LONG - TERM ANALYSIS OF CYANOBACTERIAL BLOOMS IN LAKE ROŞU (DANUBE DELTA)

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Abstract. Cyanobacteria became increasingly dominant as concentrations of total phosphorus and total nitrogen increased during the eutrophication of the Danube Delta ecosystems. As large, inedible algae, they induce a bottleneck in the carbon and energy flow of the plankton food web. Taking into account these reasons, our work aimed at highlighting the dynamics of cyanobacterial blooms in Lake Roşu at a wider temporal scale (1975-2002) and update the scientific data in the year 2011. The hypertrophy, a characteristic stage of the deltaic ecosystems in the critical period after 1980, involves increased concentration of nutrients and the nitrogen factor-limiting role of phytoplankton development. In the new environmental conditions, the chance of intense proliferation of cyanobacteria group increased, becoming dominant in the ecosystem. After 1980, yearly averages of biomass exceeded 10-30 times the "water blooms" threshold. Monthly averages in July-September period exceeded 100-125 times the mentioned limit. The spectacular values of cyanobacterial abundance and biomass between 1980 and 1990 triggered also the dominance of potential toxic species. The Mc Naughton and Wolf dominance index of phytoplankton biomass between 1982 and 1985 exceeded the threshold of 0.5 in all seasons. In general, the dominant species belong to toxin-forming Cyanobacteria: *Microcystis aeruginosa* KÜTZING 1846, *M. flos-aquae* (WITTR.) KIRCHNER 1898, *M. pulverea* (WOOD) MIGULA 1849, *Anabaena hassalii* (KÜTZ.) WITTROCK 1909, *A. scheremetievi* ELENKIN 1909, *Oscillatoria tenuis* AGARDH 1813. The edibility degree of these species is very low, the herbivorous zooplankton being forced to feed on detrito-bacterial aggregates to be able to survive. While in 2001 the diatoms and cyanobacteria biomass decreased, especially in the warm seasons, and the ecosystem tended to reach a functional regime, more stable, due to a lower nutrient pressure, in 2011, the high values of phytoplankton biomass (78.72 wet weigh mg $^{-1}$) have shown new eutrophication signals, including intense cyanobacterial blooms episodes.

Keywords: cyanobacterial blooms, long-term studies, Lake Roşu, phytoplankton biomass, Danube Delta.

Rezumat. Analiza pe termen lung a înfloririlor cianobacteriene din lacul Roşu (Delta Dunării). Grupul Cianobacteria devine dominant odată cu creşterea concentraţiilor fosforului total şi a azotului total pe parcursul procesului de eutrofizare din Delta Dunării. Cianobacteriile de dimensiuni mari, necomestibile, induc o barieră în fluxul de carbon şi energie în reţeaua planctonică. Luând în considerare aceste argumente, lucrarea noastră şi-a propus să evidenţieze dinamica înfloririlor cianobacteriene în lacul Roşu la o scară mare de timp (1975-2002) şi să actualizeze informaţiile ştiinţifice în anul 2011. Hipertrofia, stadiu caracteristic ecosistemelor deltaice în perioada critică de după 1980, a implicat concentraţii crescute ale nutrienţilor, precum şi rolul azotului ca factor limitant în dezvoltarea fitoplanctonului. În noile condiţii de mediu, a crescut şansa de proliferare a cianobacteriilor, ele devenind grupul dominant în ecosistem. După 1980, media anuală a biomasei a depăşit de 10-30 ori pragul de înflorire al apelor. Media lunară din perioada iulie-septembrie a depăşit de 100-125 ori limita menţionată. Valorile spectaculoase ale abundenţei şi biomasei cianobacteriene din perioada 1980-1990 au declanşat dominanţa unor specii potenţial toxice. Indicele de dominanţă al biomasei Mc Naughton şi Wolf în perioada 1982-1985 a depăşit pragul de 0,5 în toate sezoanele. În general, speciile dominante au aparţinut grupului Cianobacteria, cu potenţial de producere a toxinelor: *M. aeruginosa* KÜTZING 1846, *M. flos-aquae* (WITTR.) KIRCHNER 1898, *M. pulverea* (WOOD) MIGULA 1849, *A. hassalii* (KÜTZ.) WITTROCK 1909, *A. scheremetievi* ELENKIN 1909, *Oscillatoria tenuis* AGARDH 1813. Gradul de edibilitate al acestor specii este foarte scăzut, zooplanctonul ierbivor fiind obligat să acceseze agregatele detrito-bacteriene ca sursă de hrană pentru supravieţuire. În anul 2001, biomasa diatomeelor şi cianobacteriilor a scăzut, în special în sezonul cald, ecosistemul a tins către un regim de funcţionare mult mai stabil datorită scăderii presiunii nutrienţilor. În anul 2011, valorile ridicate ale biomasei fitoplanctonului (78,72 s. um. mg $^{-1}$), au arătat noi semnale de eutrofizare, incluzând intense episoade de înfloriri cianobacteriene.

Cuvinte cheie: înfloriri cianobacteriene, studii de lungă durată, lacul Roşu, biomasa fitoplanctonică, Delta Dunării.

INTRODUCTION

Nutrient and hydrological conditions strongly influence harmful planktonic and benthic cyanobacterial bloom dynamics in aquatic ecosystems ranging from streams and lakes to coastal ecosystems. Numerous freshwater genera within the diverse phyla comprising the phytoplankton are capable of forming blooms; however, the cyanobacteria are the most notorious bloom formers (PAERL et al., 2001; TÖRÖK, 2008).

The temporal dynamics of Cyanobacteria blooms is variable, with a wide range of possible biological impacts including potentially toxic effects and impacts on food web functionality. Toxin production by certain cyanobacteria (e.g., *Anabaena circinalis* RABENHORST ex BORNET & FLAHAULT 1886, *Aphanizomenon flos-aquae* RALFS ex BORNET & FLAHAULT 1886, *Cylindrospermopsis raciborskii* (WOLOSZYNSKA) SEENAYYA & SUBBA RAJU 1972, *Microcystis aeruginosa*) may lead to a wide array of biological impacts. These include: allelopathic effects on other phytoplankton (SUIKKANEN et al., 2004); suppression of zooplankton grazing, (GILBERT, 1990; FERRAO-FILHO et al., 2000; GHADOUANI et al., 2003); hepatotoxic effects on fish (ANDERSEN et al., 1993); and accumulation of toxins in tissues of invertebrates (LIRAS et al., 1998, LEHTINIEMI et al., 2002) and fish (MAGALHAES, 2001).

Lake Roşu is representative for the lacustrine-type of ecosystems, being the largest lake (1375 ha) of the fluvio-maritime delta.

The objectives of this paper were to highlight the dynamics of cyanobacterial blooms in Lake Roşu at a wider temporal scale (1976-2002) and to update the existing information by presenting the evolution of Cyanobacteria in the year 2011.

MATERIALS AND METHODS

The long-term results belong to the database of the Institute of Biology Bucharest. Updated data (2011) is the original work of the authors.

The samples were taken monthly or seasonally during 1976-2011, covering the same 5 sampling points during the entire period (Fig. 1).

Phytoplankton sampling was performed using a Patalas-Schindler (5 litres) device on water column.

The phytoplankton conservation was made in 500 ml plastic containers, with 4% formaldehyde solution. In the laboratory, phytoplankton samples were concentrated by sedimentation and filtration, using an Ø 65 mm network (VOLLENWEIDER, 1969; BRITTON & GREESSON, 1987). The identification of phytoplankton species and abundance assessment were made using a Zeiss inverted microscope according to UTERMÖHL (1958). Phytoplankton biomass was established by volumetric and gravimetric measurements (OLRIX et al., 1998).

Statistical analyses were performed using SPSS 15.0 Windows Evaluation Version and BioDiversity Pro.

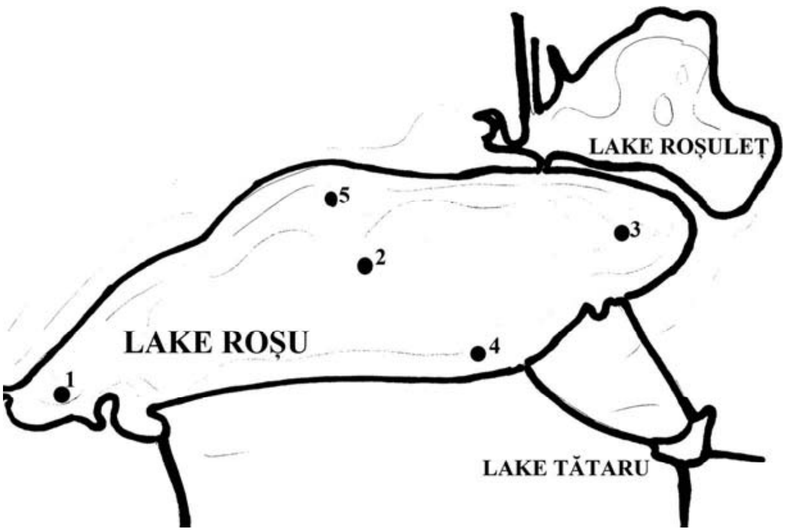

Figure 1. The map of Lake Roşu (the Danube Delta) with sampling points.

RESULTS AND DISCUSSION

The evaluation of bloom frequency highlights the high percents of cyanobacterial blooms during the hypertrophy period (1982-1986) (Table 1). Accelerated eutrophication of the water began to be evident within the Danube Delta from 1980-1982 because of the increased nutrient load in the Danube River (POSTOLACHE, 2006).

The hypertrophy, a characteristic stage of the deltaic ecosystems in the critical period after 1980, involves increased concentration of nutrients and the nitrogen factor-limiting role of phytoplankton development. In the year 2011 constant cyanobacterial blooms was recorded.

After 1980, yearly averages of biomass exceeded 10-30 times the ”water blooms” threshold (5 wet weight mg^{-1}, OLTEAN, 1985). Monthly averages in July-September period exceeded 100-125 times the mentioned limit (Fig. 2).

Among the causes for this dramatic increase in phytoplankton biomass, we mention high abundance values and dominance of filamentous, cenobial and colonial species, belonging mainly to Cyanobacteria, followed by Bacillariophyceae. The Mc Naughton and Wolf dominance index (DI) of phytoplankton biomass between 1982 and 1985 exceeded the threshold of 0.5 in all seasons. In general, the dominant species belong to toxin-forming Cyanobacteria (Table 2).

It has been reported high dominance of the species belonging to the genus *Microcystis*, other species of filamentous cyanobacteria (*Aphanizomenon flos-aquae*) and filamentous species of diatoms (*Aulacoseira granulata*, *A. granulata* var. *angustissima*) (Table 2).

Table 1. The frequency of cyanobacterial blooms during long-term studies.

Year	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**%**	**Frequency level**
1976											0	
1977											0	
1978											0	
1982							*				50	constant
1983				*	*	*	*				66	constant
1984				*	*	*	*		*		55	constant
1985					*	*	*	*		*	71	constant
1986					*		*	*	*		57	constant
1987											0	
2000				*							33	accessories
2001					*			*			66	constant
2002					*						33	accessories
2011				*		*		*			100	constant
1976-2011											40	accessories

Sampling month

* Cyanobacterial bloom

Table 2. The Mc Naughton and Wolf dominance index of phytoplankton biomass.

Year	**Month**	**DI**	**Dominant species**
1982	6	0.3642	*Microcystis aeruginosa* KÜTZING *Chroococcus limneticus* LEMM.
	9	0.6986	*Microcystis aeruginosa* KÜTZING *Microcystis flos-aquae* (WITTROCK) KIRCHNER
1983	4	0.5751	*Cyclotella chaetoceras* LEMM. *Aulacoseira granulata* (EHR.) RALFS
	5	0.3566	*Aulacoseira granulata* var. *angustissima* MÜLL. *Cyclotella chaetoceras* LEMM.
	6	0.3349	*Aphanizomenon flos-aquae* (L.) RALFS *Microcystis aeruginosa* KÜTZING
	7	0.3462	*Aphanizomenon flos-aquae*(L.) RALFS *Aulacoseira granulata* var. *angustissima* MÜLL.
	8	0.3789	*Aulacoseira granulata* (Ehr.) RALFS *Aphanizomenon flos-aquae* (L.) RALFS
	9	0.5508	*Microcystis flos-aquae* (WITTROCK) KIRCHNER *Microcystis pulverea* (WOOD) MIGULA
1984	3	0.5584	*Cyclotella chaetoceras* LEMM. *Oscillatoria tenuis* AGARDH
	4	0.7784	*Cyclotella chaetoceras* LEMM. *Diatoma elongatum* AGARDH
	5	0.5210	*Cyclotella chaetoceras* LEMM. *Aulacoseira granulata* var. *angustissima* MÜLL.
	6	0.5977	*Microcystis flos-aquae* (WITTROCK) KIRCHNER *Aulacoseira granulata* var. *angustissima* MÜLL.
	7	0.4789	*Microcystis pulverea* (WOOD) MIGULA *Chroococcus minutus* (KÜTZ.) NÄEGELI
	8	0.6141	*Microcystis aeruginosa* KÜTZING *Aphanizomenon flos-aquae* (L.) RALFS
	9	0.3984	*Aulacoseira granulata* (EHR.) RALFS *Aphanizomenon flos-aquae* (L.) RALFS
	11	0.6636	*Aphanizomenon flos-aquae* (L.) RALFS *Cyclotella chaetoceras* LEMM.
	12	0.6922	*Cyclotella chaetoceras* LEMM. *Cyclotella meneghiniana* KÜTZ.
1985	4	0.6159	*Cyclotella chaetoceras* LEMM. *Diatoma elongatum* AGARDH
	6	0.5365	*Melosira varians* C. A. AG. *Aulacoseira granulata* var. *angustissima* MÜLL.

	7	0.3158	*Anabaena hassalii* (KÜTZ.) WITTROCK *Anabaena scheremetievi* ELENKIN
	8	0.4956	*Aulacoseira granulata* var. *angustissima* MÜLL. *Aphanizomenon flos-aquae* (L.) RALFS
	9	0.5938	*Microcystis pulverea* (WOOD) MIGULA *Oscillatoria tenuis* AGARDH
2011	6	0.8885	*Aulacoseira granulata* (EHR.) RALFS *Aulacoseira granulata* var. *angustissima* MÜLL.
	8	0.1566	*Aulacoseira granulata* (EHR.) RALFS *Microcystis flos-aquae* (WITTROCK) KIRCHNER
	10	0.7756	*Aulacoseira granulata* (EHR.) RALFS *Aulacoseira granulata* var. *angustissima* MÜLL.

When blooms (or dense surface scums) are formed, the risk of toxin contamination of surface waters increases especially for some species of algae with the ability to produce toxins and other noxious chemicals (PAERL et al., 2011).

During eutrophication, in the evolution of phytoplankton, there was an important phenomenon influencing the structural and functional dynamics of zooplankton and bacterioplankton, namely dimensional variation of phytoplankton community, the nannoplankton being replaced by large and filamentous species (NICOLESCU & OLTEAN, 1984).

The phytoplankton populations have not the same nutritional value to the food web of the ecosystem. Cyanobacteria biomass has ensured a low energy value used by consumers, compared with diatoms and green algae.

All these changes in the structure and function of phytoplankton fundamentally transform the ecosystem state that affects the offer of ecological services (PARPALĂ et al., 2008).

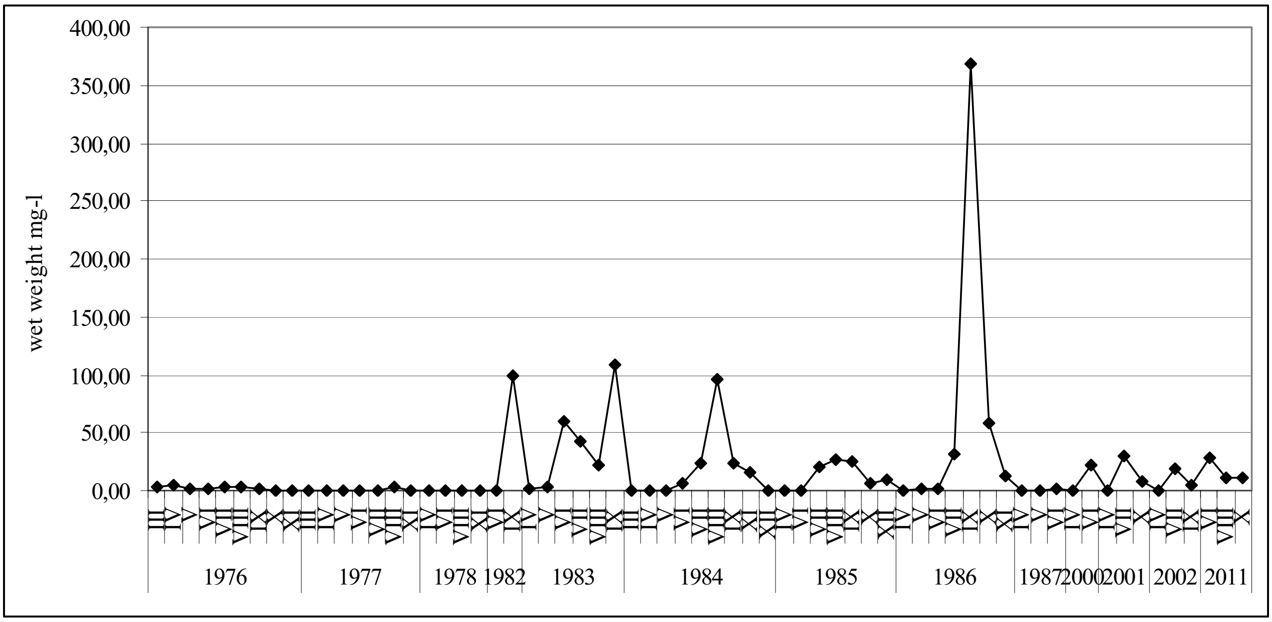

Figure 2. The long-term dynamics of cyanobacteria biomass in Lake Roşu.

When phytoplankton biomass increases during eutrophication, there are coincident changes in the taxonomic structure. Most notably the relative biomass of cyanobacteria increased with eutrophication while in 1977 (mesotrophy stage) the diatoms dominated (Fig. 3).

In 2001 the diatoms and cyanobacteria biomass decreased, especially in the warm seasons, and the ecosystem tended to reach a functional regime, more stable, due to a lower nutrient pressure (Fig. 3).

There was an increasing trend in the cyanobacterial species richness in the taxonomic composition of phytoplankton in the analysed period. It reached 35% in 2011 (Fig. 4).

The Ward's distance indicated a similarity cluster among 2000, 2001, 2002 and 2011, not far from 1983-1984 cluster (hypertrophy period) (Fig. 5). This analysis shows that eutrophication is a long-term process and the cyanobacterial blooms continue today.

The edibility degree of cyanobacterial species is very low, the herbivorous zooplankton being forced to feed on detrito-bacterial aggregates to be able to survive. As large, inedible algae, they induce a bottleneck in the carbon and energy flow of the plankton food web (GILBERT, 1990). According to Pearson correlation, in 2011, the zooplankton biomass is explained by an inverse relationship of the cyanobacteria biomass ($r = -0.559$, $p = 0.029$) (Fig. 6).

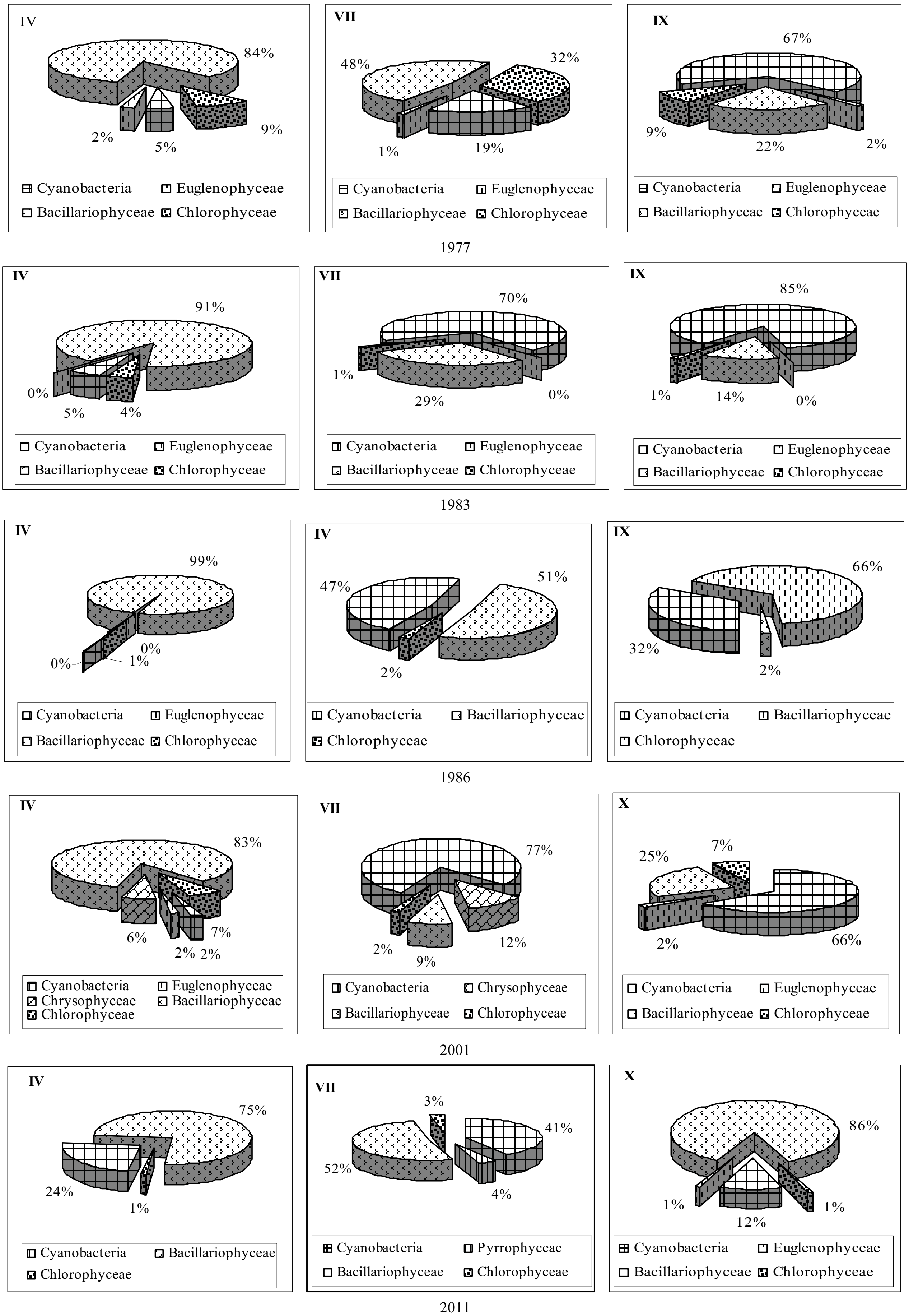

Figure 3. The seasonal variation of the intensity of the cyanobacterial blooms in the selected years.

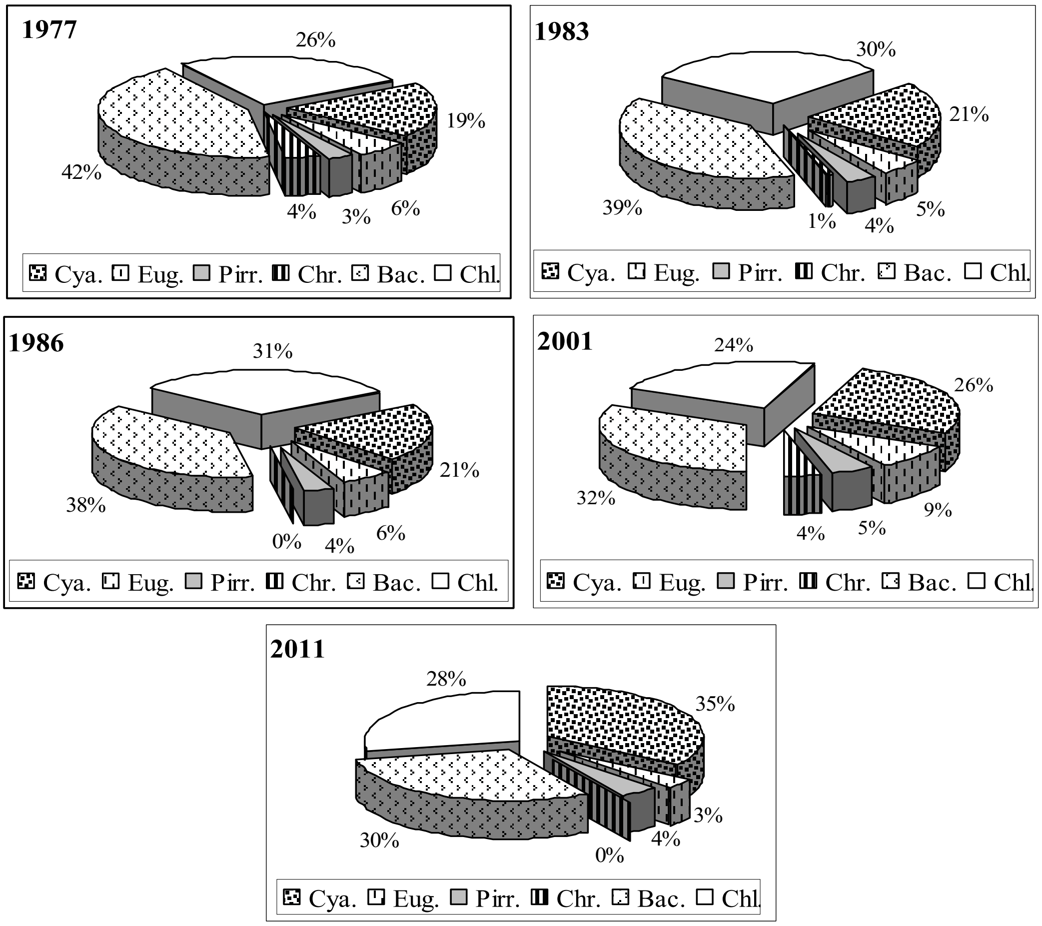

Figure 4. The annual variation of Cyanobacteria species proportion from the total phytoplankton in the selected years.

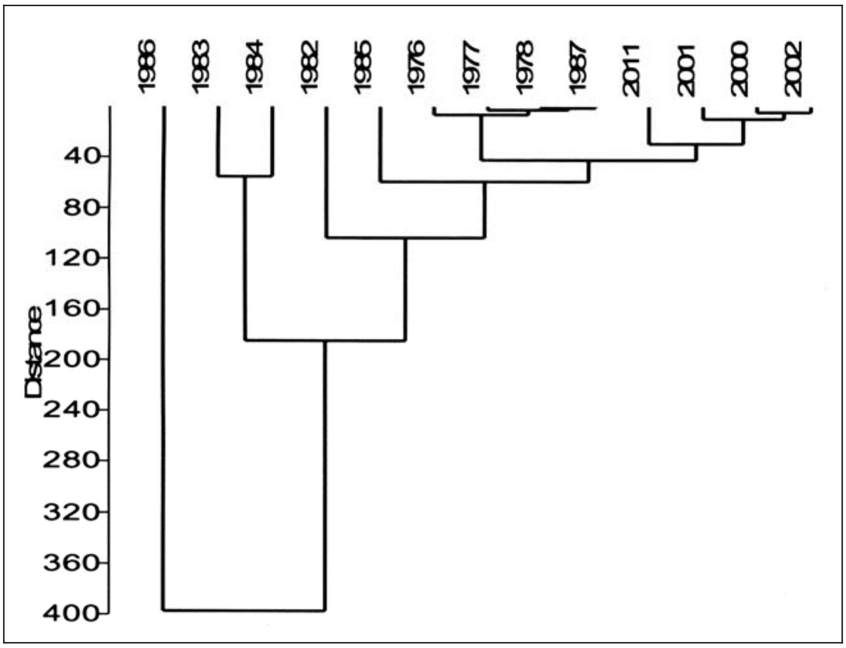

Figure 5. The similarity (Ward's method) of the studied years based on cyanobacterial blooms.

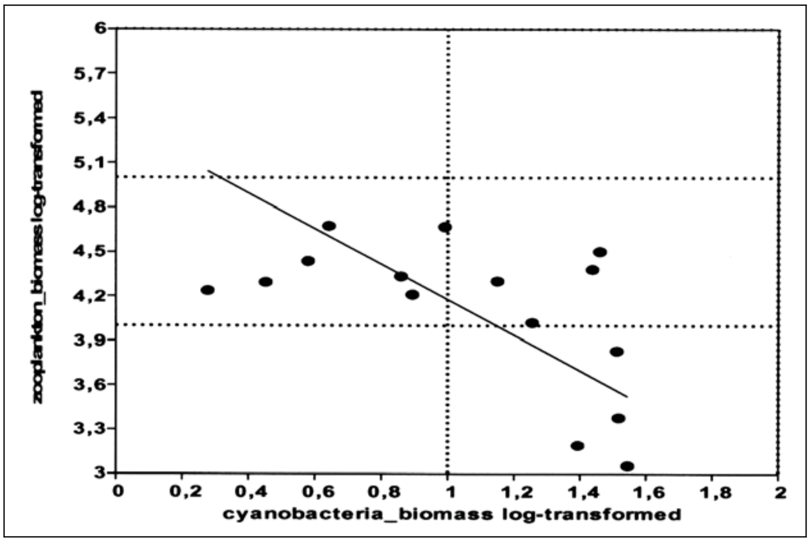

Figure 6. The Pearson correlation between zooplankton and cyanobacteria biomass in 2011 conditions.

CONCLUSIONS

In 2011, the high values of phytoplankton biomass (78.72 wet weight mg^{-1}) show new eutrophication signals, including intense cyanobacterial blooms episodes.

The frequency of cyanobacterial blooms reaches 40% in entire period.

Further investigations will establish if the cyanobacterial blooms are constant and triggered by other factors, as climate change and global warming.

ACKNOWLEDGEMENTS

This study was funded by the project no. RO1567-IBB02/2012 from the Institute of Biology Bucharest of Romanian Academy. We thank also to the Ministry of Education and Research for the financial support of Excellence Project "PROMOTOR". We thank also to Stela Sofa for the laboratory technical support.

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Received: March 4, 2013
Accepted: April 20, 2013