Mitigation of harmful algal blooms: The way forward

by David Kidwell

Harmful algal blooms (HABs) represent a broad suite of phytoplankton, macroalgae, and cyanobacteria that can have significant impacts on ecological resources, human health, and coastal economies. The specific impacts of HABs occur on multiple scales and will vary based on species, location, time of year, and proximity to key resources. Some blooms can disrupt entire ecological communities simply due to their accumulated biomass or reduction in light penetration. Others produce toxins that can cause a variety of human poisoning syndromes through either direct exposure to the organism's toxins or through the consumption of contaminated fish or shellfish (Glibert *et al.*, 2005). Risk of human exposure can prevent the harvest of commercial, subsistence and recreational fisheries, close popular beaches, or prevent the use of community drinking water supplies that might be contaminated.

The causes of HABs are varied and not always well understood, but linkages of some blooms to excess nutrient inputs and hydrologic alterations provide some direction for prevention. Once a bloom has formed, mitigation actions have primarily focused on early warning and detection to eliminate or reduce human and resource exposure, or to provide rehabilitation to distressed wildlife. Efforts to control HABs, defined as a reduction of the magnitude or restriction in the spread after bloom formation, are generally limited to small-scale systems (*e.g.*, ponds and small lakes). The challenge for larger systems (*e.g.*, larger lakes and coastal areas) is balance between the application of an effective control method while limiting unintended side-effects that may disrupt ecosystems and communities. This article will provide a brief overview of HAB mitigation and control approaches and outline a path forward to enable informed decisions on balancing their effectiveness with concerns over possible side-effects.

Approaches for HAB mitigation

Research and development of techniques to control or mitigate a HAB is a promising area of research that can be separated into three categories based on their mode of action (Table 1). Physical mitigation methods are typically those that use physical means to remove cells or toxins from the water column, limit the spatial extent of a bloom, or render them unable to reproduce (Fig. 1). A widespread physical technique currently in use is a suite of devices that enables mixing of the water column to alter nutrient dynamics, disrupt algal cell processes, or eliminate stratification. While success has been demonstrated in smaller water bodies and embayments, application of these devices in coastal systems is limited. A number of sediment-based methods (*e.g.,* clay flocculation, sediment resuspension and burial) have been the focus of research efforts demonstrating mixed results (Sengco and Anderson, 2004; Shao *et al*., 2012). Recent efforts have combined physical and biological controls through resuspension to enhance natural processes to inoculate the water column with HAB- targeting bacteria.

Fig. 1. *In situ* mesocosm testing of clay flocculation effects on a *Microcystis aeruginosa* bloom.

Categories of HAB Mitigation Techniques		
Physical Control	**Chemical Control**	**Biological Control**
Flocculation	Silica	Macroalgae
Sediment-based Methods	Barley Straw	Predator enhancements
Cell Harvesting and Removal	Biosurfactants	Bacteria and viruses
Water Column Mixing	Hydrogen Peroxide	Purified algicidal compounds
	Copper	

Table 1. Suite of possible approaches for the control harmful algal bloom.

Chemical controls represent a suite of artificial and naturally-derived compounds that interfere with cellular growth and/or result in cell lysis through a variety of mechanisms. Bales of barley straw have been used as a HAB mitigation technique with some success in smaller, enclosed water bodies. Barley straw has been shown to have algistatic and algicidal effects and studies are underway to isolate and extract the responsible compounds for possible application in larger systems (hUallacháin and Fenton, 2010). Commercially available copper-based and nutrient altering (*e.g.*, phosphorus binding or silica additions) products have been used in freshwater systems and some coastal waters. Additional chemical-based control techniques include the use of biosurfactants and the application of hydrogen peroxide (Ahn *et al*., 2003; Barrington *et al*., 2013). All of these techniques, however, have not been fully demonstrated in coastal environments and their effectiveness in mitigating HAB impacts remains an open question.

Laboratory-based research and development of biological HAB control methods are based primarily on enhancements to natural processes and/or organisms that have demonstrated an ability to eliminate harmful algal species. Several species of macroalgae (*e.g.*, *Ulva* spp., and *Graciliaria* spp.) have been known to impact HABs through nutrient competition or through allelopathic effects on HAB species (Nan *et al*., 2008; Lu *et al*., 2011). Many of the allelochemicals produced by macroalgae quickly degrade in the aquatic environment; thus the use of intact native macroalgae may be required to achieve sustained control. In addition to algae, some bacteria and viruses have algicidal or algistatic effects on phytoplankton, including HAB species. Substantial research has focused on isolation of the algicidal compounds from these organisms to develop a HAB control product (Tilney *et al*., 2014). Additional biologically-based approaches suggested for HAB mitigation include algal predator enhancements and other food-web based changes.

Balancing environmental and societal impacts

Of the existing suite of techniques that have been evaluated, many have a mode of action that is indiscriminant with possible broad effects, raising significant environmental and societal concerns (see NOAA 2015 for additional details). For example, a major concern for many techniques is a rapid increase in benthic biological oxygen demand and resultant hypoxic conditions following the death of a high biomass HAB. For biologically-based control options, possible unintended consequences and stringent regulations will likely limit the introduction of live or whole organisms to control a HAB. While especially relevant for the introduction of non-native species, similar concerns may likely exist for enhancements of native species and will likely require significant site- specific analyses to assess environmental and societal risks.

Likewise, there are significant concerns associated with many proposed chemical control techniques. Hydrogen peroxide, copper-based products, and other chemicals have a strong potential to result in significant environmental harm through mortality and/or other impacts to many non- target organisms. While some such chemicals have short environmental lives (*e.g.*, hydrogen peroxide), others have the potential to bioaccumulate (*e.g.*, copper). Other proposed chemical-based techniques, such as nutrient-altering products, can result in unintended water quality impairments that could violate local regulations and/or exacerbate the impacts of the HAB.

Similar worries have been raised about proposed physical control techniques. Many municipalities have strict water quality regulations on turbidity that would limit sediment inputs to coastal waters. Also, the resuspension of bottom sediments can reintroduce contaminants that had settled out of the water column. Efforts to control a HAB through sediment-based techniques also have the potential to directly impact key habitats (*e.g.*, submerged aquatic vegetation) and living resources (*e.g.*, clearance rates in bivalves).

Future HAB mitigation and control research should be driven by the need to balance the often competing priorities of control effectiveness and possible environmental side- effects (Fig. 2). Accomplishing this balance will require the development of a 'mitigation and control toolbox' that provides options for managers and local communities. To facilitate toolbox development, all techniques should have demonstrated effectiveness and evaluation of possible side- effects before widespread application and use. Taxon- or species-specific techniques that limit possible unintended consequences and specific treatment requirements, in parallel with on-going education and engagement with local communities, will be critical for addressing environmental and societal concerns. Development of best management practices and requirements for pre- and post- treatment monitoring will further help to facilitate transition from research to application. Ultimately, mitigation of HABs should attempt to minimize the risk of unintended consequences to ensure a treatment will not make the problem worse.

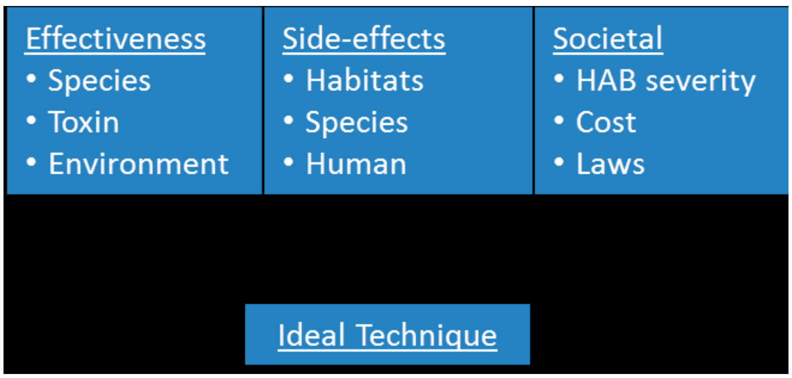

Fig. 2. Balancing multiple factors in selecting an optimal mitigation strategy and/or control technique for harmful algal blooms.

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David Kidwell (david.kidwell@noaa.gov) is a Research Oceanographer at the National Oceanographic and Atmospheric Administration where he is manager for coastal science programs focused on evaluating the causes and impacts of ecosystems stressors. His current programs are focused on coastal hypoxia and sea level rise, but he previously collaborated in the development and implementation of the Preventions, Control, and Mitigation of Harmful Algal Bloom (PCMHAB) program. He recently completed an assessment to evaluate possible environmental and regulatory concerns with implementation of PCMHAB in the United States. David was an invited speaker at a PICES-2014 workshop on "Mitigation of harmful algal blooms: Novel approaches to a decades long problem affecting the viability of natural and aquaculture fisheries."