Planktonic:

In-water Intervention and Prevention Strategy
Substantial Supporting Field Data

Benthic:

In-water Intervention Strategy
Limited Supporting Field Data

Flocculation is the use of added compounds to bind, inactivate, or sink harmful algae or cyanobacteria. After the strategy was implemented successfully in marine systems (Sengco and Anderson 2004), investigation began for use of this intervention to control freshwater cyanobacteria blooms (Pan et al. 2006, Zou et al. 2006). Research teams tested an acidified mixture of local sediments combined with surfactants like chitosan (crustacean shell derivative) and polyaluminum chloride (PAC). The latter is commonly used as a coagulant in drinking water facilities for cyanotoxin removal in Ohio. These proved effective in the flocculation and settling of HCB blooms and some of their associated cyanotoxins in a variety of water bodies, from ponds and lakes to brackish estuaries. A mixture of suspended sediment/PAC/chitosan to reach 100 mg soil/10 mg PAC/5 mg chitosan in a lake (Pan et al. 2011) followed by capping (covering) with local sands can remove the HCB and support growth of submerged grasses, which are effective nutrient and sediment traps and provide habitat for many juvenile fish (Pan, Chen, and Anderson 2011, Pan et al. 2019).

PLANKTONIC AND BENTHIC
EFFECTIVENESS • Any water body type • Any surface area or depth • Any trophic state • Water body uses: Recreation, drinking water source • If no capping is done, best if used in a system with high near-bottom flushing rates
NATURE OF HCB • All HCB types • Singular or repeating HCBs • Toxic and nontoxic HCBs; can remove cyanotoxins as well as cells • Intervention strategy
ADVANTAGES • Effective for most HCBs • Removes cells and cyanotoxins • Used in many areas • Easy spray dispersal
LIMITATIONS • May require permit for dispersal • Requires large volumes of acidic surfactants and sediments and high-volume pumps • Scalable, but costly with increasing HCB area • May impact bottom oxygen levels and benthic fauna and increase nutrient fluxes • Repeated additions may be required

This technique is effective for most ponds, lakes, reservoirs, and saline environments. The surfactant chitosan can be dissolved thoroughly in 0.1 N HCl or dilute vinegar (acetic acid). Because the flocculated material settles, capping can prevent resuspension and bloom return. If the capping material is mixed with seeds of submerged grasses, HCB areas can revegetate (Pan, Chen, and Anderson 2011). If capping is not employed in deep, stratified systems, decomposition of settled material can promote oxygen reduction and associated problems with hypoxia, anoxia, and loss of habitat and induce high nutrient fluxes from the sediments.

Figure 1. Spraying of local soils and chitosan in China.
Source: G. Pan, Nottingham Trent University, UK.

COST ANALYSIS

In one study (Pan et al. 2019), costs ranged from $148/acre to $245/acre with two different surfactants and sediments; with capping, the cost increases to $3,648–$8,197/acre. Costs for sediment, surfactants, pumps, and hosing can be high and are proportional to the treatment area. A boat may be required if the HCB cannot be treated from the shore.

Relative cost per growing season: Clay and surfactant flocculation

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

REGULATORY AND POLICY CONSIDERATIONS

Dispersing sediment may require a permit. If flocculation is not followed by capping, bottom impacts should be considered, including the smothering of bottom plants and animals, development of hypoxia/anoxia and associated loss of habitat for fish, and enhanced nutrient fluxes from bottom sediments that could exacerbate additional blooms.

CASE STUDY EXAMPLES

Xuanwu Lake, China: Peak abundances of *Microcystis aeruginosa* exceeded $2.7{\times}10^7$ cells/mL in the summer of 2005.

Through intermittent spraying of modified clays (3–5 tons/km^2/d or 30–50 tons/km^2 over 10 days), *M. aeruginosa* was reduced to 6×10^3 cells/mL and dissolved microcystin was reduced to <0.01 µg/L from 0.03–0.62 µg/L. Removal of flagellated algal blooms required rigorous sediment preparations and costly infrastructure for dispersal (Yu et al. 2017).

South Korea: Clays and electrolysis of local seawater have been used to remove toxic dinoflagellates in aquaculture areas (Park et al. 2013).

Lake Tai and Cetian Reservoir, China: Chitosan flakes were dissolved in 0.5% acetic acid (vinegar) and stirred until all the chitosan was dissolved; the solution was diluted with pond water to obtain a final concentration of 1 g/L before use. Based on lake acreage, the required volume of chitosan solution was mixed with the soil suspension (diluted using pond water) to make up a final concentration of 100 mg soil/L and 3 mg chitosan/L in the pond after spraying. For the Cetian Reservoir pond experiment, chitosan-PAC-modified local sediment (MLS) was prepared by adding dissolved PAC to chitosan-modified local soils to achieve a final concentration of 100 mg soil/L, 10 mg PAC/L, and 5 mg chitosan/L in the pond. After treatment nutrient concentrations and chemical oxygen demand (COD) dramatically declined (Pan et al. 2019).

Tanxi Bay, Lake Tai, China: In 2012, approximately 16 kg of chitosan-MLS was sprayed into a 400 m^2, 1.5-m-deep pond with a Secchi depth <5 cm. After treatment, the blooms were removed from the pond within 2 hours. Secchi depth (water clarity) increased to 1.5 m on the second day. The chlorophyll *a* concentration in the treated pond decreased from 85 µg/L to 13 µg/L and remained below this level for 20 days after the treatment. chlorophyll *a* in the control pond continually increased, reaching a concentration of 350 µg/L on day 20. Turbidity was reduced from 95 NTU to 5.3 NTU in the treatment pond, while it was maintained above 100 NTU in the control pond during the same period. COD and nutrient concentrations declined as well (Pan et al. 2019).

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