Solutions for managing cyanobacterial blooms

A scientific summary for policy makers

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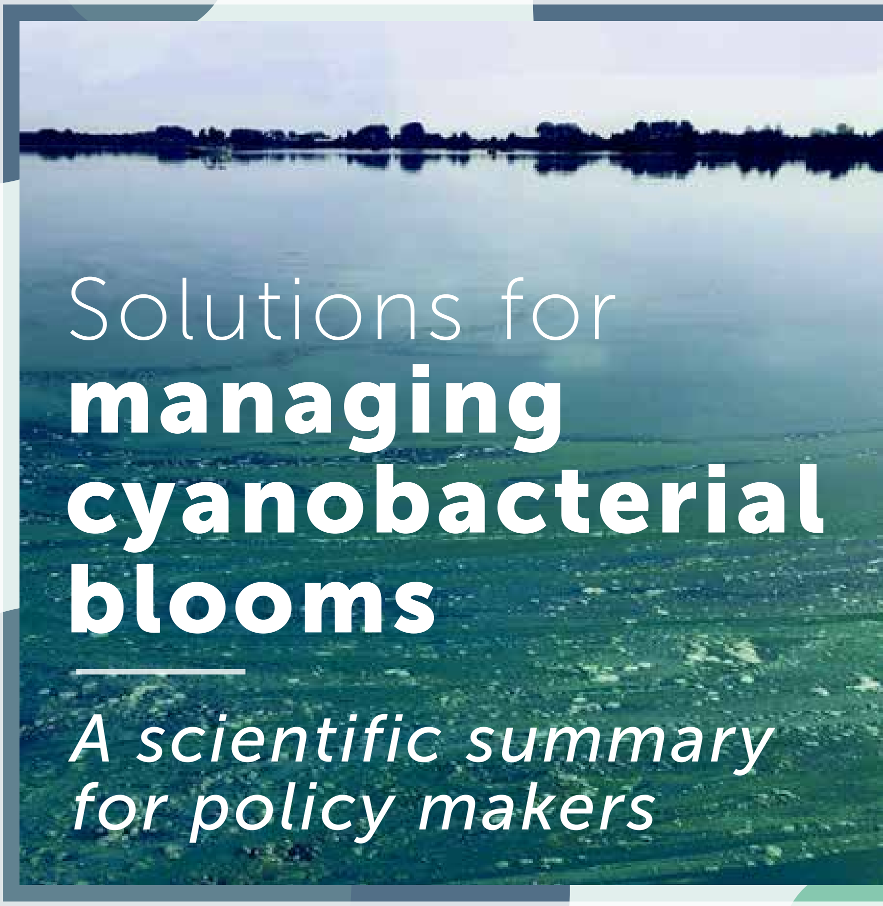

Solutions for **managing cyanobacterial blooms**

A scientific summary for policy makers

International Council for Science
SCOR
Scientific Committee on Oceanic Research

UNESCO
United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

GlobalHAB
IOC-SCOR

This report was prepared by the SCOR-IOC Scientific Steering Committee of the Global Ecology and Oceanography of Harmful Algal Blooms research programme GlobalHAB, with contributions from colleagues.

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Contents

Cyanobacteria (= blue-green algae) responsible for harmful algal blooms

Algae grow wherever there is water; in oceans, freshwater lakes, rivers, streams and pools. They underpin aquatic food webs, providing nutrition for animals in the system, and along with microbes, are responsible for cycling energy and nutrients throughout the environment. Problems arise when algae bloom, which is often the result of excess nutrients. These nutrients may come from a range of sources, including rainfall and associated runoff from fertilizer application and land erosion, as well as discharge from sewage and other high-nutrient sources.

One of the key groups of algae that can bloom in freshwaters, marine and brackish waters is cyanobacteria (also known as blue-green algae). Cyanobacteria are technically not algae, as they are a more ancient lifeform, but they share characteristics in common with algae, including needing sunlight for photosynthesis. They are particularly prolific in calm waterbodies, such as lakes, ponds, weirs and reservoirs, or slow flowing rivers. Cyanobacteria can proliferate in these environments because longer water residence times allow many of them to grow and form blooms. They can also float on the water surface more readily than other algal groups.

One of the major problems with cyanobacterial blooms, or cyanoHABs, is that some species can be toxic. Their toxins (cyanotoxins) can have diverse health effects on people and animals, ranging from mild to serious, and impacts on whole ecosystems. Water intended for human and animal consumption generally needs to be treated to remove toxins before drinking, significantly adding to the cost of supply. In many countries, testing methods for cyanotoxins are not available and people may inadvertently be exposed to these health hazards.

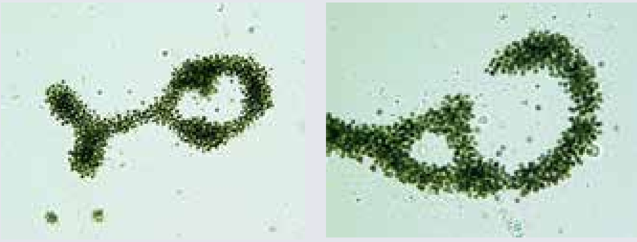
Even when blooms are not toxic, their use of oxygen at night (= respiration), and bloom decay can result in low-oxygen conditions which kill fish and other animals. They can cause earthy/musty or bad odours via excretory products and decomposing blooms, e.g. rotten egg smells, and can wash up on shores and affect recreational use. They can also cause severe skin irritation for swimmers.

There is a wide range of within pond/lake system management and mitigation products, methods and tools available for controlling cyanoHABs blooms. However, it is often difficult to determine which products and approaches may be most effective for a particular waterbody. This provides an overview of the products and and physical, chemical and biological solutions available for control of cyanoHABs, and some detail on their benefits and relative costs. It also points to other publications with more detailed information.

Dominant species

Commonly occurring cyanoHABs

We have highlighted some of the most dominant cyanoHAB genera causing blooms globally which are associated with toxins. The dominant toxic genera of concern that occur around the world are:



Microcystis

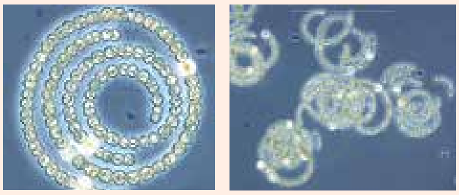
Photo: Glenn McGregor

Microcystis is one of the most common bloom-forming genera, occurring on every continent, except Antarctica. It often grows in colonies of spherical cells linked by polysaccharides, is highly buoyant, and may often form distinct surface scums. It can produce the potent toxins, microcystins and anatoxin-A toxins, although not all blooms are toxic. Globally, microcystins are perhaps the most prevalent cyanotoxins in water bodies and are the only cyanotoxins for which the World Health Organisation has set drinking and recreational water guideline values for health protection.

Raphidiopsis (=Cylindrospermopsis)

Photo: Glenn McGregor

Raphidiopsis is a commonly occurring genus originally believed to prefer warmer temperatures, but is increasingly being identified in temperate regions of the world. It forms filaments and is capable of using atmospheric nitrogen (= nitrogen fixation) for nutrition when dissolved nitrogen (nitrate, ammonium) levels are low. It produces cylindrospermopsin toxins in some countries, e.g. Australia, while in South America it produces saxitoxins. In many other countries, e.g. USA the genus is typically not toxic.



Dolichospermum (previously Anabaena)

Photo: Michele Burford

Dolichospermum is a filamentous genus of cyanoHABs capable of nitrogen fixation. It occurs around the world. It can produce a range of toxins, including microcystins, anatoxins, saxitoxins, and cylindrospermopsins.

Planktothrix

Photo: Nordicmicroalgae.org

The filamentous genus *Planktothrix* can dominate in temperate areas globally, and is reported less frequently in the tropics and subtropics. It produces microcystin toxins.

Aphanizomenon

Photo: Alchetron.com

This filamentous genus shares many attributes with the other most common bloom-forming cyanobacteria. It is capable of producing microcystins, anatoxins, saxitoxins and cylindrospermopsins, and is found across the globe.

CyanoHABs across the globe

Blooms of cyanoHABs occur throughout the world, predominantly in freshwater lakes, ponds and reservoirs, but also in brackish water and marine systems. Several high-profile cyanobacterial blooms have had major impacts environmentally, socially and economically. These include Lake Taihu in China, Lake Erie in North America and the Baltic Sea.

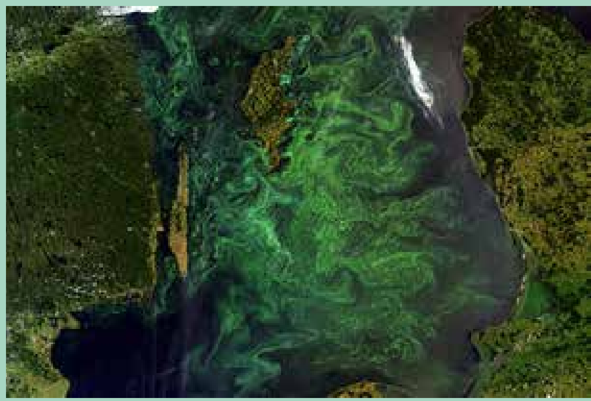
A large bloom of the toxic *Microcystis* in Lake Taihu in Jiangsu Province, China in 2007 affected the water supplies of 2 million people around the lake, and had major economic costs. The bloom prompted management responses, including reducing catchment nutrient loads, planting aquatic plants, booms to skim the surface and stop the bloom from entering drinking water treatment intakes, and the harvesting of biomass (see photo), which was used for other applications, e.g. as a fertilizer.

Photo: Michele Burford

Harvesting *Microcystis* using dissolved air flotation water treatment technology.

Source: blog.nationalgeographic.org

The Great Lakes in North America are an important water resource containing approximately 18% of the world's available freshwater. In 2011, there was a record-setting bloom of toxic *Microcystis* in Lake Erie which extended 5,000 km^2, infiltration of microcystins into the water supply of the City of Toledo, Ohio. It left more than a half million people without drinking water for a short time in 2014.



Source: earth.esa.int

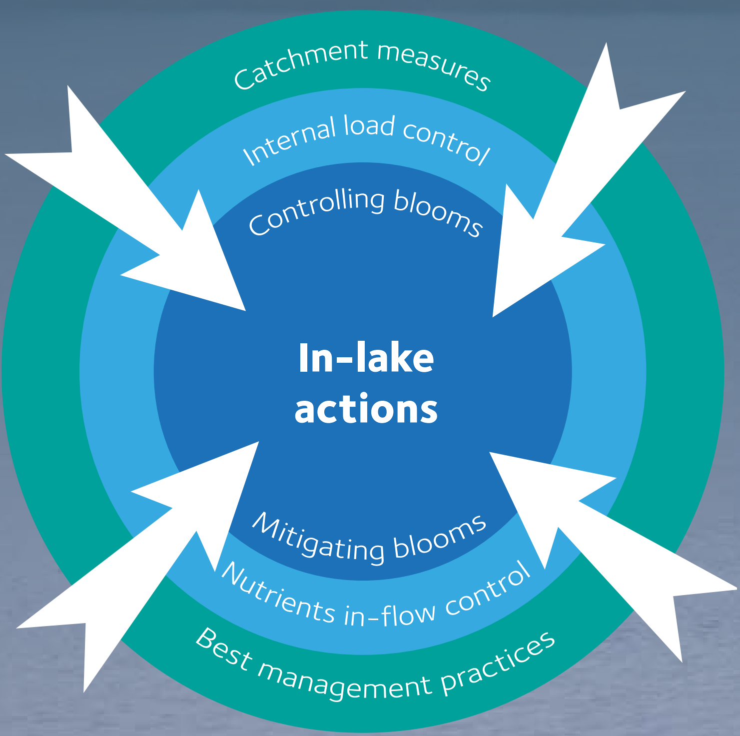
Each summer, the Baltic Sea has major blooms of toxic cyanobacteria, *Nodularia* and *Aphanizomenon*, ranging in area up to 200,000 km^2. Bloom intensity and duration have increased over the years due to human-induced eutrophication and climate change, and these blooms are having major environmental, social and economic impacts.

Challenges for water management

Managing cyanoHAB toxins has three key elements – monitoring, mitigation and prediction. Mitigation is likely to be most effective in the long term if nutrients are managed in catchments to reduce nutrient runoff into waterways. However, it is a long-term strategy requiring long-term investment.

Methods that are commonly used to reduce nutrient loads include: upgrading sewage treatment plants; more effective management of stormwater; controlling erosion on hillslopes, gullies and river channels; reducing excess fertilizer in agriculture; utilizing retention ponds and wetlands to intercept and assimilate nutrient loads.

Nutrient reduction has repeatedly been proven to be the most effective approach for the sustained control of CyanoHABs but it may take decades to be effective. In addition to these proactive measures, the serious and immediate human and animal health threats posed by cyanobacterial blooms make it desirable to have reactive options for quickly responding to cyanoHABs with in-lake mitigation strategies. Given the wide array of methods and products available it is often difficult to determine which methods are most likely to be effective. This document seeks to provide information on the pros and cons and appropriateness of available approaches for types of water bodies and blooms.



Within system methods for mitigating blooms

Physical approaches

Screens/barriers

Oil screens, booms or curtains may be used to concentrate cyanoHABs that float on the surface, and subsequently remove them, or deflect them away from water intake points.

The effectiveness of these barriers for removing cyanoHABs is difficult to quantify but they have been used to provide some level of protection for water supply intakes, e.g. in Lake Taihu, China during several *Microcystis* sp. blooms.

Photo: Rijkswaterstaat

Photo: Miquel Lurling

Ultrasonics

High power ultrasound will destroy any organism in its power beam. It comes with relatively high energy costs. High frequency ultrasound can rupture the buoyancy regulating capacity of cyanobacteria, but has very limited penetration through the water column.

There is no evidence that low power, low frequency ultrasound works.

Surface Mixers/Fountains

The aim of surface mixers or fountains is to mix surface waters so that buoyant cyanobacteria cannot accumulate at the surface and form blooms.

The effectiveness of these systems varies depending on the severity of the bloom and the rate of mixing. These systems generally require high energy inputs to ensure that blooms do not form. In some areas such mixing will cause accumulation in areas immediately outside the mixing zones. They may also create aerosols containing toxins.

Fountain and warning for cyanobloom "avoid contact with water" August 7th 2018, Eindhoven, NL (Photos: M. Lurling)

Oxygenation

Aeration/oxygenation is used to increase oxygen levels in deep waters. There is a range of options such as air-lift pumps which lift low-oxygen bottom waters to the surface, or injection systems with linear or circular diffusers. Oxygenation can also be achieved by injecting oxygen into bottom waters directly.

The aim is, amongst other things, to increase oxygen levels in bottom waters to reduce the release of bottom-sediment nutrients, particularly phosphate, which can stimulate algal blooms. This system is only appropriate in deeper, stratified water bodies where there is a colder layer of water that is separated from the surface waters. The method can be quite expensive in terms of infrastructure and running costs, and studies show mixed results.

Dredging or excavation

In many water bodies, particularly those that are shallow and/or have large accumulations of muddy sediments, the largest source of nutrients to the water body can be from the sediments. Hence, dredging can remove sediments containing nutrients which stimulate cyanoHABs, as well as seed stocks of cyanoHABs that may ultimately cause blooms in the water. Excavation can also be effective if a water body is drained first. These methods are relatively expensive and time consuming, may temporarily impair water quality by disturbing bottom sediments, and are generally not suitable for large systems. There is also the challenge of sediment disposal and treatment.

Withdrawal of bottom waters

This method involves release or gravity feed of bottom waters from a lake or reservoir to remove low-oxygen, nutrient-rich waters. These waters are released downstream. The principle of the method is that it limits the nutrients available for cyanoHAB growth. As with the other physical methods, it works principally in systems where the bottom waters are cooler than the surface waters, and oxygen concentrations are low in the bottom waters. It is a relatively inexpensive approach but requires elevation for gravity feed to remove bottom waters. One disadvantage of the method is that the low-oxygen waters and high nutrients released downstream can have negative effects on fish and other aquatic life.

Artificial deep mixing

There are a range of artificial circulation approaches such as surface mixers that may be designed to deepen the surface mixed layer and prevent surface accumulations, or mixing to transfer surface blooms into bottom waters where conditions are unsuitable for growth, or alternatively mix the whole water column. The success of this method is highly dependent on the type of cyanobacteria present. It works well for species that form surface scums, e.g. *Microcystis*. In the case of this species, surface scums are broken up by the increased circulation. Artificial circulation can be effective for smaller waterbodies, or where only a portion of large lakes needs to be mixed. Set-up costs are lower than for some other approaches but there are significant energy costs.

Chemical approaches

Hydrogen peroxide

A popular chemical for controlling cyanoHABs is hydrogen peroxide. When administered at the correct dose and distributed homogeneously, this chemical can preferentially kill or inhibit cyanoHABs without affecting other algae, aquatic animals and plants. The advantage of this chemical is that it quickly converts to water and hydrogen so has no lingering effects. The amount of chemical needed for each cyanobacterial species and in each waterway varies, so it requires trials to optimise dosages.

In cases where more resistant cyanoHABs such as *Microcystis* are prevalent, hydrogen peroxide may not be capable of fully removing cyanoHABs without harming zooplankton.

In lakes with a high abundance of eukaryotic algae, the breakdown of hydrogen peroxide may be so fast, that it will not remain long enough in the water to effectively kill cyanobacteria. Furthermore, the use of hydrogen peroxide in water bodies larger than a few hundred hectares is likely impractical and not cost effective. Hydrogen peroxide may, however, be helpful within drinking water plants for combating cyanoHABs and/or their toxins.

Copper sulfate

Historically, copper sulfate was a popular method for controlling cyanobacteria in reservoirs and lakes. However, as knowledge of the toxicity effects of copper on foodwebs increases, and concern grows about its persistence in sediment, many authorities globally are banning or discouraging its use.

Photo: Andy Bruere

Geochemical compounds

Alum is aluminium sulphate which forms flocks in the water column. This traps cyanobacteria and adsorbs phosphate from the water and also in sediments, removing one of the key nutrients that allows algae to grow to bloom proportions. The commercial product Phoslock™ is a type of phosphate-binding clay that forms a stable mineral with phosphate, making it no longer available for cyanobacteria. These products tend to be most useful in systems where the phosphorus loads are internal (i.e. from bottom sediments) rather than external (e.g. from runoff) and can be reapplied once the product's binding capacity has been exhausted.

Photo: Andy Bruere

Sediment capping

Sediment capping can provide either an active or passive physical barrier between the existing bottom sediments and the overlying water column. Phoslock™, for instance, acts a as an active barrier of which a layer of only a few millimetres is sufficient. In contrast, sand capping is passive so will probably need a much thicker layer. A capping layer is designed to reduce nutrient releases from the sediment to the water column. Like dredging, capping is time consuming and expensive.

Biological approaches

Biological treatments

A range of bacterial, fungal and yeast products is under consideration as potential agents to control cyanoHABs, although their effectiveness requires verification. Some reviews suggest that there is little evidence of the effectiveness of these products. In accordance with a central tenant of microbial ecology, everything is everywhere and the environment selects, meaning that the microbes introduced via such products are likely already present within water bodies and the likelihood of those microbes proliferating and/or discouraging the growth of cyanoHABs will be a function of environmental conditions, not the introduction of the said microbes.

Plant extracts

Rice straw used for controlling cyanoHABs. Photo: Michele Burford

The most commonly studied plant products that can potentially control cyanoHABs are barley and rice straw, with loosened, rotted straw being more effective than compact, fresh straw. There is some evidence that the polyphenol extracts released from straw, under the effect of sunlight, can produce hydrogen peroxide which can differentially suppress cyanoHABs, compared with eukaryotic algae. There is also some evidence to suggest that the straw supports the growth of fungi that secrete anti-microbial compounds that are active against cyanoHABs. Whilst there have been cases of suppression of all algal species, not just cyanoHABs, with barely straw, success has been mixed. However, the method is relatively inexpensive and straightforward. It is most practical for use in small waterbodies.

A range of other plant products have been tested, but studies are limited and much more work needs to be done before these may be applicable and cost effective at larger scales.

Biomanipulation of food web

Fish introduction or removal can be used as a short-term method used to reduce nutrient concentrations, but do not replace the need for catchment or watershed nutrient reduction strategies. Removal of bottom-feeding, herbivorous fish can reduce resuspension of particles from the bottom and the associated nutrients. However, this may only be useful for shallow lakes and ponds where sediment derived nutrients are the largest source of nutrients to the system and where fish populations are very dense. Once these fish are removed, submerged aquatic plants can be established which can help reduce nutrient concentrations. Additionally, removal of fish species that feed on zooplankton can, in turn, increase zooplankton density and hence their grazing of primary producers, including cyanoHABs. However, this is not always effective because some zooplankton species will actively avoid eating cyanoHABs as they can be difficult to handle or digest, or in some cases they avoid cyanotoxins that may be produced.

Alternatively, some fish may consume the cyanoHAB predators. Overall, although fish removal may be a useful short term strategy, it is often not possible to achieve a stable, effective system in the longer term. Other factors of importance are insufficient fish removal or recovery of fish species that graze on zooplankton.

Another method of potential cyanoHAB control involves the addition of filter-feeding fish which graze directly on algae and cyanobacteria. This method is suggested for highly productive lakes, e.g. subtropics and tropics, where zooplankton grazing is ineffective, in reducing bloom populations. Its success has been varied, however, possibly because the extra fish also produce a substantial nutrient load. Introduction of filter-feeding mussels is another strategy to increase the grazing pressure on cyanobacteria.

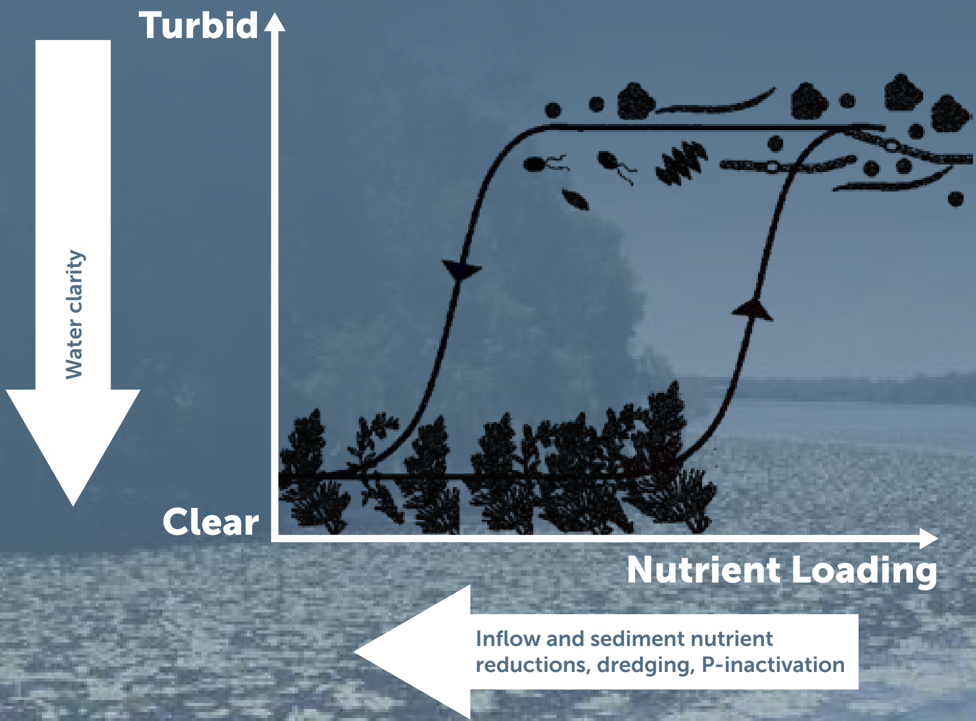
Aquatic plants

Aquatic plants compete with cyanoHABs for nutrients and may shade the water body, and thus can play a useful role in controlling cyanoHABs. However, unless waterbodies are shallow, their effectiveness may be limited, as they typically grow only as deep as the light penetrates. Alternatively, some rooted plants with surface dwelling propagules are not dependent upon in-lake light penetration although their growth is still restricted to shallower water bodies. Additionally, growth of some exotic species can be counterproductive, choking waterbodies and creating low-oxygen conditions which can cause nutrient release from sediments, and kills fish and other aquatic life. Promoting aquatic plant growth, via translocation or introduction of shoots and propagules, is most likely to be effective when coupled with other cyanoHAB control methods.

Floating islands and wetlands

In some cases, plants can be placed on floating islands of various sizes. The plants on the island continually removes nutrients while the island concurrently shades the water column. Wire cages may be used to contain these floating masses. The plant biomass on the island can be left to continually grow or may be harvested over time. There can be considerable time spent maintaining these structures.

Wetlands can provide a means to remove nutrients before they are accessible to cyanoHABs. However, this requires availability of additional land and ongoing maintenance to optimize nutrient removal.



Concept of hysteresis where a clear shallow lake with weeds (macrophytes) is initially resilient to additional nutrient loading, but can rapidly transition into an algal-dominated system that requires additional measures to reduce nutrients and restore the clear-water state.

Summary of within lake management options

Type	Action	Target(s)	Cost	Scientific evidence	Difficulty
Physical	Ultrasonics	CyanoHABs	High (for high power ultrasound) Medium (for low power ultrasound)	For high power units, cyanobacterial cells are disrupted but there is limited penetration through water. For low power units, there is no scientific evidence of benefit.	High power units cannot give sufficient penetration in field settings.
	Booms & curtains	Buoyant cyanoHABs	Low	High power units kill everything.	Only effective when blooms are dense and very buoyant. As surface scums are easily broken up by wind, timing can be difficult.
	Surface mixers	Buoyant cyanoHABs, mixing generally	Moderate to high	Can be effective but understanding of the physical, chemical and biological conditions of the lake is needed.	Methodology relatively straightforward but could require designation of the mixing zone as a hazardous area. Ongoing investment in energy for mixer or fountain. Operation may produce noise and odours from hydrogen sulfide.
	Fountains	Buoyant cyanoHABs, mixing generally	Medium to high	Limited evidence of any benefit.	Fountains waste a great deal of energy relative to their intended effects of mixing surface waters. Maintenance of fountains can be an issue. Operation may produce noise and odours from hydrogen sulfide.
	Oxygenation (including nanobubbles)	Dissolved oxygen (bottom waters) and nutrients	High	Can be effective but understanding of the physical, chemical and biological conditions of the lake is needed.	May require on-site oxygen production or storage tank. Has a potential advantage over destratification in that it should not be associated with odour production because bottom waters are oxygenated.
	Dredging	Sediment nutrient stores	High	Can be effective but understanding of the physical, chemical and biological conditions of the lake is needed.	Very expensive. Disposing of spoil is often a major issue. Resuspended sediment during operation is a common problem which can lead to ongoing algal problems.
	Destratification	Dissolved oxygen (bottom waters), nutrients and cyanoHABs	High	Considerable scientific evidence supporting benefits for some species, e.g. *Microcystis*. Likely not effective for *Raphidiopsis (= Cylindrospermopsis)*	Requires careful design to optimise air flows, bubble sizes and energy efficiency in mixing the water column. Ongoing investment in power supply and maintaining aerators required. Detailed engineering design essential. Operation may produce noise but likely to be reduced compared with fountains or mixing.
	Withdrawal of bottom waters	Dissolved oxygen, nutrients (bottom waters)	Low to medium	Can be an effective management tool.	Relies on having the capacity to withdraw bottom waters. Low oxygen and nutrients may have negative impacts downstream.
	Light exclusion technology	CyanoHABs	Medium to high	Limited evidence of benefit.	Not suitable for large waterbodies. Floating plants may require maintenance. Shadecovers and other floating devices can have unexpected consequences on enhancing sediment nutrient production.
	Flow manipulation	CyanoHABs	Low	Considerable evidence of benefit in river systems	Relies on having the capacity to manipulate flow.
Chemical	Hydrogen peroxide	CyanoHABs	Moderate	Considerable scientific evidence for effectiveness targeting cyanobacteria but dose must be optimized.	Likely to involve boat injection of hydrogen peroxide. Controllable safety hazard from use of hydrogen peroxide.
	Geochemical compounds (e.g., alum, Phoslock™, Aqual-P, etc.)	Phosphorus (water column and sediments)	Moderate to high	Considerable literature showing benefits if dosage and background conditions are appropriate.	Methods and targets (i.e., water column and/or sediment phosphorus pool). Can be highly effective under appropriate conditions and doses. Small risk of legacy effects (e.g., chemical could remain in bottom sediments).
	Sediment capping	Internal (sediment) nutrients	High	Evidence of benefit, depending on the system characteristics and application rates.	Involves capping bottom sediments to prevent them from releasing nutrients back into the water column. Requires consideration of sediment deposition rates to examine longevity of treatment.
	Plant extracts	CyanoHABs	Low	Demonstrated effectiveness in small systems were sufficient plant material, e.g. barley straw, can be added.	Some evidence that decaying barley straw can promote toxic cyanoHABs, but its effectiveness in controlling blooms is not guaranteed.
Biological	Biological treatments, e.g. bacterial seeding	Algae	Low	Very limited.	Introduced organisms may not necessarily outcompete resident populations. Continual reseeding may be needed.
	Biomanipulation of food web	Bioavailable nutrients	High	Evidence of the benefits is mixed. Seems to be system specific.	Food web controls are notoriously difficult such as manipulating zooplankton or fish.
	Aquatic plants	Nutrients (nitrogen and phosphorus)	High	Floating and submerged plants are used. Evidence of benefit in shallow systems.	Costly, use by birds (for floating platforms) could increase faecal contamination and nutrients. Large number of plants needed to have impact.

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