Communications

Phytoplankton blooms – a 'fever' of the Baltic ecosystem*

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Abstract

This paper examines the phenomenon of Baltic phytoplankton blooms in a new light. They are investigated from the standpoint of the author's own studies of chlorophyll and its derivatives in deep Baltic sediments, and of the influence of inorganic and organic pollutants on unicellular algae. Algal blooms in the Baltic should be perceived as perfectly normal phenomena that are neither time- nor space-specific. At the same time, they are signals given by the basin that something – not necessarily the level of nutrients – has changed in the environment and are a response of the ecosystem to that change.

Investigations into the effects of pollutants on the biotic components of the Baltic environment have focused, as in the other seas of the world, on animals, *i.e.* mussels, fish and birds (HELCOM 1987, 1990). This priority was motivated by their closer position to man in the food chain in comparison to plants, and their stronger accumulative

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properties. Nevertheless, plants (phytoplankton algae included) are also seriously affected by metals, radionuclides or organic pollutants. Macroalgae have been studied as pollution monitoring organisms in the Baltic Sea (HELCOM 1993). The impact of metals or organic pollutants on unicellular algae (phytoplankton) has been examined by numerous workers, especially on axenic algal cultures under laboratory conditions, *e.g.* Sunda 1990, Cripps & Priddle 1991, but has been overlooked in interpretations of anthropogenic influences on biota in the Baltic. It is only recently that scientists have taken notice of this problem (HELCOM 1993, Gunmarson *et al.* 1995).

Phytoplankton in the Baltic ecosystem has been studied mainly with respect to eutrophication, which has generally been regarded as one of the basic pollution problems in that sea (HELCOM 1987). Assumed to be a parameter proportional to phytoplankton abundance in seawater, the chlorophyll *a* content has been routinely determined in monitoring studies of the Baltic for over twenty years (HELCOM 1981, 1996, Trzosińska & Łysiak-Pastuszak 1996). By 'eutrophication' we generally mean an intensive bloom of algae resulting from elevated concentrations of nutrients, *i.e.* of various nitrogen (nitrates, nitrites and ammonium), phosphorus (mainly phosphates) and silicon (mainly silicates) ions in seawater, and its consequent adverse environmental effects (AMBIO 1990). Frequently, it is tacitly assumed, especially in mathematical modelling, that these ions are anthropogenic, totally foreign to the natural environment (ICES 1998). In actual fact, however, they contain elements abundant in nature and which are also formed naturally. This occurs above all during the decomposition of organic matter, but also in other processes: for instance, nitrites and nitrates are produced from atmospheric nitrogen during thunderstorms. It is a generally accepted fact that human activities in the Baltic drainage area in the last fifty years have given rise to considerable fertiliser runoff, primarily from agriculture, and that this can be held responsible for the intensive algal blooms (HELCOM 1987). None the less, unspecified 'organic matter' has also been indicated as a potential cause of the blooms (ICES 1998). Studies of recent sediments in the Gotland Basin and the North Central Basin (Kowalewska *et al.* 1998, 1999) indicate that the amounts of chlorophyll *a* in layers formed even thousands of years ago are much the same as those found in the chlorin-richest surface (0–10 cm layer) sediments of the Gdańsk Deep or Szczecin Lagoon (Kowalewska 1997) (Fig. 1). Now chlorophyll *a* is not very stable. Obviously then, if the pigment is still detectable after as long as eight thousand years, there must have been not only favourable sedimentation and postdepositional conditions (anoxia) but also a high flux of plant material in the past. Hence, the blooms occurring,

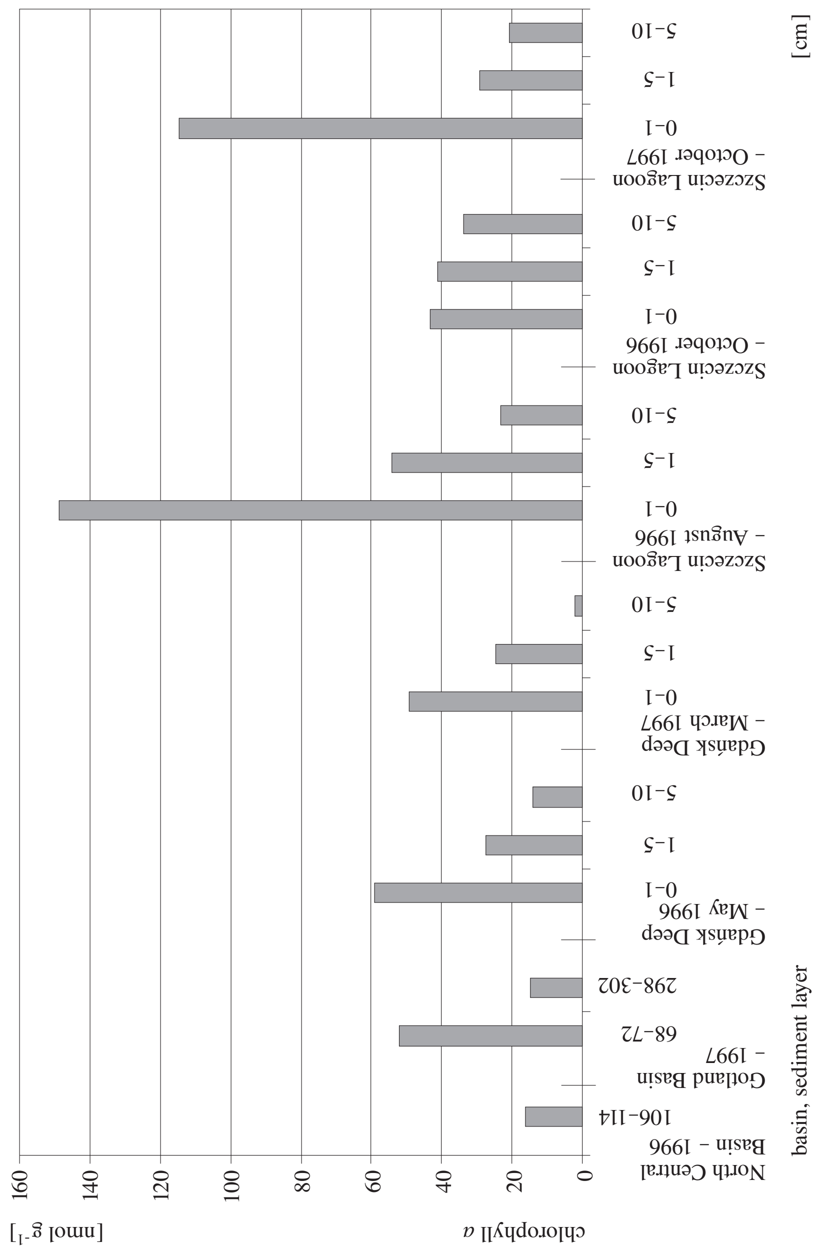

Fig. 1. Chlorophyll a [nmol g^{-1}] in deep and surface sediments of the Baltic Sea: North Central Basin (NCB 58°49′N, 20°15′E), Gotland Basin (GB, 57°17′N, 20°07′E), Gdańsk Deep (G–2, 54°50′N, 19°20′E) and Szczecin Lagoon (L 53°43′N, 14°26′E) (Kowalewska 1997, Kowalewska *et al.* 1998, 1999)

say, in the Middle Ages or even a few thousand years ago, will have been as intensive or more so than those of today. This inference goes against the commonly accepted view that the present-day eutrophication of the Baltic is an extraordinary phenomenon.

If we look at the nutrient biogeochemistry of the Baltic Sea, we often cannot distinguish cause from effect. A high content of nitrites or 'organic phosphorus' in the water is not necessarily the cause of a phytoplankton bloom; it may well be the result of one. In recent decades, nutrient ions in the Baltic have occurred in concentrations high enough to sustain the growth of algae. In such a situation, it is not so much the nutrients as the trace components of the environment and the physical conditions, especially light, that are responsible for the growth and species composition of the phytoplankton population in any part of this sea.

Our studies of chlorins (*i.e.* chlorophyll a and its derivatives) in recent sediments have revealed a very high correlation of these pigments with organic carbon, especially in the coastal zone and in the surface 0–1 cm sediment layer (r = 0.96–0.98) (Kowalewska 1997). This indicates that phytoplankton and the detritus derived from it make up the main stock of organic matter for the southern Baltic environment. Both living cells and phytoplankton detritus are potential active or passive high-capability sorbents of all the ionic and neutral contaminants present in seawater.

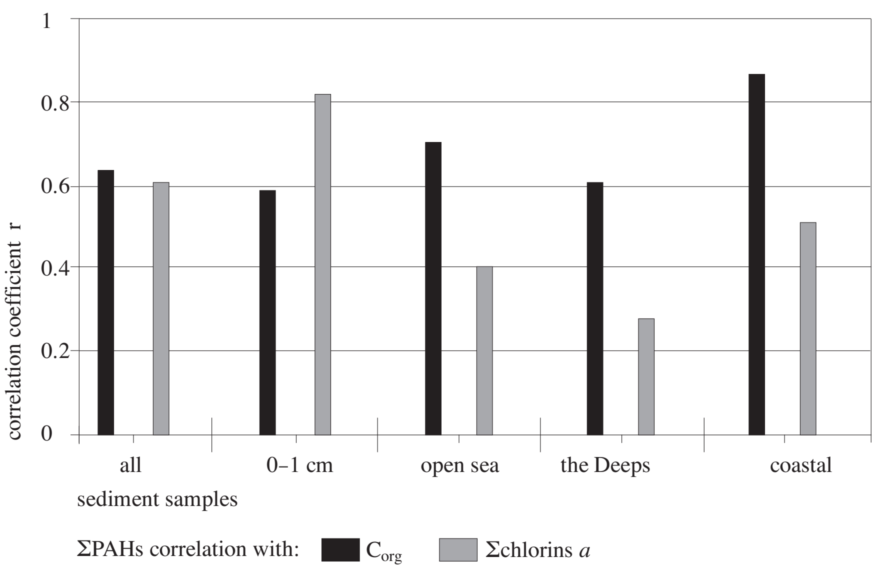

Fig. 2. Correlation of the sum of aromatic hydrocarbons (PAHs) with organic carbon and the sum of chlorins (*i.e.* chlorophyll a and its derivatives) in recent sediments of the southern Baltic (Kowalewska & Konat 1997a)

However, even a change in a single parameter like salinity may cause some ions or compounds to be released from or bonded to these associates. The sorbent capacity of phytoplankton has been very well illustrated by a series of studies on polynuclear aromatic hydrocarbons (PAHs) (Kowalewska & Konat 1997a, Kowalewska *et al.* 1997). The sum of chlorophyll *a* and its derivatives was very well correlated with PAHs in Baltic sediments, especially in the 0–1 cm layer. This demonstrated that PAHs are absorbed by phytoplankton and the detritus derived from it in the water column, and also that the sorbed molecules are subsequently transported to the bottom sediments (Fig. 2). Analysis of plankton samples has confirmed that this is indeed the case. In samples consisting mainly of phytoplankton, PAHs were present in amounts up to $16\,\mu\mathrm{g\,g}^{-1}$, *i.e.* twice as great as those in the most PAH-rich sediment samples of the Gulf of Gdańsk and the Szczecin Lagoon (up to $\sim$7 and $\sim 8\,\mu\mathrm{g\,g}^{-1}$ respectively). Samples consisting mainly of zooplankton did not contain measurable amounts of PAHs (Kowalewska & Konat, 1997b). These results also indicate that sorption of PAHs by living phytoplankton cells is selective and depends on the chemical structure of the PAH in question. Another example, this time of inorganic ions, is radium-226, which is also selectively sorbed from seawater by diatom cells. This process considerably shortens the residence time of this isotope in the water column (Kowalewska & Łotocka 1989).

Field observations have shown algal blooms to be linked with the concentration of copper in water, since an increase in this concentration was thought to be the cause of the blooms, the so-called ‘red tides’ (*e.g.* Arzul & Gentién 1990). On the other hand, copper sulphate was used already in the early 20th century to ‘force’ algal blooms to occur in lakes (Moore & Kellerman 1905). Such apparently contradictory effects may be reconciled when one understands the part played by the concentration of metal ions in the medium on algal growth. Experiments with laboratory cultures of blue-green algae (Kowalewska & Łotocka 1991), diatoms (Kowalewska *et al.* 1992) and green algae (Kowalewska, unpublished results) have shown that a rise in copper concentration in the cultivating medium initially caused a sharp fall but later a rise in chlorophyll content and/or cell number in the culture (Figs. 3a and 3b). So, depending on the concentration range, copper can act either as a stimulator or inhibitor of algal growth. Moreover, different species react differently to the same copper concentration in the medium. Though its significance to different species varies, the light factor is also very important for the growth of a culture. These differences in behaviour are responsible for the so-called succession of species. Copper had been suspected of being the cause of this phenomenon (*e.g.* Steeman-Nielsen & Wium-Andersen 1971), recorded in seawater by numerous authors (*e.g.* Sanders *et al.* 1981). These are only a few examples taken from my own experience of the interaction of the phytoplankton population with environmental pollutants. There must surely be many other examples.

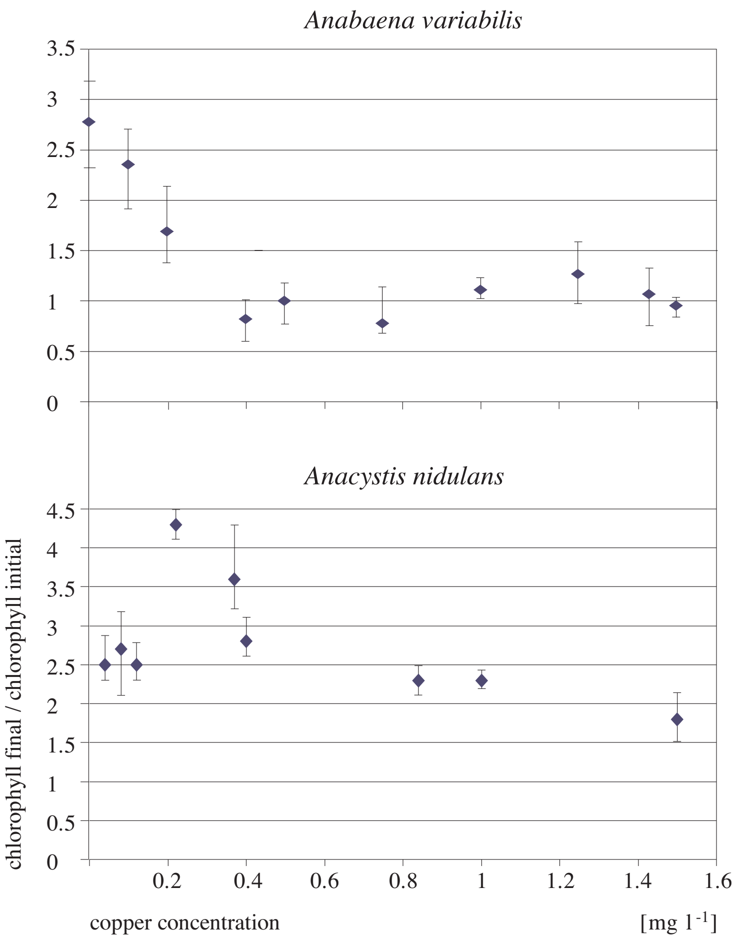

Fig. 3a. Influence of copper on chlorophyll a content in blue-green algae laboratory cultures *Anabaena variabilis* and *Anacystis nidulans*. Conditions: medium BBM, pH = 8, t = 25°C, light $5\,\mu\mathrm{E\,m^{-2}\,s^{-1}}$ (Kowalewska & Łotocka 1991)

When describing the pollutants in the Baltic Sea with the aid of a model, the ideal situation would be if this sea could be treated as a system in a state of equilibrium. Unfortunately, however, only an isolated system can reach the state of equilibrium. When there is an exchange of matter or energy with the environment we can at best speak about a steady-state condition where fluxes pass through the system but the chemical concentrations remain invariant. Such a situation may obtain in a river with a steady water flow

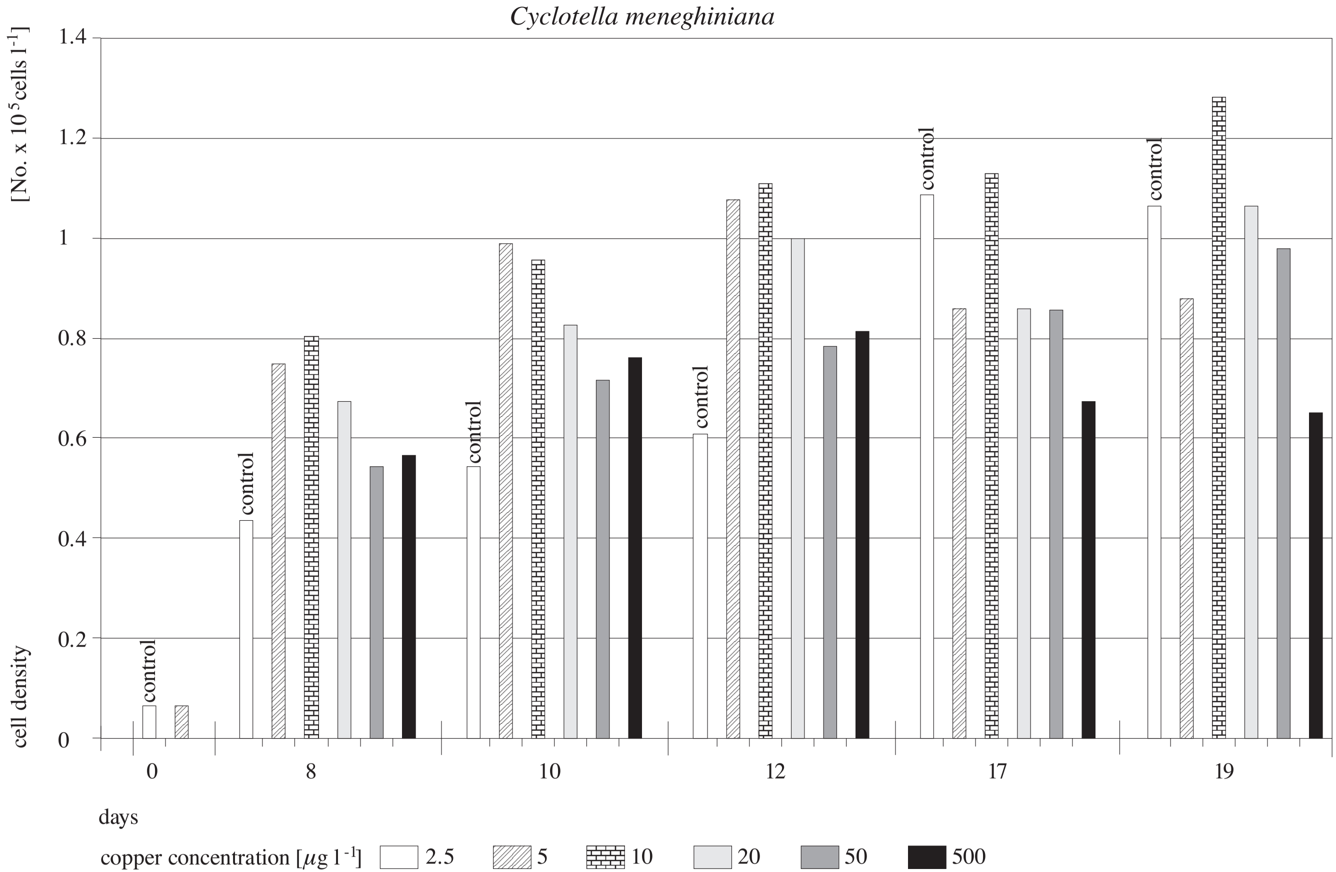

Fig. 3b. Influence of copper on cell density in cultures of the diatom *Cyclotella meneghiniana*, originally isolated from the Baltic Sea. Conditions: medium f/2, t = 18°C, light $27\,\mu\mathrm{E\,m^{-2}\,s^{-1}}$ (Kowalewska *et al.* 1992)

rate or a constant concentration of substances in the water, or else in a sea area when the flux of a substance across the sea-atmosphere interface is equal to that precipitated in the water column and sedimenting on the seafloor. Any change in the mass or energy flux through such a system will disturb this balance. If such a change promotes the growth of a certain species, this develops more intensively than other species do. If this is not the case, two things can happen. One is that the dedefensive mechanisms of every member of a species in the system are strong enough to counteract the change and so all the individuals survive. On the other hand, the defensive possibilities within a species are varied and then only the resistant individuals survive to give rise to a new, more stress-resistant population. From the standpoint of the ecosystem the time scale of such a change is very important. If it is rapid but short-lived, the system may return to its previous state, as was the case with the Pomeranian Bay after the river Odra flood in 1997 (Trzosińska & Andrulewicz 1998, Kowalewska *et al.* 1998). But when the change is slow and prolonged, the system may develop defensive mechanisms. A good example of such a situation is the Szczecin Lagoon, where the annual algal blooms are regularly accompanied by an elevated zooplankton population. The result is that the area is in astonishingly good condition, considering the pollutant load it is receiving (Chojnacki 1991). A further situation is when the change is rapid but irreversible, the most difficult one for the biota of an ecosystem to cope with. A good example of such an area was Puck Bay (Ciszewski *et al.* 1992).

To conclude, an algal bloom should not necessarily be treated as an exclusively anthropogenic disaster, but rather as a signal that something has changed in the environment. At the same time, it is a way in which the aquatic system responds to environmental conditions, including pollution. For growth, algae need not only macro-components but also micro-components, sometimes even trace components (inorganic and organic), and appropriate light, temperature and salinity conditions. Different algal species have various optimum requirements for maximum growth. Moreover, they react variously and at different rates to changes in environmental conditions, including the micro-components of the medium. All such reactions contribute to the succession of species, which enables the whole marine ecosystem to respond more flexibly to stress factors. When treating the sea as an entity we can look upon an algal bloom as an agent cleaning the water through the sorption of pollutants and their further transport to the sediments, where they are either stored in bonded form or are decomposed by diagenesis. Of course, the sediments may undergo resuspension with the subsequent release of pollutants to adjacent waters. Pollutants can also be accumulated by benthic organisms or fed to phytoplankton already in the water column; in this case, however, they are 'diluted' in the phytoplankton biomass.

On the other hand, when algae grow too intensively, the environment deteriorates. In addition, a decrease in biodiversity may occur, or species toxic to other organisms may develop. The bloom can be compared to a fever in the sick human organism: it can combat disease, but it can also weaken and even kill that organism. Understood in this way, a bloom is a normal occurrence in every aquatic basin, neither time- nor space-specific. Simultaneously, though, it is a signal that something has been introduced into the environment either in a natural way or by man, and/or that the physical conditions have changed. To understand the life of the Baltic ecosystem it is crucial to possess a knowledge of which substances introduced into the environment by man induce which effects, and how strong these effects are under given physical conditions in comparison to natural factors. Though this problem was remarked upon some years ago, the main difficulty lies in finding a solution. Certainly, it is most often not the nutrients but the other, minor or even trace pollutants that give rise to the observed intensive blooms of algae and the subsequent eutrophication.

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