Temperature and N:P ratio as factors causing blooms of blue-green algae in the Gulf of Gdańsk

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Marcin Pliński,
Tomasz Jóźwiak
Institute of Oceanography,
Gdańsk University,
al. Marszałka Piłsudskiego 46, PL–81–378 Gdynia, Poland;
e-mail: ocemp@univ.gda.pl

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Abstract

The bloom dynamics of two planktonic, nitrogen-fixing species of blue-green algae *Aphanizomenon flos-aquae* (L.) Ralfs and *Nodularia spumigena* Mertens in the Gulf of Gdańsk were studied. The Gulf of Gdańsk is a shallow part of the Baltic Sea where the water has a mean salinity of *ca* 8 PSU. Increased riverine nutrient input and/or changes in the N:P ratio are indicated as factors causing blue-green algae blooms. A low N:P ratio appears to trigger blooms. The mean annual value of N:P in the Gulf of Gdańsk since 1981 is 6.5 with a minimum of *ca* 3. There could be a link between temperature and the year-to-year differences in bloom intensities. A huge bloom of toxic *N. spumigena* was reported in July 1994 when the water temperature rose to 22°C.

1. Introduction

Blue-green algae, also known as cyanobacteria, are a diverse group of aquatic and terrestrial organisms with a very wide distribution. The biological specificity of this group has determined their ecological role in aquatic ecosystems. Owing to the absence of a definite nucleus as in other prokaryotes, reproduction in these algae is asexual, which provides for rapid and intensive growth. Their predominant mode of nutrition is by photosynthesis because of the pigments they contain. Components of food chains, blue-green algae can be important contributors to the cycling of nutrients in ecosystems; moreover, they raise the fertility of water bodies as many of them fix atmospheric nitrogen. This is why they play such an important role in the eutrophication of water.

Eutrophication is the enrichment of an ecosystem with mineral nutrients, especially phosphorus and nitrogen, leading to enhanced algal and higher plant biomasses (Sutcliffe & Jones 1992). Although eutrophication can occur as a natural geological process, in which case it is referred to as natural eutrophication, the main cause of this process is the increased discharge of phosphorus and nitrogen into a waterbody as a result of human activities; this is artificial eutrophication. Fertiliser run-off from agricultural land, the discharge of raw or untreated sewage from fish farms, as well as industrial effluents, are the main sources of this type of eutrophication. However, nutrient enrichment alone is not sufficient to account for the frequent dominance of the phytoplankton community by the blue-green algae, which can constitute more than 98% of the bloom biomass. Although nutrient levels, particularly phosphorus, do set an upper limit to the size of the total phytoplankton crop, the blue-green algae bloom may not be reached because of a number of environmental physical and biological factors (Codd 1992).

This paper focuses on the water temperature and the N:P ratio as factors causing the blue-green algae blooms in the estuarine conditions of the Polish Baltic coast (Gulf of Gdańsk). Although blooms of blue-green algae in the Baltic Sea have been known since the mid-19th century (Horstmann 1975), the extent and intensity of the blooms has recently increased as a result of anthropogenic eutrophication (Kahru *et al.* 1994, Leppäkoski & Mihnea 1996). However, the question of which environmental factors are responsible for the increase in blue-green algae remains open.

2. Study area

The Baltic Sea is a semi-enclosed, shallow sea with a narrow connection to the North Sea through the Danish Straits. A marine ecological system, it falls into the oligohaline and mesohaline regime, *i.e.* 0.5–18 PSU. The Baltic Sea is best compared to a stratified fjord with a rich supply of riverine fresh water. Because of the low salinity the number of species in the Baltic is small (Pliński 1994).

Seasonal thermal stratification is established during April or May, according to latitude. The maximum temperature of the surface layer in July–August is usually *ca* 15–18°C, though in some summers it can rise to over 20°C. During the summer the upper mixed layer is 10–20 m thick in response to fluctuations in wind and buoyancy flux through the sea surface (Stigebrandt & Wulf 1987).

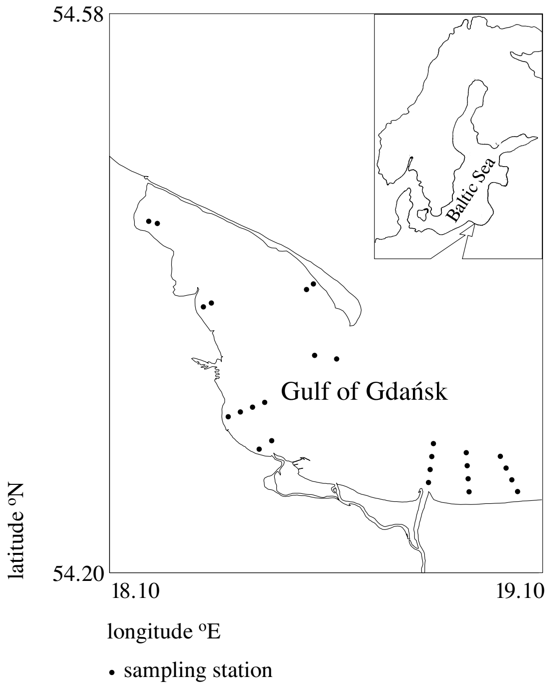

Fig. 1. Outline of the area in the Baltic Sea where samples were taken – the Gulf of Gdańsk

The study samples were taken from the Gulf of Gdańsk (Fig. 1). From the geographical point of view the Gulf of Gdańsk is part of the southern Baltic – a relatively shallow shelf sea with a limited exchange of water with the world ocean. Being a basin with a small absorptive capacity, it is vulnerable to the inflow of various types of pollution from the land (Pliński 1989). Results of long-term studies indicate that highly significant changes are taking place in the biocoenosis of the Gulf of Gdańsk. In the 1970s there was a sharp drop in zoobenthos biomass, but in later years this trend was reversed. Making up over 80% of the biomass, molluscs were prevalent in the zoobenthos, the two dominant species being the cockle *Cerastoderma glaucum* and the mussel *Mytilus edulis* (Wołowicz 1993).

3. Material and methods

The material was usually collected every two weeks during the summer from 1992 to 1996. At each station water samples were taken with a 5-litre sampler at every 10 m of depth, depending on the water depth there, and immediately preserved in Lugol solution on board ship. The quantitative analysis of blue-green algae occurrence was calculated as the average number of cell in the water column from 0 to 10 m.

The microscopic analyses were performed using an inverted microscope in accordance with the methods recommended by BMB (Baltic Marine Biologists Organisation). The sub-samples were sedimented for 24 hours in a 50 ml chamber. In order to render the biomass values comparable, all the data were recalculated using uniform species carbon contents, according to BMB recommendations (Edler 1979).

4. Results and discussion

Blooms of nitrogen-fixing, filamentous blue-green algae have been reported in the Gulf of Gdańsk during late summer. This is a phenomenon very specific to the Baltic ecosystem (Edler *et al.* 1984). Abundant blooms usually occur during calm and sunny periods in July and/or August, and are dominated by *Aphanizomenon flos-aquae* (L.) Ralfs and *Nodularia spumigena* Mertens. *Anabaena* species are less abundant. The dominant species are the same every year, but the abundance ratio of *A. flos-aquae* and *N. spumigena* is highly variable. Because of the toxicity of *N. spumigena*, the species abundance relationship is of crucial significance from the environmental and public health points of view.

The abundance of the dominant species in the Gulf of Gdańsk has been observed to fluctuate from year to year (Table 1). The mean biomass of the two species studied was *ca* 100 $\mathrm{mg\,C\,m^{-3}}$ in 1992. In 1993 this value fell sharply to less than 50% of the previous year's biomass. In July 1994, the biomass rose to 130 $\mathrm{mg\,C\,m^{-3}}$. The main feature of these changes in bloom

Table 1. Mean biomass [$\mathrm{mg\,C\,m^{-3}}$] of *A. flos-aquae* and *N. spumigena* in the Gulf of Gdańsk in the years 1992–1996

Year	Month	*A. flos-aquae*	*N. spumigena*
1992	July	93	11
	August	80	15
1993	July	36	8
	August	4	4
1994	July	1	128
	August	4	22
1995	July	42	26
	August	12	58
1996	July	40	9
	August	5	47

biomass is the clear shift in dominant species between 1992 and 1994. In 1992 the dominant species was *A. flos-aquae*, in 1994 it was *N. spumigena*. During the two next years, in 1995 and 1996 the blue-green algae biomass was lower than in 1992 and 1994. In both of these last two years, *A. flos-aquae* was dominant in July, *N. spumigena* in August.

Which environmental factors were responsible for the fluctuations in blue-green algae blooms remains an open question. As blue-green algae are not limited by nitrogen, the initiation of their blooms has been traditionally related to the competitive advantage over other phytoplankton groups where excess phosphorus was available in the water (Niemi 1979). The existence of blue-green algae blooms in the nitrogen-limited Baltic Proper and their absence in the phosphorus-limited Gulf of Bothnia, Gulf of Riga and eastern Gulf of Finland has been used as the major supporting argument. The non-appearance of blue-green algae blooms in the western Gulf of Finland since 1985 has also been associated with the increased N:P ratio and the subsequent loss of the competitive advantage provided by nitrogen fixation (Kononen 1992). Obvious candidates as causal factors are therefore increased riverine phosphorus input and changes in the N:P ratio. However, the reappearance of the blooms in the western Gulf of Finland in 1992–1993 points to other regulatory factors (Kahru *et al.* 1994). Our observations from the Gulf of Gdańsk confirm these suggestions. None the less, the initial cause of an blue-green algae bloom appears to be a low N:P ratio.

For several years now, nutrients, especially phosphorus, have been increasing in the Gulf of Gdańsk (Fig. 2). Moreover, the N:P ratio has been decreasing steadily. The mean annual value of N:P in the Gulf of Gdańsk since 1981 has been 6.5, with a minimum of 2.8 in July, when the blue-green algae bloom begins. No evident changes in nutrient concentrations were recorded in 1992–1996 (unpublished data). Therefore, the observed fluctuations in the biomass of the blue-green algae blooms should be linked to other factors.

Temperature is one of the most important ecological parameters influencing growth and biological activity. The different temperature optima of the two species analysed are clearly evident (Kononen 1992 and references therein). The temperature optimum reported for *Aphanizomenon* varies within 15–28°C, and the minimum temperature at which growth ceases lies below 10°C. The optimum growth temperature of *Nodularia* strains isolated from the Baltic Sea is 20–25°C; no growth is observed at 10°C. Temperature affects the life cycle of *Nodularia* as well, since the akinetes germinate at temperatures >16°C (Huber 1984). These data show that the growth of *N. spumigena* is strongly temperature-dependent.

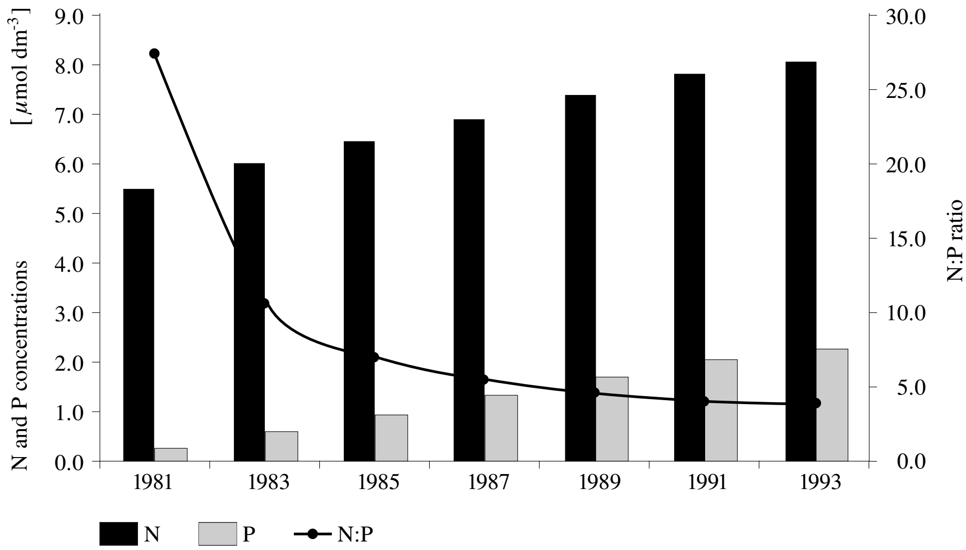

Fig. 2. Mean nutrient concentrations and N:P ratio for the Gulf of Gdańsk during the period 1981–1993

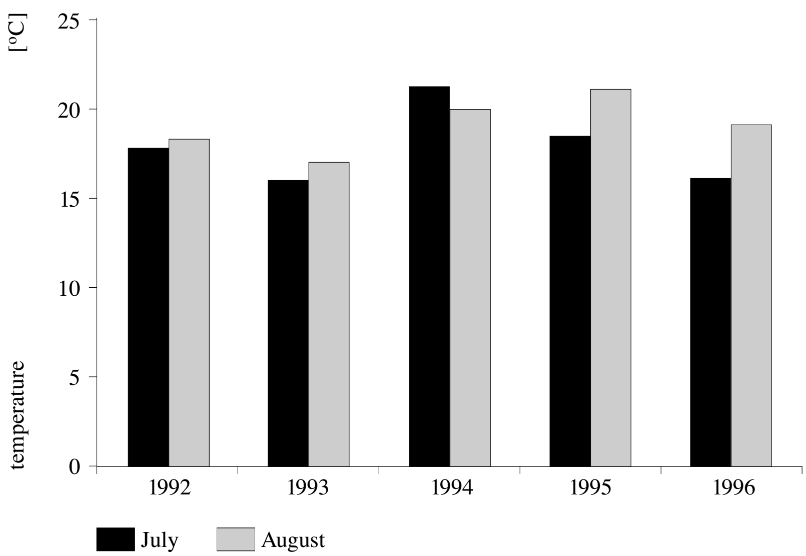

Fig. 3. Mean seawater temperatures in the Gulf of Gdańsk in the years 1992–1996

Our observations confirm the fact that *N. spumigena* prefers a temperature higher than the optimum one for *A. flos-aquae* growth. Both species grow intensively when summer temperatures are >18°C. In 1992–1996 the mean summer seawater temperature fluctuated widely (Fig. 3). The biomass of these species was lowest in 1993, when the water temperature was lowest (16°C in July). In July 1994, when the temperature rose to 22°C, a huge bloom with significant domination of *N. spumigena* was reported. In 1995 and 1996 August was warmer than July; *N. spumigena* was predominant in August, whereas *A. flos-aquae* prevailed in July. Comparison of the biomass data with temperature shows that it is the water temperature that could be the main factor governing the species dynamics in blue-green algae blooms.

5. Conclusion

The results show that the intensity of blue-green algae blooms depends not only on the increase in nutrient input and the decrease in the N:P ratio, but also on the temperature. Compared with the growth requirements of *A. flos-aquae*, higher temperatures could be the factor triggering the *N. spumigena* bloom. Therefore, the warming up of the water resulting from global climatic changes represents a risk for coastal areas, as this stimulates the blooming of *N. spumigena*, a toxin-producing species. Hepatotoxin (nodularin) was detected in the blooms of July 1994 and August 1997.

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