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Cyanobacterial blooms in freshwater ecosystems: Causes and consequences on their functioning and their uses

Policy Brief n°1

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Cyanobacterial blooms almost always occur in freshwater ecosystems displaying high phosphorus and nitrogen concentrations (eutrophic ecosystems). These phenomena are visually easy to identify due to the very pronounced green color of the water during the blooms and due to the accumulation of green materials at the surface of the lakes for some species (**Fig 1**).

If cyanobacteria are known to be very ancient microorganisms that have played an important role in the evolution of our planet and contributed significantly to primary production in aquatic ecosystems, their proliferation in freshwater ecosystems is a growing concern for human populations due to the ability of some species to produce harmful toxins.

For this reason, numerous studies have been performed during the past 30 years with the goal of better understanding (I) the causes of the increasing occurrence of cyanobacterial blooms, (II) the sanitary risks associated with these blooms for human and animal populations and (III) their consequences for the uses of freshwater ecosystems, in particular for the supply of water.

Fig 1. Cyanobacterial blooms in freshwater ecosystems

I. The cyanobacteria and their toxins

Cyanobacteria are photosynthetic microorganisms that are able to grow in all surface water ecosystems (rivers, lakes, ponds, etc.). They belong to phytoplanktonic and phytobenthic communities with microalgae (chlorophytes, diatoms, etc.), and consequently, they play an important role in the primary production of these ecosystems.

Depending on the species, cyanobacteria display very various morphologies; they can be found as isolated cells or organized in the form of colonies or filaments, some of which are visible to the naked eye.

Cyanobacteria are able to produce numerous metabolites, some of which are toxic to humans and animals. Among these toxic metabolites, three classes of cyanotoxins have been distinguished:

- Hepatotoxins: Microcystins are the most common hepatotoxins produced during planktonic blooms of cyanobacteria. These toxins have been involved in human and animal poisoning, sometimes leading to fatalities. Microcystins could be involved in primary liver cancer, and they have more recently been described as reprotoxic (having an effect on fertility).
- Neurotoxins: Anatoxins can be produced by some planktonic species, but they are the most common cyanotoxins produced during the proliferation of benthic cyanobacteria. They are frequently involved in the death of animals, particularly dogs.
- Dermatotoxins and irritant toxins are frequently produced by planktonic cyanobacteria. They are not involved in mortality events, but they can deeply disturb recreative activities in freshwater ecosystems.

The main exposure manners of humans to these toxins are (I) the consumption of nontreated water by populations directly using lake water during a bloom for drinking and/or cooking and during bathing activities or using poorly treated water, (II) the consumption of fish with accumulating cyanotoxins in lakes experiencing severe cyanobacterial blooms and (III) skin and/or eye contact with dermatotoxins during recreational activities and/or bathing.

Following World Health Organization (WHO) recommendations for reducing the risk of exposure of human populations to cyanotoxins, monitoring programs of cyanobacteria have been implemented in numerous countries in water resources used for water supply and/or recreational activities. In addition, these countries also defined acceptable limits for cyanobacteria cell abundances or biomasses and several cyanotoxin concentrations (microcystins, for example) in raw and treated water.

The new guideline values (GV) proposed by the WHO concerning cyanotoxins are as follows:

-For **microcystin**s: Lifetime drinking-water GV: 1 µg/L; recreational water GV: 24 µg/L

-For cylindropsermopsins: Lifetime drinking-water GV: 0.7 µg/L; recreational exposure: 6 µg/L

-For anatoxins: Acute or short-term exposure by drinking water GV: 30 µg/L; recreational water exposure GV: 60 µg/L

-For saxitoxins: Drinking water GV: 3 µg/L; recreational water GV: 30 µg/L

II. Main causes of cyanobacterial blooms

The biomass produced by phytoplankton communities in water bodies depends largely on nutrient availability, particularly phosphorus (P) and nitrogen (N), the two most limiting elements in freshwater ecosystems. Consequently, the P and N concentrations define the trophic status of water bodies, from oligotrophic for those displaying low P and N concentrations to mesotrophic, eutrophic and hypereutrophic with growing P and N concentrations (). The progressive nutrient enrichment of aquatic ecosystems is a long-term natural process that can be greatly accelerated by human activities, which is why natural eutrophication is frequently distinguished from anthropogenic eutrophication.

Trophic levels in lentic freshwater ecosystems

	Total Phosphorus concentrations (µg/L)	Chlorophyll-a concentrations (µg/L)
Oligotrophic	0-10	0-3
Mesotrophic	10-30	3-10
Eutrophic	30-100	10-30
Hypereutrophic	>100	30-400

Under conditions of high nutrient concentrations, the primary producers will generate, during the growth seasons, large amounts of organic matter in water bodies.

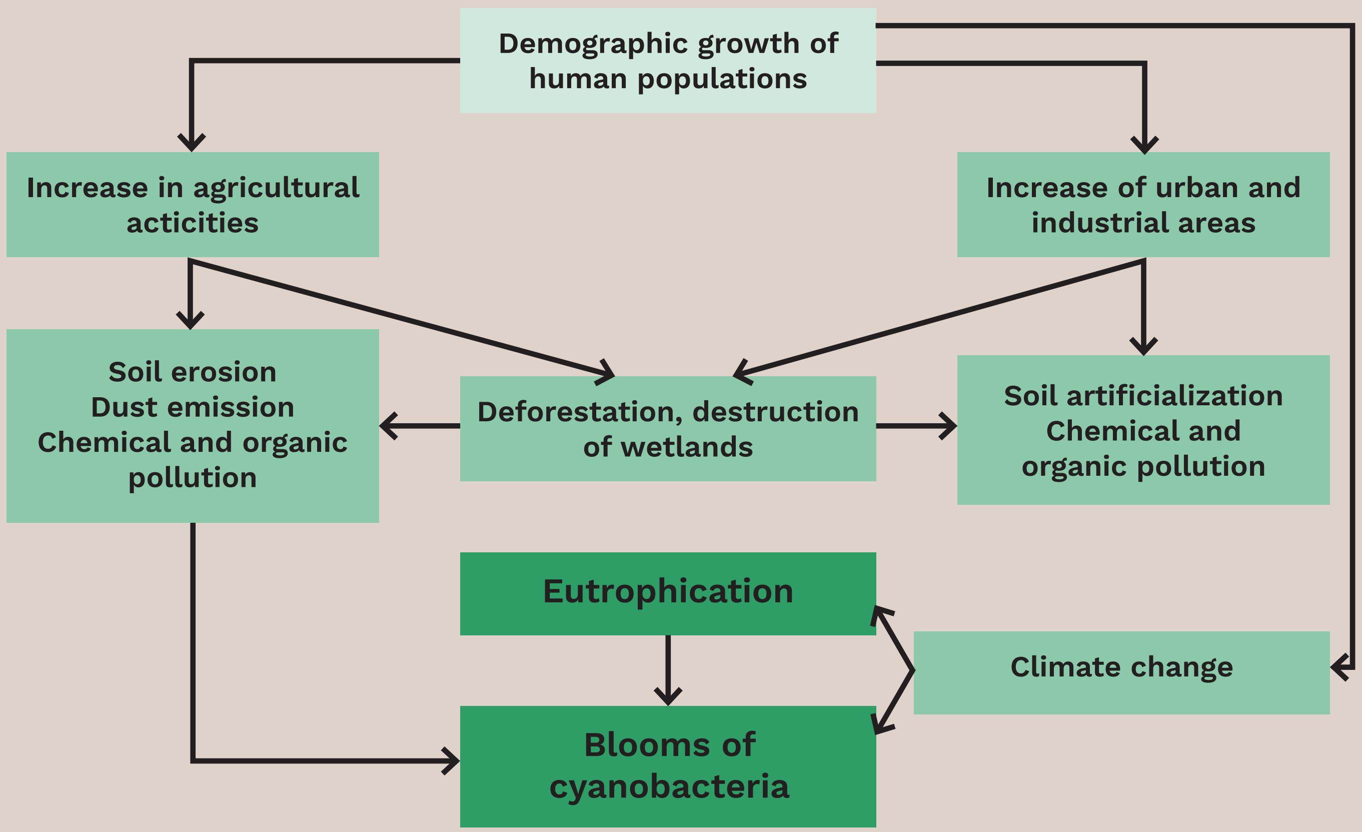
This biomass accumulation leads to a decrease in water transparency and thus in light availability for photosynthetic micro- and macroorganisms. This process promotes cyanobacteria and floating plants (for instance, water hyacinth) in eutrophic freshwater ecosystems because they are able to occupy the surface of water bodies. Indeed, many cyanobacterial species contain gas vesicles into their cells, giving them very good floatability and consequently facilitating their access to light.

The anthropogenic eutrophication of numerous freshwater ecosystems has been widely studied in recent years. From all these works, it appears that human population growth is involved in the eutrophication of freshwater ecosystems in multiple ways, which are summarized in **Fig 2**. Indeed, human population growth results in increasing agricultural activities, which have many consequences in terms of soil occupation and soil erosion. Moreover, these activities are associated with chemical pollution (e.g., by the use of N/P fertilizers) and organic pollution (e.g., by liquid manure), which play a major role in the eutrophication process.

Human population growth is also associated with an increase in urban and industrial area surfaces and results in the production of liquid and solid wastes. In countries where the collection and treatment of wastewaters is limited, their concentrated production in urban areas will also contribute significantly to the eutrophication of aquatic ecosystems.

Finally, it is now well established that human activities play a major role in climatic changes leading to an increase in air and water temperature and in the frequency of extreme meteorological events. Concurrently, it has been shown that (I) the increase in extreme rainfall events enhances soil leaching and consequently the nutrient inputs in freshwater ecosystems and (II) the increase in water temperatures results in increasing growth rates of cyanobacteria.

Fig 2. Main links between human population growth and cyanobacterial blooms in freshwater ecosystems



III. Main consequences of cyanobacterial blooms

Cyanobacterial blooms have multiple impacts on the functioning of freshwater ecosystems and on the goods and services they provide.

Regarding the biological functioning of aquatic ecosystems, cyanobacterial blooms result in a decrease in the biodiversity of phytoplankton communities because during bloom events, cyanobacterial communities generally represent more than 95% of the total phytoplankton biomass. Knowing that zooplanktonic organisms generally poorly consume cyanobacteria, the dominance of cyanobacteria in phytoplankton communities modifies the functioning of trophic networks in aquatic ecosystems. If fish production is globally enhanced in eutrophicated ecosystems, severe blooms of cyanobacteria can also lead to the massive death of fishes due to the anoxia of water generated by the oxygen consumption of bacteria degrading the organic matter produced by cyanobacteria.

In addition, cyanobacterial blooms are also associated with an increase in pH and water turbidity and very strong variations in oxygen concentrations at a daily scale, which are stress factors for the biotic communities of lakes, potentially leading to deep changes in trophic networks.

> During cyanobacterial blooms, there is a dramatic reduction of the biodiversity into the phytoplankton communities, with cyanobacteria frequently representing >99.5% of the total phytoplankton biomass. Moreover, this dominance of cyanobacteria during the blooms is associated with profound modifications in the networks of positive and negative interactions occurring between phytoplankton species. If there is a progressive recovery of the diversity in phytoplankton communities after the blooms, their recurrent occurrence in freshwater ecosystems may affect the whole trophic networks, from bacteria to fishes.

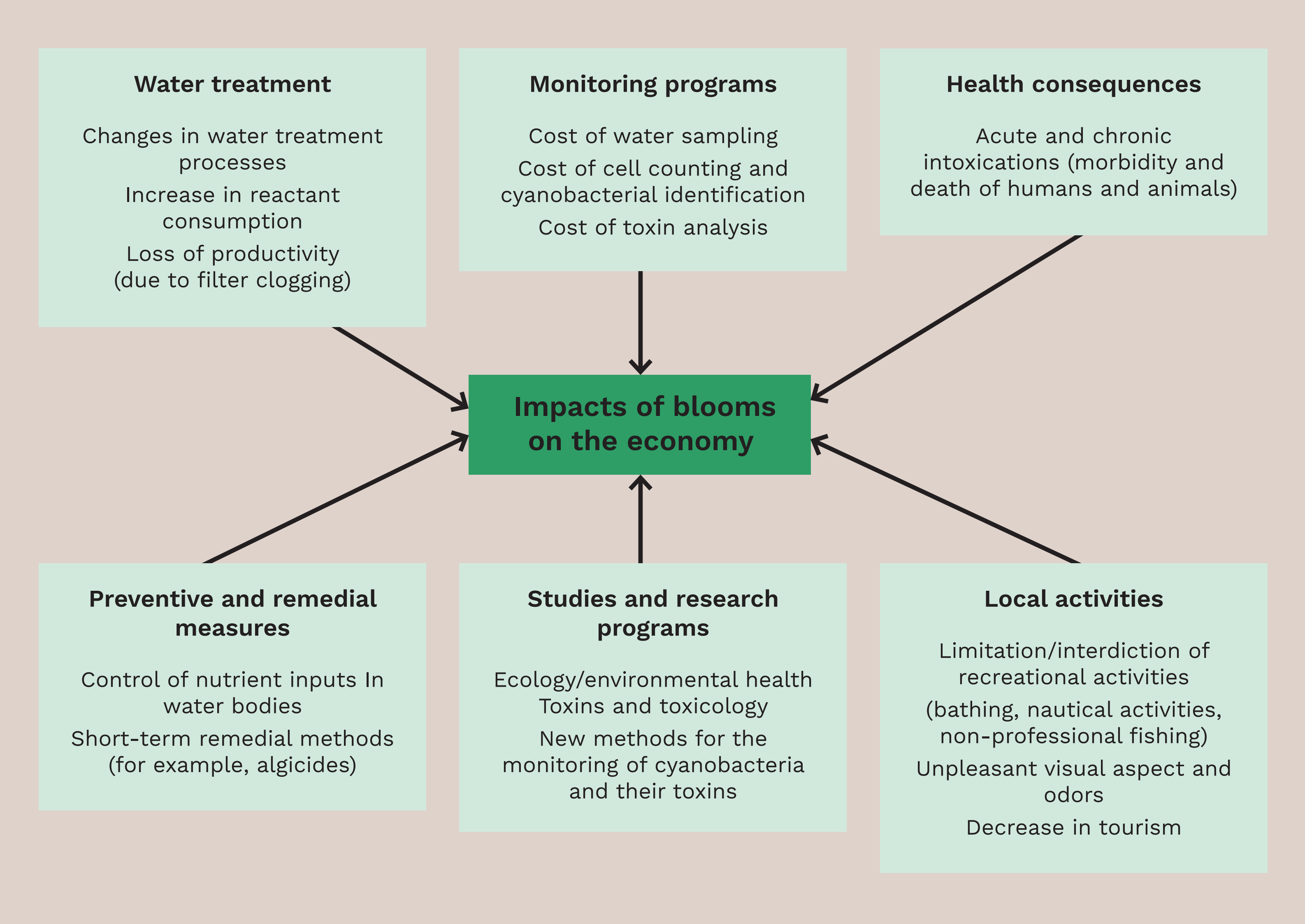
Blooms of cyanobacteria are also well known to disturb numerous water uses and to have an impact on the economy (**Figure 3**). These disturbances are due (I) to the very high quantities of organic matter produced during blooms and (II) to the potential toxicity of these blooms.

The occurrence of cyanobacterial blooms in water bodies used for water supply has consequences for the technological choices for the water treatment processes and their efficiency. It has been shown, for example, that during blooms, there is an increase in the cost of water treatment due in large part to an increase in the quantity of products used at the coagulation-flocculation stage. Considering that in Africa, the price of water usually has a significant impact on its use by populations, the health consequences can be significant for human populations that could be led to use other, less secure water resources.

The potential toxicity of blooms results in a restricted use of water bodies for recreational activities but also for some other uses, such as animal and/or culture watering, to limit human exposure to cyanotoxins.

Finally, several studies in developed countries have shown that cyanobacterial blooms have a cost in freshwater ecosystems, which are far from negligible (estimated at several hundred millions of dollars in the USA) and that derive from the implementation of monitoring programs, water treatment processes, and tourism activities, among others.

Fig 4. Multiple impacts of cyanobacterial blooms of the economy



IV. Conclusions

While all world institutions working towards human well-being have expressed, for a few decades, great concerns about water availability for the future, water quality has been less considered until now. However, there are fears that this water quality issue is likely to be as important as that of water availability in the forthcoming years. In particular, due to human growth and associated activities, cyanobacterial blooms are likely to worsen in developing countries.

Finally, knowing that cyanobacterial blooms can be considered dyes of anthropogenic eutrophication in freshwater ecosystems, the fight against cyanobacterial blooms appears to be the same as that against eutrophication.

Redactors of this Policy Brief:

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In French
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-Cylindrospermopsin: https://apps.who.int/iris/handle/10665/338063
-Anatoxin: https://apps.who.int/iris/handle/10665/338060
-Saxitoxins: https://apps.who.int/iris/handle/10665/338069

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