissolved oxygen, oxygen saturation, conductivity) using a portable SensoDirect 150 multimeter. Measurements of basic nutrients and chlorophyll *a* were performed according to standard laboratory protocols (APHA, 1998) using a Lovibond Tintometer® spectrophotometer. The measurement of basic physicochemical parameters, nutrients, and chlorophyll *a* was carried out on integrated water samples using a Ruttner water sampler. To measure dissolved nutrients, the water sample was first filtered through 0.45 μm membrane filters. The maximal depth was measured with a weighted marked line.

The plankton material was collected using a plankton net (pore size 10 μm) slowly dragged using a motor boat or using vertical column mixing. The collected material was preserved in 4% formaldehyde or Lugol's solution for further processing in the laboratory (WHO, 1999).

All plankton material was analyzed by standard light microscopy, but for better visualization of the mucilaginous envelope, the material was also stained with China Ink and analyzed in detail. Microphotographs were taken of both native materials and stained colonies with Nikon eclipse E800M LM with Nikon Coolpix 4500 camera. The identification of the species was performed using standard literature (Komárek and Anagnostidis [23], Šejnohová and Maršálek [24]) as well as the main report for European *Microcystis* morphospecies (Komárek and Komárková [25]).

Toxin analyses were performed as follows: 50 ml of the integrated water sample was filtered in situ through glass-fiber filters 47 mm (GF/C) using a vacuum filtration device. The filtrated samples were transported on cold and kept frozen at –20 °C until the analysis day. The quantitative detection of free dissolved microcystins in the samples was performed using the Microcystins-ADDA ELISA kit from Abraxis (Product No. 520011) according to the manufacturer's instructions. All analyses were performed in triplicate. The assay was calibrated with microcystin-LR and the results were expressed as microcystin-LR equivalents.

RESULTS

In RN Macedonia, there are three natural tectonic lakes — Ohrid, Prespa, and Dojran, and approximately 110 manmade reservoirs [26]. The most prominent and famous, Ohrid Lake, has been the subject of scientific research for over a century and continues to attract interest as a UNESCO World Heritage site. Although the lake is considered to be in an oligotrophic state of pollution, as noted in the latest Management Plan [27], there is consistent evidence suggesting that the lake is experiencing increased anthropogenic eutrophication [28, 29], especially in the littoral zone. While only occasional and sporadic manifestations of eutrophication have been detected in the littoral zone of the lake, we are not considering them here, which does not mean that this ecosystem is not under the eutrophication influence as well.

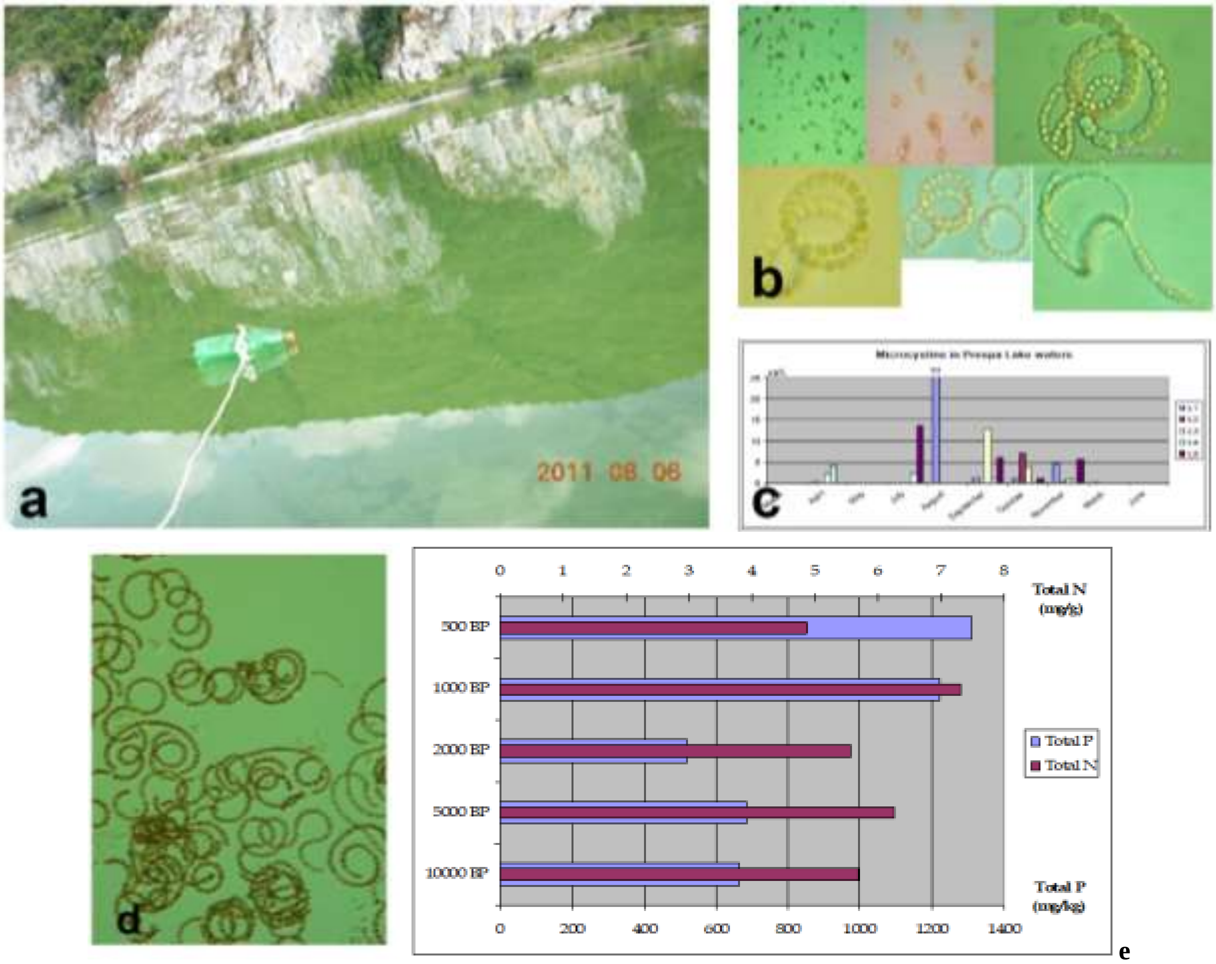

Figure 2. Water blooms in Prespa Lake (a) caused by massive proliferation of *Dolichospermum flosaquae* and *D. circinale* (b) during the summer months of 2011. The highest recorded total microcystins presence (c) in 2011 was 53 g·l^{-1}. (photo S. Krstić). A *Dolichospermum flosaquae* water bloom was also detected in 2015 (d, photo B. Aleksovski). e. Core sample analyses of total N and P content in sediments of Prespa Lake of the last 10ka [30].

Lake Prespa

During the summer of 2011, a quite visible vivid green water bloom was detected in Lake Prespa. The phytoplankton analyses disclosed a massive domination of *Dolichospermum flosaquae* and *Dolichospermum circinale*. The highest recorded total microcystins presence was detected in August 2011, with 53 g·l^{-1} [30, 31]. The sampling campaign of Lake Prespa in 2015 confirmed the dominance of *Dolichospermum flosaquae* in this ecosystem. The overall results of several sampling campaigns indicated that Prespa Lake is evidently a *Dolichospermum*-type lake; the other potentially toxic blue-green types, such as *Microcystis* spp. or *Aphanizomenon* spp., were found only rarely and in a limited number of colonies.

Lake Dojran

Over the past 10 years, several sampling campaigns (2010, 2015, 2016, 2019, 2020) have unequivocally shown that Lake Dojran is a typical *Microcystis*-type blooming eutrophic lake. In 2010, the plankton community revealed dominance of four *Microcystis* taxa (*M. aeruginosa, M. wesenbergii, M. flos-aquae, M. ichthyoblabe*) along with *Planktolynbya contorta* as a subdominant species [31]. During 2010, two significant concentration peaks of total microcystins were detected – one in June with concentrations of 288 µg·l^{-1} and the other in October with a maximum value of 105 µg·l^{-1}, while the total cyanotoxin levels were kept lower than 5 µg·l^{-1} in all of the remaining months (Fig. 3, [31]). These findings suggest that Lake Dojran experiences several periods of very high toxin concentrations (peaks) throughout the year, each lasting only a few days, after which the ecosystem returns to a baseline microcystin level of only a few µg·l^{-1} [32].

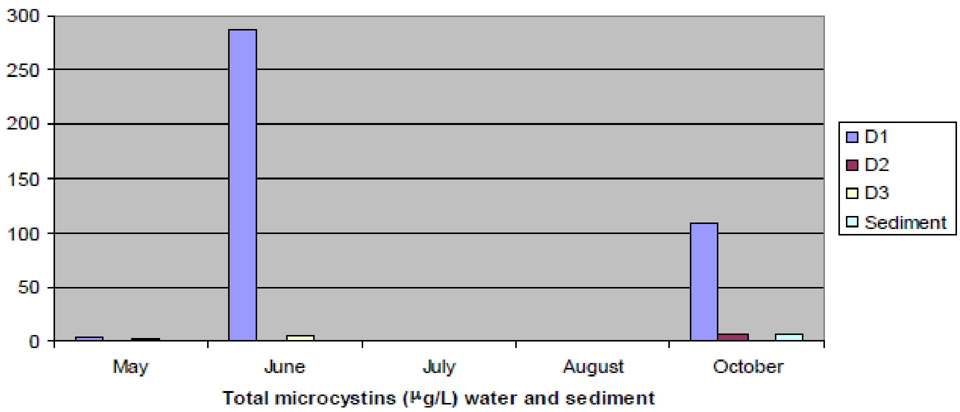

Figure 3. Microcystins detected in three sampling sites on Dojran Lake and in sediments during 2010

In 2015, the state of Lake Dojran worsened, with an overall dominance of even nine co-existing *Microcystis* species (*M. aeruginosa, M. botrys, M. flos-aquae, M. ichthyoblabe, M. novacekii, M. protocystis, M. smithii, M. viridis, and M. wesenbergii*) documented in this small lake, and with the domination of the pan- and neo-tropical species *M. protocystis*, for the first time recorded in a European lake [32-33]. The values of total microcystins obtained in this period were in the range of 0.5–2.84 µg·l^{-1} [33].

The results of the sampling campaign in 2020 [34] also confirmed the severe proliferation of *Microcystis* species in the phytoplankton and scum of Dojran Lake. Additionally, a clear domination of endogloeic *Pseudanabaena* species was detected in the mucilage of the *Microcystis* colonies, along with well-developed filaments of several *Dolichospermum* species (Fig. 4). The total levels of microcystins in the integrated water sample reached 1.3 g·l^{-1}, while the total mean microcystin levels in the scum material were assessed as 22.8 ± 2.8 µg·l^{-1} and the overall cell-bound MCs concentration was assessed as 67.1 ± 1.9 µg/g dry phytoplankton biomass. (Fig. 5, [34]). The mud of Dojran Lake was very rich in microcystin concentration – 172.4 ± 2.8 µg/g dry mud.

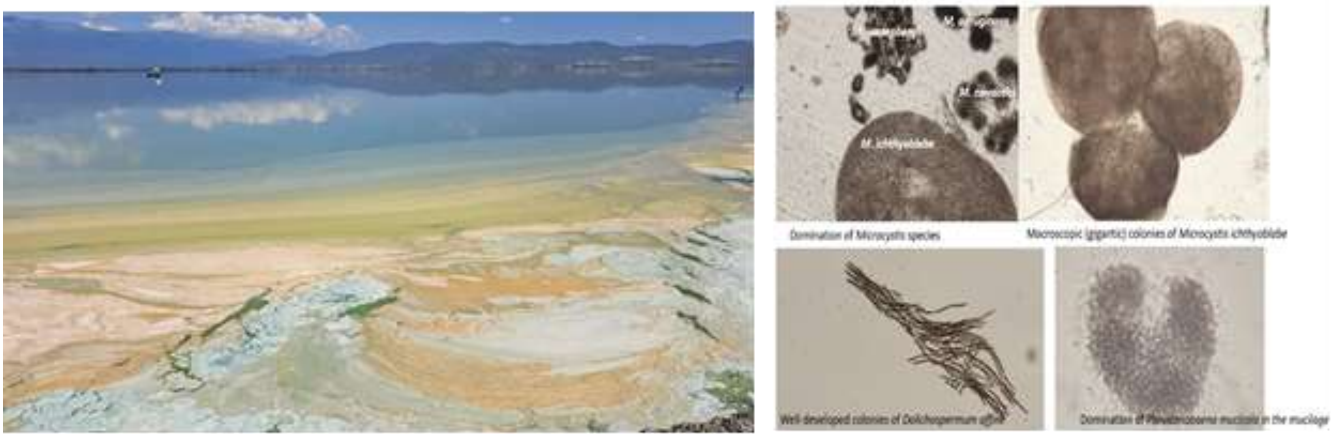

Figure 4. Visible massive proliferation of cyanobacteria and primary constituents of the scum in Dojran Lake in 2020 [31]. (photo S. Krstić and B. Aleksovski)

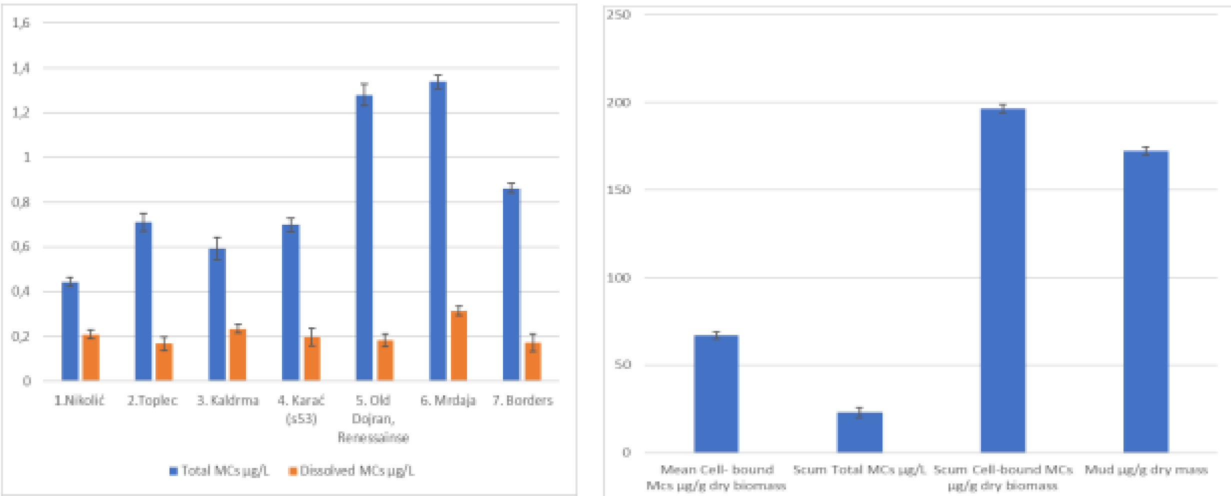

Figure 5. Total and dissolved microcystin presence in waters and sediments of Dojran Lake in 2020 [31].

Cases of water blooms in North Macedonia reservoirs

Between 2005 and 2011, several cases of severe water bloom formation were detected in reservoirs across North Macedonia. In 2005, a *Planktothrix rubescens* bloom was documented in the "Strezevo" reservoir near Bitola (Fig. 6). Later, in 2008, this cyanobacterium was found in the water bloom of the "Tikves" and "Ratevsko" reservoirs, resulting in a large-scale fish kill [31].

During multiple investigations, the "Tikves" reservoir (Fig. 7) was predominantly observed to exhibit a reddish algal bloom, although intermittent occurrences of a dark-green bloom were also documented. The primary cyanobacterial species identified across all samples were *Planktothrix rubescens* and *Planktothrix agardhii* [31], with the species identified based on the bloom coloration. Both species are well-known for their toxin-producing capabilities. Consequently, the analytical results revealed the presence of microcystins in both the water column and the sediment, with concentrations reaching a peak of 53 g·l^{-1} and 9 g·g^{-1}, respectively [31]. Other algal taxa were found to be relatively sparse, with minimal and infrequent occurrences. As expected, these conditions led to a large-scale fish mortality event in the cage farms located in the "Tikves" reservoir in August 2011.

Figure 6. *Planktothrix rubescens* red bloom in "Strezevo" reservoir Bitola in 2005. (photo S. Krstić)

Figure 7. *Planktothrix rubescens* red bloom in "Tikves" reservoir in 2008 and consequent fish kill in 2011 (small picture insert floating cage for fish farming) (photo S. Krstić)

The drinking water reservoir of the Ratevska River in Berovo (Fig. 8) has consistently been associated with red blooms on the ice, primarily caused by *Planktothrix rubescens*, during the winter months over the past decade. So far, this remote and small ecosystem has been sampled during the winters of 2008 and 2011, with the aim of assessing microcystin concentrations in the water [31]. Surprisingly, despite the high densities of algal cells and their rapid lysis within the ice matrix, only very low concentrations of microcystins (around 1 $\mu g \cdot l^{-1}$) were detected in the water [31]. Nevertheless, the presence of toxins was confirmed in this reservoir, which, like many others in North Macedonia, requires increased scrutiny and management attention in the near future.

Figure 8. *Planktothrix rubescens* bloom in "Ratevska Reka" reservoir Berovo in 2008. (photo S. Krstić)

The Mantovo Reservoir was analyzed during a sampling campaign in 2021. According to the local citizens, the ecological condition of the reservoir has suffered a sudden deterioration since 2018, characterized by strong turbidity and greenish water, along with the appearance of foam and massive cyanobacterial scrums. The phytoplankton analysis conducted in 2021 revealed a massive water bloom of *Aphanizomenon klebahnii* as the dominant species in the reservoir. *Aphanizomenon klebahnii* in the plankton was primarily represented in a dense mass of trichomes aggregated in bundles; such straightforward bundles (Fig. 9) from 100 μm to 1 mm in size (sometimes macroscopically) dominated in each of the five analyzed measuring points. Part of the material in the fifth measurement site (pond 3 "Bate Wase") was detected in the final stage of decomposition, in the form of a water bloom of individual trichomes that also dominated the phytoplankton. The total microcystin concentration peaked 9 μg·l^{-1}.

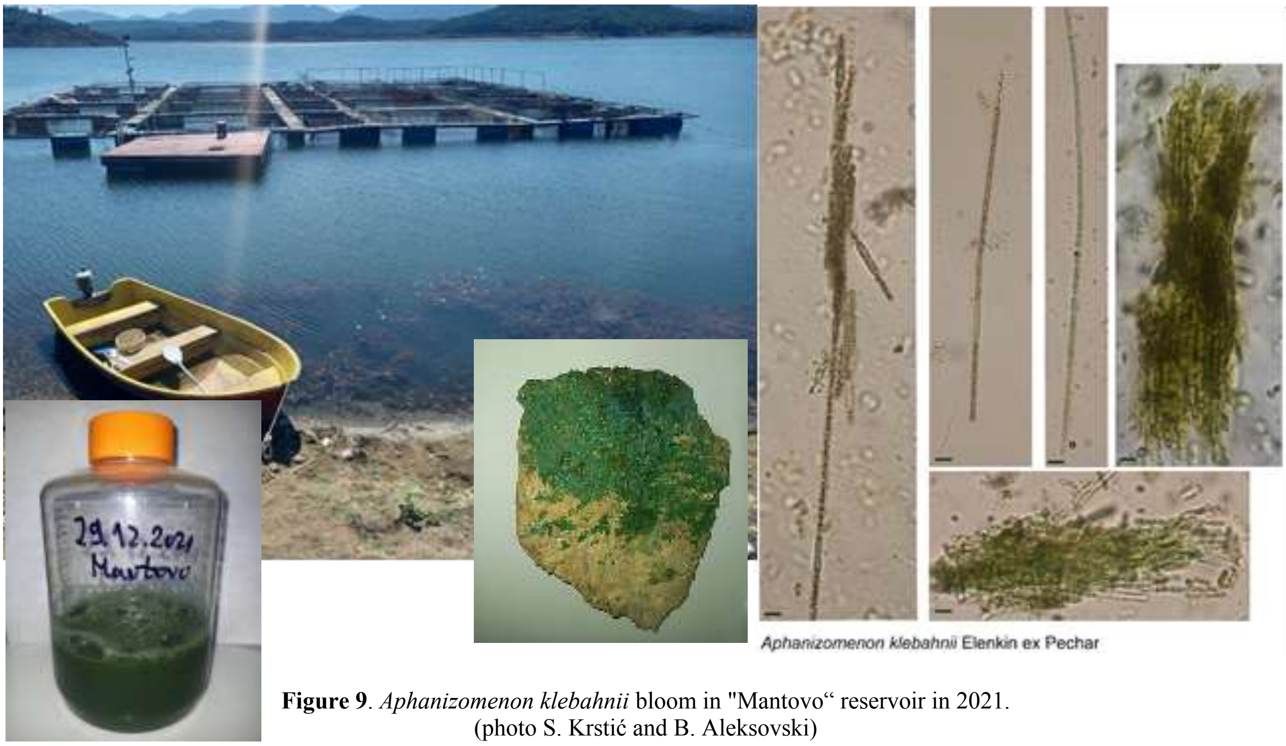

Figure 9. *Aphanizomenon klebahnii* bloom in "Mantovo“ reservoir in 2021. (photo S. Krstić and B. Aleksovski)

DISCUSSION

It is quite clear that eutrophication is a universal and widespread phenomenon that may have contributed to the fundamentals of life on our planet. Its basic principles are simple, based on food availability and utilization, which leads to excessive growth of algae as primary producers. This triggers a whole range of changes in the ecosystems, eventually (if persistent and long-lasting) leading to the destruction of principal freshwater ecosystems. On the other hand, excess of nutrients and consequent algal blooms in marine environments is a starting point for 'boom of life' in restricted areas where whole food chain is formed as a consequence; when the circumstances change, the whole food chain disappears and the system goes back to 'marine dessert'.

Naturally, 'accelerated eutrophication' is a random and occasional process caused by significant natural catastrophes, such as earthquakes or volcanoes, whose effects dissipate over time without any traces. Unfortunately, anthropogenic activities, including intensive pollution, wastewater discharge, and forced environmental changes, lead to the prolonged or permanent input of nutrients into aquatic environments, causing their long-term deterioration. Prolonged input of nutrients basically changes the 'total capacity' of the ecosystem accumulating excess of organic and inorganic chemicals in the system, thus creating a pool for further increase of bloom events and therefore a total degeneration of the ecosystem. Given enough time, this process could also affect the oceans on our planet.

As might be elucidated from Figure 2 for Lake Prespa, humans started to change the natural environment approximately 1,000 years ago, possibly through the deforestation of specific areas, which led to accelerated leaching of nutrients (mainly phosphorus) into the water environment. Early human influence, even before the industrial era, has been recorded in very remote environments, such as high-altitude lakes in the Nepal Himalayas [35], indicating that human impact on pristine ecosystems has become a global phenomenon. Since then, and especially after the modern industrial and agricultural revolutions, man has produced so many pollutants in vast quantities that almost all freshwater environments are now under severe stress [4].

In the case of North Macedonia, data suggests that no watercourse or stagnant water ecosystem is deprived of negative human impact. Regarding rivers, there are numerous documented cases of deteriorated environments [36] that transport immense amounts of nutrients and pollutants to downstream recipients, as there are no functional wastewater treatment plants. Where wastewater treatment plants are installed, they are either not functioning properly or not functioning at all. It is, therefore, not surprising that almost all lentic water bodies in the country experience intensive eutrophication. Water blooms by cyanobacteria in natural lakes are recurrent and have become more intense over the years. Lake Prespa is a *Dolichospermum* type of lake, while Lake Dojran is dominated by *Microcystis*; both lakes have been found to contain cyanotoxins.

On the other hand, the manmade reservoirs usually host *Planktothrix rubescens* as the dominant cyanobacteria. Toxic cyanobacteria, such as *Planktothrix rubescens*, came to dominate temperate lakes in the middle to late 20th century [37]. *P. rubescens* can produce hepatotoxins (microcystins), as well as neurotoxins (anatoxin-a), posing a risk to human and animal health [38]. These risks negatively affect lake ecosystem services such as drinking water and recreation [39]. In some cases, the decay and decomposition of cyanobacterial blooms have led to anoxic conditions and fish kills [40] (figure 6). In several European, lakes such as Mondsee (Austria), Bourget (France), Garda (Italy), Zurich and Hallwil (Switzerland), this cyanobacterium remained even after extreme phosphorus reduction [38].

Evidently, it is final time that human society starts to take care of the environment much more profoundly than so far. Once the deterioration of the water ecosystems is initiated, enormous efforts are needed to restore the natural environment. In the case of RN Macedonia (most likely as in the rest of the modern society), it is ultimately important to start implementing the EU (Water Frame Directive) and domestic legislation and promote the 'good status' of its waters prior to making any negative decisions. Some of these negative decisions include: the construction and full operation of a domestic wastewater collector system prior to postulating and building a wastewater treatment plant; not taking care of the efficiency of existing wastewater treatment plants; applying not sustainable agricultural practices; lack of permanent and scientifically based monitoring system; promoting the 'blooming' lakes (like Lake Dojran) as healing environment, etc. Otherwise, in light of global climate change, we are facing a very grim future where the majority of surface waters will become useless and harmful to any human activity.

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ЕУТРОФИКАЦИЈА – ПОТРЕБА ОД РАЗБИРАЊЕ НА ОПАСНОСТА ОД СТАРИОТ НЕПРИЈАТЕЛ

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Збогатувањето со хранливи материи на водните средини, или еутрофикацијата во современи термини, е фундаментален исконски планетарен процес кој овозможува пролиферација на животот во инаку „стерилни“ екосистеми. Таа силно го поддржува брзото ширење на примарните продуценти, пред сè алгите, кои иницираат формирање супсеквентни синџири на исхрана, што доведува до поттикнување на животот во одредени области. Оваа таканаречена „природна“ еутрофикација била движечка сила за живите форми низ историјата на нашата планета и можеби била прикажана дури и во Библијата. Сепак, развојот на човечкото општество, вклучително и земјоделството, индустриската и технолошката експанзија и создавањето отпад, беше почетна точка на таканаречената културна или забрзана еутрофикација, што претставува бројни проблеми и за животната средина и за луѓето. Врз основа на избрани природни и вештачки екосистеми во Република Северна Македонија, овој труд укажува на неопходноста од разбирање и борба против штетниот ефект од забрзаната еутрофикација на секое водно тело.

Клучни зборови: еутрофикација; забрзана еутрофикација; причини; последици; управување