Planktonic:

In-water Intervention and Prevention Strategy
Emerging Supporting Field Data

Benthic:

In-water Intervention and Prevention Strategy
No Available Supporting Field Data

Viruses, fungi, protozoa, and indigenous bacteria have been suggested as agents that can remove cyanobacterial cells and cyanotoxins from the water column via a broad range of mechanisms (Sigee et al. 1999, Yoshida et al. 2008). Some bacteria may settle cyanobacteria out of the water column by aggregation or bioflocculation. Other bacteria and viruses may lyse (break open) cyanobacteria cells; still other bacteria may degrade microcystins and perhaps other cyanotoxins. A relatively new hybrid application involves using microporous bubbling aeration techniques to destratify the lake and reoxygenate deep bottom waters, followed by seeding the bottom sediments with bacteria or enzyme mixtures to oxidize settled cyanobacteria and reduce the availability of recycled nutrients that would support cyanobacteria regrowth. The hybrid treatment appears to be most effective when destratification and bottom organic matter oxidation are followed by the addition of micronutrients that favor the growth of non-cyanobacteria. There is concern, however, that the introduction of non-native or engineered bacteria may have unforeseen and irreversible consequences, such as altering bacterial communities and processes that drive ecosystem dynamics.

Multiple bacteria and several viruses, fungi, and protozoa have been isolated that, in the laboratory, lyse bloom-forming cyanobacteria (Jiang et al. 2019) and degrade cyanotoxins (Li, Li, and Li 2017). These potential biological control agents include members of the Bacteroides-Cytophaga-Flavobacterium complex, specifically *Bacillus* spp., *Flexibacter* spp., *Cytophaga*, and *Myxobacteria* (Gumbo, Ross, and Cloete 2008). For these bacteria to be used for biocontrol, they must have densities approximating 10^6/mL and complement high cyanobacteria abundances, ensuring close contact between the two populations. In the laboratory, Nakamura et al. (2003) inoculated a “floating carrier” of biodegradable, starch-based plastic with *Bacillus cereus* N-14. The addition yielded a 99% decline in planktonic cyanobacteria in 4 days; without the carrier, the decline was only 7.5%.

Attaining high population densities of desirable bacteria in small volumes should be relatively inexpensive, since the methods to culture bacteria are well known and can be readily applied. However, scaling to the volumes of bacteria needed for whole-lake application would be expensive. Wang et al. (2020) described the use of bacteria as a control because of their “potential effectiveness, species specificity, and eco-friendly characteristics.” While using bacteria to control blooms may eventually be a cost-effective, safe treatment, timing for posting the treatment for general use in a lake for recreation or drinking water is unknown. Since exocellular polysaccharides are also produced by bacteria, a noncontact period for recreational waters might be considered to avoid potential allergic reactions to these by-products. In addition, cyanotoxin analyses should occur, as cyanotoxins can be released when cyanobacteria cells die, are lysed, or settle out of the water column and break down in the sediments. This might be mitigated through the addition of a second microcystin-degrading bacterium assemblage, or other treatment agents (for example, oxidation agents such as peroxide or ozone).

PLANKTONIC AND BENTHIC
EFFECTIVENESS • Water body types: Pond, lake/reservoir • Surface area: Small • Depth: Any depth • Trophic status: Eutrophic • Any mixing regime • Alkaline systems • Water body uses: Recreation, drinking water • Confined to bloom area or isolated coves
NATURE OF HCB • Toxic and nontoxic HCBs • Intervention strategy

ADVANTAGES • Unlikely carryover after bloom dissipation, as the added bacteria or other microbial agent can then shift to a different energy source • Low potential for adverse impacts if indigenous isolates are used
LIMITATIONS • Very limited field use to date • Needs a laboratory to culture the large volumes of effective isolates, a boat for delivery, and floating inoculated substrates • Limited toxicity information for cultured isolates • Cyanotoxin control may be limited; only microcystin degradation has been studied • Surface water criteria concerns for cyanotoxin release as cells lyse • Permitting requirements unknown • Potential long-term, irreversible ecosystem impacts if non-indigenous isolates are used

The use of bacteria, viruses, fungi, or protozoa for cyanobacteria removal requires a benthic or planktonic cyanobacteria bloom, a high density of the effective biological agent, and interventions to ensure high bioagent–cyanobacteria contact (for example, bioflocculation or flotation carriers). A section of a lake can be isolated (for example, a cove on the windward side of the lake or vertical weir curtains dropped in a lake).

COST ANALYSIS

Relative Cost Per Growing Season: Microbial Biomanipulation

ITEM	RELATIVE COST PER GROWING SEASON
Material	$$$
Personal Protective Equipment	$$
Equipment	$$$
Machinery	$$
Labor	$$$
O & M Costs	$$
OVERALL	**$$$**

No cost projections are readily available, but initial costs would be high for culturing equipment (large-volume vats, autoclaves, incubators, glassware, media, and expendables). There would be costs for preparing starch-based carriers and methods and space for inoculating these substrates. The use or reuse of vertical weir curtains to separate water bodies further increases costs. Staffing and time demands would be substantial.

REGULATORY AND POLICY CONSIDERATIONS

Permitting requirements are unknown, but adding live isolates (bacteria, viruses, fungi, or protozoa) to natural waters requires evaluation.

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