ECOPHYSIOLOGICAL PERSPECTIVES OF CYANOBACTERIAL BLOOMS.

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ABSTRACT

Cyanobacteria (blue-green) alage) have had a profound and unparalleled impact on the aquatic environment because of the phenomenon of bloom formation. In many countries, water management is threatened with extensive and persistent noxious blooms of cyanobacteria in surface and near-surface mesotrophic and eutrophic waters. In view of this, ecological and physiological factors responsible for blue-green algal dominance are discussed. The implications of bloom formation are highlighted and recommendation made to combat this menace.

INTRODUCTION

Of the major groups of phytoplankton in freshwater, cyanobacteria (blue-green algae) are a well circumscribed class. Perhaps the most clear-cut distinction between cyanobacteria and other phytoplankton is the fact that they are prokaryotes (have nucleus and organelles that are not membrane-bound, possess gas-vesicles and can fix nitrogen). Among prokayotes however, cyanobacteria differ in carrying out oxygen-evolving photosynthesis, lacking flagellar motility and in their tendency to periodically accumulate as high-density bloom populations in surface and near-surface mesotrophic and eutrophic waters (Carr & Whitton, 1982; Bryant, 1994).

Cyanobacteria are widely distributed and include at least 22 genera and over 90 species. Well known as "pioneer organisms," they are initial colonizers and dominant phytoplankton in such inhospitable habitats as recently filled volcanic craters, geothermal pools, alpine and desert ponds and lakes, highly polluted (either with organic and / or inorganic wastes) lacustrine and riverine systems (Fogg et al, 1973; Gibson & Smith, 1982). Eutrophication of freshwater and the appearance of cyanobacterial blooms have become a worldwide problem especially when bloom-forming species release potent toxins. Permanent cyanobacterial dominance is therefore regarded as the ultimate phase of eutrophication. Associated with blooms are other negative effects such as reduced transparency, decreased biodiversity, elevated primary production and the potential occurrence of oxygen depletion which may result in massive fish kills, odour and taste in water. In addition, algal blooms are an unsatisfactory food source for many organisms in the food web (Reynolds, 1991).

While toxin producing algae occur among the Prymnesiophyceae, Dinophyceae (dinoflagelates) and Cyanophyceae, it is the latter that cause most of the problems in freshwater environments (Carmichael, 1986). Although it is clear that the increased input of nutrients is a prime cause of blooms, other physico-chemical "forcing factors" and physiological mechanisms also contribute significantly in promoting their growth and persistence during bloom periods. This paper will examine ecophysiological adaptations which have been responsible for the remarkable success of these prokaryotic photoautotrophs in planktonic and benthic freshwater communities.

MORPHOLOGICAL DIVERSITY

The cyanobacteria display a wide spectrum of morphological features including structurally and functionally differenciated cells, cell shapes, dimensions and solitary versus colonial habits. Depending on environmental constraints during growth phases and physiological requirements, many genera are able to regulate the extent of colonial or filamentous development (Paerl, 1988).

Four basic morphological groups can be recognised:

1. Unicellular picoplankton (0.2 – 3 ?m in diameter). They occur as coccoid, ovoid or rod-shaped solitary cells e.g. *Synechococcus*, *Synechocystis* (Fig 1).
2. Colonial nanno- and micro-plankton (2 – 10 ?m in diameter).

   Representative genera include *Gomphosphaeria, Microcystis, Chroococcus.*
3. Solitary filamentous microplankton. These consist of cylindrical cells forming long, straight filaments. Vegetative cells in filaments can differenciate to form **akinetes**, a type of resting spore. Examples are the genera *Oscillatoria* and *Lyngbya*.

4. Colonial filamentous microplankton. These genera form aggregates of filaments resulting in large buoyant, suspended or benthic colonies. Majority of aggregated filamentous genera are capable of nitrogen fixation following morphological and physiological differenciation of vegetative cells into **heterocysts** e.g. *Anabaena, Aphanizomenon, Nostoc, Nodularia, Gloeotrichia*.

However, there are also non-heterocystous nitrogen fixing genera such as *Lyngbya, Oscillatoria, Phormidium.*

FACTORS FAVOURING BLOOM FORMATION

Ecophysiological factors responsible for algal blooms are numerous and complex (Table 1). Rarely will a single factor be responsible for their dominance but physico-chemical factors are frequently of overriding importance in determining which genera and species become established in specific ecosystems (Paerl & Tucker, 1995).

IMPLICATIONS OF BLOOM FORMATION

Cyanobacterial blooms lead to some of the most ominous symptoms of water quality degradation including bottom water anoxia and hypoxia, odour, taste and toxicity problems; destruction of the aesthetic and recreational values of water and structural shifts in plankton communities. However, the most economically important consequence of bloom formation involves mortality and morbidity in fisheries resources.

Generally, cyanobacteria are k-selected organisms with relatively slow growth rates but high competitive ability for limited resources (Kilham & Hecky, 1988). Hence, the low biomass-specific rates of net carbon fixation translates into reduced fish yields. The efficiency of food transfer may be further reduced when blooms are present because they are poorly utilized as food (Paerl 1988). The slow growth rates of blue-green algae also means that they are poor oxygenators of water on a per unit biomass basis compared to other phytoplankton species. In addition, surface bloom communities reduce net input of dissolved oxygen to water because oxygen production is restricted to the upper few centimetres. Massive die-offs of cyanobacterial communities results in oxygen depletion as dead algal cells are decomposed. Fish kills in tropical lakes as a consequence of blooms occur but are rarely reported (Belay and Wood, 1982; Ochumba, 1990; Romdhane et al, 1997).

The production of highly odorous and/or toxic metabolites by some species causes great economic loss in fisheries. Two metabolites of blue-green algae geosmin and 2-methylisoborneol cause earthy-musty odours and off-flavours in pond-cultured fish (Van der Ploeg *et al.*, 1992). Several blue-green algae produce toxins which have potent cyto-, hepato- and neuro-toxic effects on fish, shellfish, invertebrates, birds and mammals (Carmichael, 1986; Oudra *et al.*, 1997).

In Egypt and other developing countries, inoculation of rice fields with dinitrogen fixing cyanobacteria is an important practice that enhances rice production. Increases in yields of 15 – 25% were achieved by substitution of 1/3 to 1/2 of the recommended rate of fertilizer nitrogen by inoculation with cyanobacteria. Other advantages of this practice include increased availability of native phosphorus, better soil particle aggregation, antagonism of aquatic macrophytes and stability of the N-status of the ecosystem for healthy plant growth without increasing susceptibility to pests (Yanni & Carmichael, 1997). However, the capability of cyanobacteria to produce toxins is not considered by inocula producers. Isolates in an inoculum normally find their way to soil and water resources which are frequently used by marginal farmers for animal and human consumption.

The capacity of bloom organisms to drive diversity downwards results in a structural shift in the plankton community structure and dynamics of the ecosystem.

CONTROL

In proposing control strategies against algal blooms, water column turbulence or mixing assumes a prominent role. This realization has fostered the application of artificial mixing strategies in reducing and eliminating bloom populations. However, to be effective mixing must operate more or less continually during favourable bloom growth periods.

Close monitoring of the ambient nutritive conditions in water bodies is necessary. Decreased phosphate availability can lead to declines in algal bloom potentials particularly for nitrogen-fixing genera.

There is the possibility of biological control using amoeboid protozoans which are active grazers on blue-green algae even when higher-ranked crustacean zooplankton find such cyanobacteria either inedible, distasteful or toxic (Fulton & Paerl 1988). However, bloom eradication and mitigation approaches utilizing biological control measures require careful and critical evaluation prior to deployment on the natural community.

More recently advancements in biotechnology offer prospects for the use of "bloom" species. It has been discovered that many micro-organisms are a promising new source of bioactive substances which could be used in the manufacture of industrial chemicals, marine biomedicals and non-polluting energy sources. Notable among these, is the discovery of antileukaemia activity in blue-green algae of the family Oscillatoriacea. Thus in the near future, blue-green algal blooms may be harvested and exploited for the production of novel compounds (Ninawe, 1995).

Table 1 FACTORS INFLUENCING BLOOM FORMATION

FACTORS	EFFECTS OR IMPACTS
ECOLOGICAL FACTORS	
Physical	
Temperature	Generally warm water temperatures accompanied by a stratified water column and high nutrient loading rates promote blooms.
Large scale vertical mixing	Prevents surface bloom accumulations and forces competition for light and nutrients with non-buoyant eukaryotic taxa.
Small scale turbulence	May disrupt filaments, colonies and mutualistic associations with other micro-organisms.
High water transparency	Promotes bloom formation because unlike other eukaryotic phytoplankton bloom-forming genera can withstand long periods of exposure to high photosynthetically active radiation (PAR).
Low hydraulic retention time / flushing	Prevents bloom establishment or removes bloom if flushing rate exceeds growth rate of bloom taxa.
Chemical	
Eutrophication / Nutrient input	Favours bloom formation especially if the ratio of N to P loading is low.
Salinity	Salinity in excess of a few ppt may be an effective barrier to the development and persistence of blooms.
Environmental pH	Generally high pH favours blue-green algal growth.
Trace metals	Under high N & P loading, restricted availability of Fe may favour cyanobacteria.
Biological	Absence or scarcity of herbivorous zooplankton and larger filter feeding species that can ingest blue-green algae.
Physiological factors	Buoyancy regulation which enables maximum use of resources in an environment with rapidly shifting gradients of light, temperature, oxygen and nutrients
1. Intracellular gas vacuoles	These harbour the oxygen-sensitive nitrogenase enzyme complex and confer on the algae N-fixing ability. They are thus at a competitive advantage under limiting nutrient conditions.
2. Presence of thick- walled, or oxygen devoid heterocysts cells	These toxins can negatively impact potential competitors for resources and/ discourage grazing and consumption by herbivores.

3. Production of toxic metabolites e.g. Geosmin, microsystin, saxitoxin 4. Specialized perennating spores – akinetes Source: Paerl & Tucker, 1995.	Ensure survival & re-establishment of the species under adverse environmental conditions.

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