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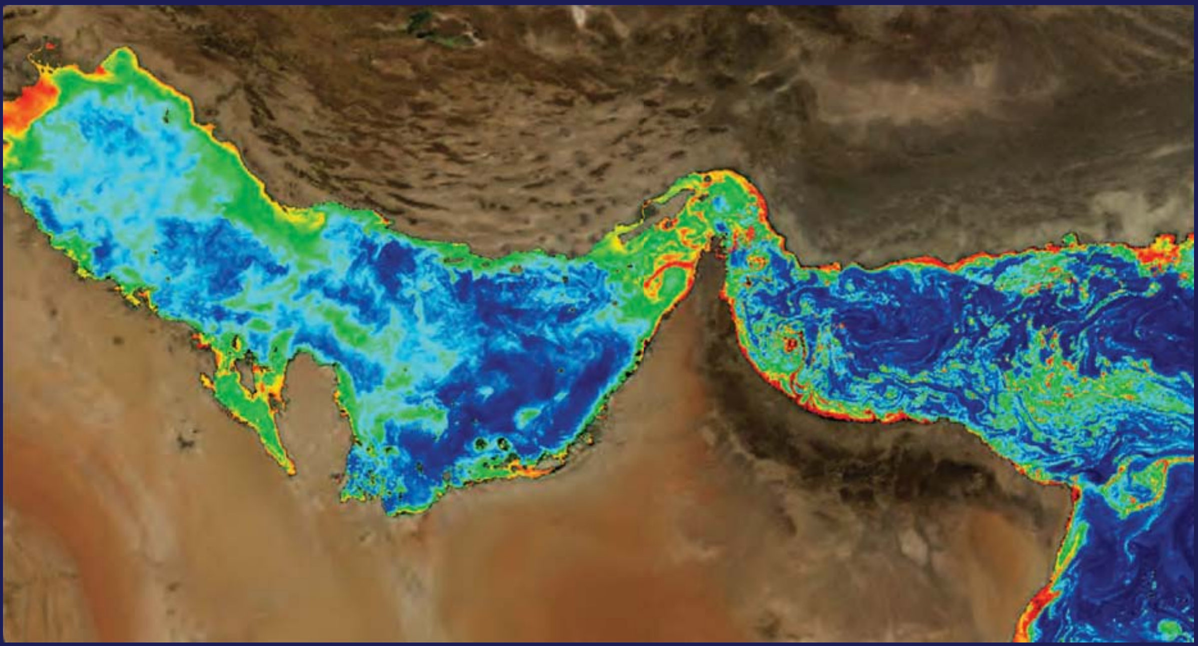
Harmful Algal Blooms (HABs) and Desalination: A Guide to Impacts, Monitoring, and Management



Edited by:

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7 BLOOM PREVENTION AND CONTROL

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7.1 INTRODUCTION

Harmful algal blooms (HABs) are a serious and growing problem to many sectors of society, including the desalination industry. The many problems that HABs present for seawater reverse osmosis (SWRO) desalination plants include: 1) the production of dangerous toxins that have the potential to contaminate treated water; 2) high algal biomass that clogs intake filters; and 3) contributing to biofouling of equipment and SWRO membranes.

It is important to limit the impact from HABs by preventing blooms from reaching SWRO plants in the first place, while also reducing their effects in the event that ingress to the plant has occurred. Many of the management actions taken to respond to HABs can be termed mitigation – i.e., dealing with an existing or ongoing bloom, and taking whatever steps are necessary or possible to reduce negative impacts. Mitigation strategies can be classified into two categories, *precautionary impact preventions* and *bloom controls* (Kim 2006; Anderson 2004). Precautionary impact preventions refer to monitoring, predictive, and emergent actions - essentially actions taken to keep HABs from happening or from directly impacting a particular resource. Several problems are immediately apparent in this regard. For one, we do not have all of the knowledge we need about why HABs form in many areas, so it is obviously difficult to regulate or control those factors. This argues for substantial and sustained research on all aspects of HABs, including their ecology, physiology, and oceanography. All too often managers and agency officials view these topics as fundamental or basic science issues that have little direct practical utility, but in reality, such knowledge is essential for the design and implementation of effective prevention strategies.

Another problem that arises with the concept of HAB prevention is that even if certain environmental factors are known to influence the population dynamics of a specific HAB organism, there are limitations on what can feasibly be done to modify or control those factors. It might be known that a particular HAB is strongly influenced by the outflow of a river system – that it is associated with a buoyant coastal current, for example - but are unlikely to be able to justify the alteration of that river flow solely on the basis of HAB prevention. As discussed below, it is nevertheless important to factor the possible impacts on HABs into large-scale policy decisions on such topics as pollution reductions or alterations in freshwater flows in response to agricultural and drinking water demands.

Obvious examples of impact prevention in the context of desalination are pretreatment strategies that remove cells and the organic compounds they produce. These are described in Chapter 9. In effect, these strategies are used to cope with HABs and to manage around them. The question often arises, however, as to whether it is possible to be more pro-active. Can something be done about blooms before they happen, or can something be done to destroy or suppress them while they are occurring? These questions highlight the “control” aspects of HAB management.

Bloom control is both challenging and controversial. The concept refers to actions taken to suppress or destroy HABs, intervening directly in the bloom process. Curtailing or suppressing the duration and magnitude of a HAB through physical, chemical, or biological intervention are potential approaches, but this is one area where HAB science is rudimentary and slow moving. Anderson (1997) highlighted the slow research progress on bloom control, in contrast to aggressive policies to control pests and nuisance species in terrestrial agriculture. A number of reasons were listed for the reticence or reluctance of scientists and managers to explore and implement control strategies. These include:

- HABs are complex phenomena in highly dynamic environments. Many are large, covering thousands of km^2. Control strategies would be massively expensive and logistically challenging.
- HABs are caused by algae from many phylogenetic clades (see Chapter 1), including eukaryotes (armored and unarmored dinoflagellates, raphidophytes and diatoms, euglenophytes, cryptophytes, haptophytes, pelagophytes, and chlorophytes) and microbial prokaryotes (cyanobacteria that occur in both marine and freshwater systems). Given this biodiversity, no single strategy or approach to bloom control or suppression will apply to all harmful algae.
- HAB phenomena remain poorly understood, i.e.,“we can’t control what we don’t understand”.
- Few, if any, countries have government agencies with the mandate to conduct research or to implement strategies to control marine “pests”.
- The solutions may cause more damages than do the HAB problem being treated.

Each of these arguments has a counter argument, as discussed in Anderson (2004), but the bottom line is that progress on bloom control has been slow, with advances being made by only a few countries. The challenge is even more significant when viewed in the context of a desalination plant. In the discussion that follows, traditional and emerging technologies in the field of HAB mitigation and control are summarized in the context of their applicability to HAB risk management at SWRO desalination plants. In doing this, it is recognized that desalination plants are unlikely to undertake any large-scale bloom control or suppression strategies outside their plants, given the cost, logistics, and uncertainty of such efforts. It may be that bloom control would be considered at a small scale within an embayment or intake lagoon, and thus it is important to know the various approaches that have been attempted in different systems. This will also help operators address a very common question from the public, or from plant management – "*Is there anything we can do to control or stop this bloom before it enters the plant?*"

7.2 BLOOM PREVENTION

7.2.1 Nutrient load reduction

For many HABs, particularly those caused by freshwater or brackish water cyanobacteria or nearshore or estuarine dinoflagellates, the reduction of nutrient inputs is an appropriate strategy for preventing and/or limiting bloom magnitude. In the context of a desalination plant, it is obviously not feasible for a plant to alter regional nutrient inputs. If HAB problems persist in an area, the plant can, however, join with other advocates of pollution controls to help reduce the nutrient loadings which often favor HAB development (Anderson et al. 2002; Heisler et al. 2008).

7.2.2 Nutrient load

An example of major intervention in manipulating nutrient loads to coastal waters is the brackish Baltic Sea. The Baltic has a long and on-going history of hypoxia and fish kills associated with cyanobacterial blooms, such as *Nodularia spumigena* (Zillén et al. 2008). Agriculture is the largest source of nitrogen entering the Baltic, but point source discharge of sewage makes up a significant fraction of the load. To respond to these inputs, Sweden has adaptively managed sewage outflow by intermittently releasing more N into surrounding waters when there is a high risk of encouraging potentially toxic blooms of cyanobacteria species, some that are N_2-fixers (i.e., the cells use elemental nitrogen from the atmosphere to form nitrate and thereby grow in waters that have low N:P ratios). If additional N is supplied to the system, however, they are less likely to bloom (Elmgren and Larsson 2001). After the Helsinki Convention of 1974, these Baltic blooms have been largely controlled by heavy restrictions on land-based nutrient pollutants.

A second example is from Lake Erie, the shallowest, warmest, and most human-impacted of the Laurentian Great Lakes in North America. While not a coastal system, its large size and far-reaching impacts make it a good case study for marine HAB control in the context of desalination plants. The predominant bloom species in this region is *Microcystis aeruginosa*, a cyanobacterium that produces the hepatotoxin, microcystin. Importantly, and with direct relevance to desalination, this freshwater toxin is now a known contaminant of coastal marine waters as well due to its ability to move unaltered from watersheds to the ocean (Miller et al. 2010). Phosphorus abatement strategies in the late 1970s successfully suppressed blooms of cyanobacteria in Lake Erie, but only until 1995 when an invasion of foreign mussels (*Dreissena polymorpha* and *D. bugensis*, zebra and quagga mussels, respectively) opened an ecological niche for *Microcystis* by selectively feeding on its competitors (Budd et al. 2001; Juhel et al. 2006). As a result, a water treatment plant in Ohio, USA detected microcystin at concentrations more than threefold higher than the WHO threshold of 1.0 part per billion (ppb) in drinking water. This forced a shutdown of the municipal water supply (Henry 2013), an event that was repeated in Toledo, Ohio in 2014 affecting nearly 500,000 people (Nelson 2015). Adaptive control of N and P akin to strategies in the Baltic Sea may be an effective way to limit *M. aeruginosa* blooms in freshwater systems where drinking water is either directly filtered or where adjacent coastal regions/SWRO plants may be affected by the toxin. Ultimately, reductions in nitrogen and phosphorus must be considered as freshwater, brackish, and oceanic system productivity (including HABs) responds spatially and seasonally to both nutrients (Fisher et al. 1999; Conley et al. 2009; Smith and Schindler 2009).

7.2.3 Hydraulics

Decreasing residence times in some inland systems through alteration of river flows and flushing rates can reduce blooms of cyanobacteria (Maier et al. 2004; Paerl 2014). Sellner et al. (2015) documented the potential role of rapid flushing of ponds, lakes, or basins in limiting recurrence of *M. aeruginosa* blooms in the coastal plain of Maryland, USA. The process relies on elevated bottom shear stress to resuspend and then advect (transport) overwintering populations of the *Microcystis* to systems downstream into waters less favorable for growth. Similar hydraulic control of recently settled HAB populations might be feasible for intake lagoons or holding ponds where treatment plant waters might be manipulated to purge vegetative or resting stages of HAB taxa periodically from direct intake into the SWRO plant.

7.2.4 Mixing/destratification

Several physical disturbance methods are now being tested that may not translate well to the open, coastal zone, but may be highly applicable to intake lagoons or holding ponds given their success in lakes and fjords. These include sediment capping with chitosan - modified sands (Pan et al. 2012), dredging of nutrient-rich waters to reduce cyanobacterial bloom initiation followed by application of Phoslock® to trap and sequester dissolved phosphorous (Lürling and Faassen 2012), and even solar-powered circulation to disturb cyanobacterial habitat in freshwater systems (Figure 7.1; Hudnell et al. 2010).

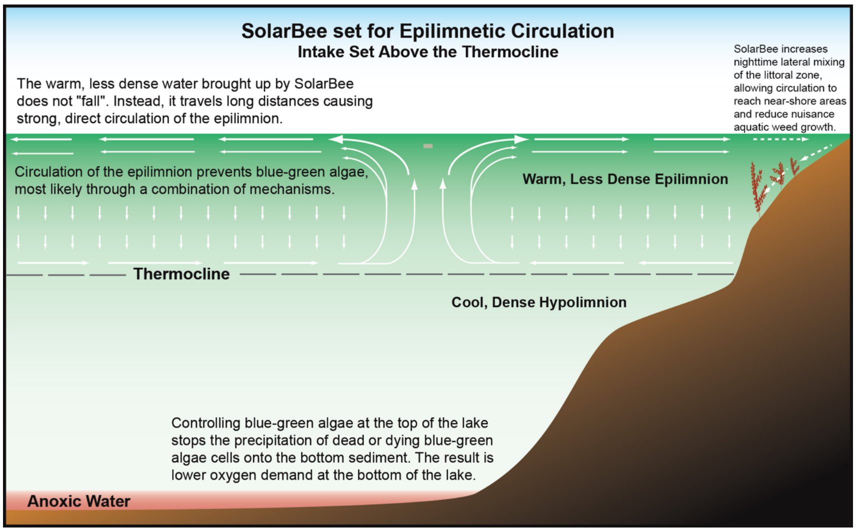

Figure 7.1. SolarBee water circulator, drawing water from depth and circulating water horizontally near-surface by rotating paddles. Figure: Medora, Co.

Another novel and potentially environmentally benign approach to control blooms of cyst-forming HAB species (e.g., *Alexandrium*) in shallow, localized systems is currently being explored; the method might be applicable in holding ponds prior to SWRO intake. With this method, manual mixing of bottom sediments buries cysts uniformly throughout the disturbed layer, greatly reducing the number of cysts in the oxygenated surface layer, and thus the potential inoculum for future HABs (D. Anderson, unpubl. data). Another unique approach has been proposed, a 'sediment-lift' process (Imai et al. 2015) whereby bottom sediments rich in diatom spores are pumped into nutrient-rich, mixed surface waters (Saiki Bay, Japan). Dispersal of these resting stages in surface water may facilitate diatom growth rather than growth of slower-growing dinoflagellates, preventing HAB impacts on local mariculture operations. For constrained coastal bays with documented recurrent dinoflagellate blooms, this approach might be feasible or at least explored in pilot studies. The risk to desalination plants from such a strategy would be that the bloom that is facilitated or encouraged might still be deleterious to operations if it reaches cell densities that can cause fouling.

7.3 BLOOM CONTROL

7.3.1 Barley straw

In lakes and ponds, deployment of barley straw (Figure 7.2) or dispersal of its extract can be cost-effective alternatives to controlling some HABs (Sellner et al. 2013; see also references in Brownlee et al. 2003). It was suggested that phenolic compounds in barley straw (recently identified as flavonoids, Xiao et al. 2013; Huang et al. 2015) are the main inhibitor of growth of new dinoflagellate cells (i.e., algistatic) (Terlizzi et al. 2002). Iredale et al. (2012) showed that microbial degradation of the barley straw releases hydrogen peroxide as well as inhibitory products from the lignin; mechanical shearing is a possible solution for accelerating this process if using fresh rather than rotting barley straw. Note, however, that decomposition of the barley straw is light-dependent, and decomposition products must accumulate for maximum effect; hence, barley straw efficacy requires long residence times for straw breakdown, presumably not feasible for high-volume SWRO intake systems. Additionally and unfortunately, barley straw may have limited use in coastal marine environments where only a few dinoflagellate species (Terlizzi et al. 2002; Brownlee et al. 2003; Hagström et al. 2010) and halotolerant *Microcystis aeruginosa* (K. Sellner, unpubl. data) appear susceptible. The growth of some dinoflagellate species may even be stimulated by barley straw extract (Terlizzi et al. 2002). That said, the heightened specificity of the approach is appealing if trying to avoid widespread ecological consequences (Ferrier et al. 2005) and may prove cost-effective in closed systems.

Figure 7.2. Barley straw bales distributed across shoreline of drained Williston Lake, MD, USA. On refilling the lake, the bales would be in the littoral zone for slow decomposition and release of *Microcystis*-inhibiting compounds. Photo: K. Sellner.

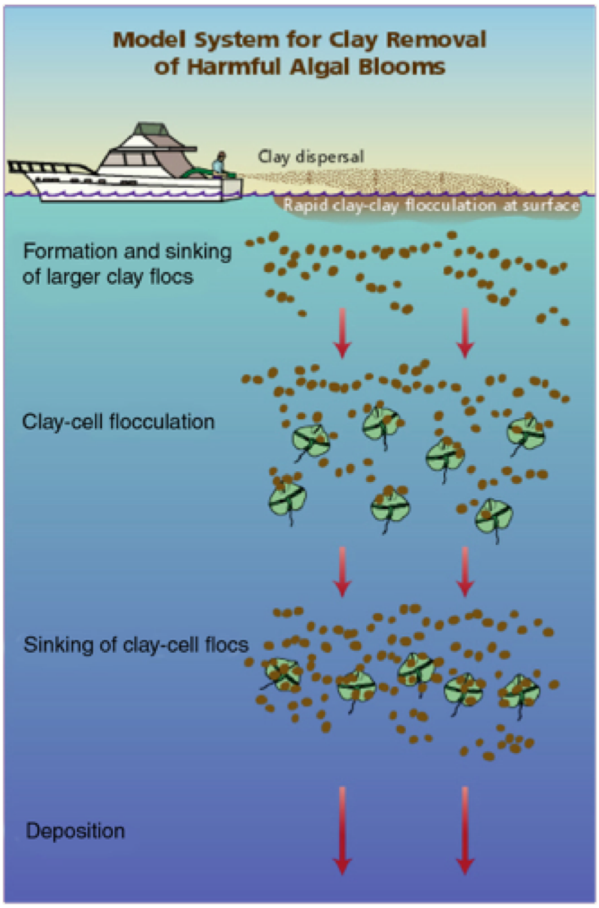

Figure 7.3. Schematic diagram showing how dispersal of a clay slurry can lead to particle flocculation in seawater, and scavenging and sedimentation of HAB cells. Figure: D.M. Anderson.

7.3.2 Flocculation

Clay minerals such as kaolinite and loess compounds have been used effectively to control HABs in Asia, Europe, and the USA, and may be a viable solution for suppressing blooms on fairly large scales in the waters upstream or downstream of intakes. Liquid suspensions of the clay are sprayed onto the surface layer of a bloom, resulting in scavenging and flocculation of algal cells (Figures 7.3, 7.4), with 80 - 95% removal efficiency of biomass from surface waters in some cases (Sengco and Anderson 2004). Phoslock®(lanthanum-modified bentonite) and chitosan have both been applied to cyanobacterial and *Prymnesium* blooms. In the case of Phoslock®, which caps bottom sediments and reduces phosphorous inputs and concentrations and thus induces phosphorous limitation in HAB species, pH, growth phase, colony size, surface charge, and chitosan quality also influence the results (Sellner et al. 2013; Li et al. 2015). Increased ammonium regeneration is one possible negative outcome (Sellner et al. 2013), as this could further promote cyanobacteria that respond to both P and N inputs (Paerl et al. 2011).

Figure 7.4. Clay dispersal for HAB control in Korea. Photo: D.M. Anderson.

A concern about the use of chitosan is that bloom removal is often successful only at very high clay and chitosan levels; Sellner et al. (2013) noted that concentrations of both materials used in field intervention had to be 3-50x the levels suggested by Zou et al. (2006). Another HAB former, *Prymnesium,* has been an expanding problem for fish aquaculture in Tasmania. Body (2011) described successful removal of the flagellate cells from fish ponds using clays, and current research (Seger et al. 2014) is focused on determining the most effective clays for toxin removal. 'Ball' clay (20-80% kaolinite, 10- 25% mica and 6-65% quartz) has also proved effective in severely reducing blooms of *Pyrodinium bahamense* var. *compressum* and *Gymnodinium catenatum*, both marine dinoflagellates posing problems in Philippine coastal waters. Removal efficiencies exceeded 90% (Padilla et al. 2007; Rivera 2015). A number of other flocculants have been explored, including the wastewater treatment plant flocculant poly-aluminum chloride (PAC, Sengco et al. 2001; Ghafari et al. 2009; Lu et al. 2015). In the latter study, Lu et al. (2015) found PAC-clay was effective in removing 90% of a cultured *Alexandrium tamarense* population, 43–60% of total phosphorus and 17–30% of total nitrogen, as well as most of the saxitoxins produced by the dinoflagellate. Extracts of many angiosperm leaves and fruits (e.g., Li and Pan 2013; Wang et al. 2013; Tian et al. 2014) have also been proposed as local, natural control agents in flocculation, with limited routine use due to impracticalities of mass extraction, distribution, and application. It should be noted that clay application can pose serious threats to benthic fauna, for example, molluscan clearance rates (Frank et al. 2000; Shumway et al. 2003; Seo et al. 2008), juvenile clam growth rates (Archambault et al. 2004), and burial of resident populations. Cranford and Gordon (1992 in Hagström et al. 2010) reported "…extensive mortalities and/or significant impact on somatic and reproductive tissue growth…" in *Placopecten magellanicus* when exposed to 0.002-0.01 g bentonite L^{-1}. Cuker (1993) reported altered pelagic food webs via reduced visual predation of fish feeding on *Chaoborus* larvae in montmorillonite-treated limnocorrals, leading to elevated midge larvae grazing on crustacean zooplankton. Rensel and Anderson (2004) noted that a clay slurry of 200 g m^{-2} induced short-term coughing in penned Atlantic salmon (*Salmo salar*). Further, acidified chitosan, one of the flocculants noted above, has been shown to kill rainbow trout at concentration $\geq$0.038 ppm (Bullock et al. 2000). Bottom currents and depths and flushing rates in systems considering clay application should be known and considered in selection of this option for open systems upstream of SWRO intakes.

7.3.3 Miscellaneous

Ozonation, electrolysis, and ultrasound-induced cavitation have been proposed as a mitigation option for small systems. All three generate free radicals, reducing harmful algae and some toxins (e.g., Lürling et al. 2016). Several marine HA taxa have been lysed with ozone (0.25-1 g O_3 m^{-3}) including *K. brevis*, *Prorocentrum triestinum*, *Scrippsiella trochoidea*, *Karenia digitale*, and *Amphidinium* sp. (Schneider et al. 2003; Ho and Wong 2004; Oemcke et al. 2005). Brevetoxin was significantly reduced, but not eliminated, at 135 mg ozone L^{-1}, a substantially higher oxidant level than would be found in commercial ozonation (Schneider et al. 2003). Electrolysis of seawater yields hypochlorite, effective in killing several dinoflagellates (see below and Jeong et al. 2002) and is used with clays to flocculate *C. polykrikoides* in Korean waters (see Park et al. 2013).

Ultrasound, through the sonication of algal biomass, can kill cells, but this can release dissolved organics, which can then be removed with addition of flocculant (e.g., Hakata et al. 2011). Ultrasound may be quite effective at controlling bloom growth (93.5% of *M. aeruginosa*, Zhang et al. 2009) and removing toxins. Song et al. (2005) and Wu et al. (2011) noted microcystin degradation, most effective at frequencies ~20kHz. In closed water treatment plants such as SWRO plants, ultrasound might be an environmentally friendly alternative to chemical control methods (Wu et al. 2011), but studies are needed to follow the fate of toxins and released organic matter.

7.3.4 Chemical additions

7.3.4.1 Copper sulfate

McKnight et al. (1983) once called copper sulfate the "algicide of choice" for HABs in lakes and reservoirs in the USA. This is because copper sulfate takes advantage of the natural toxicity of cupric ions to phytoplankton (McKnight et al. 1983) and has been successful in mitigating HABs in closed freshwater systems (recreational fountains, pools, ponds). Cyanobacteria are particularly susceptible due to the inhibition of N_2-fixation by $CuSO_4$, making it most effective in freshwater systems (Elder and Horne 1978). Copper sulfate with chlorination is still used routinely to rid drinking water reservoirs of nuisance algae and toxins (Zamyadi et al. 2012). In one case, it was added to a coastal marine system using crop-dusting aircraft to combat *Karenia brevis* blooms in the 1950s (Rounsefell and Evans 1958). It was also dispersed in brackish hybrid striped bass ponds resulting in fish kills and toxin in pond waters; these negative effects were remedied by the subsequent addition of $KMnO_4$ (see below, Deeds et al. 2004). It is the collateral damage due to the non-specific toxicity of copper to many marine organisms that poses severe constraints on its use in the open environment.

7.3.4.2 Hydrogen peroxide

Additions of peroxide are also effective against several cyanobacteria (Lusty and Gobler 2017), *M. aeruginosa* (Lürling et al. 2014), and *Planktothrix rubescens* (Mattheiss et al. 2017) and *P. agardhii* (Matthijs et al. 2012) in lakes and small basins. Successful suppression of an *Alexandrium ostenfeldii* bloom in a brackish water creek in The Netherlands (Burson et al. 2014) as well as a microcosm "brown tide" of *Aureococcus anophageferrens* (Randhawa et al. 2012) have also been noted. Importantly, peroxide additions do not seem to harm macrofauna, and levels under 2.5 mg L^{-1} appear safe for herbivorous zooplankton resulting in a final lake-wide application of 2 mg L^{-1} (Matthijs et al. 2012). Since eukaryotic phytoplankton are not significantly affected by dilute peroxide, it is unclear how successful this approach would be in coastal applications where the dominant HAB species are not cyanobacteria. Higher concentrations would be harmful to all marine life, and as a result, peroxide treatment is limited due to cost and hazardous chemical permitting (particularly in the USA).

7.3.4.3 Sulfuric acid

Acid rain, volcanic activity, and mining are known sources of sulfuric acid to aquatic systems and have been shown to be detrimental to phytoplankton populations via overall acidification of surface waters (Geller et al. 1998). Enclosure experiments with toxic *Prymnesium parvum* demonstrated the inhibitory effect of lowered pH on bloom development and toxin (prymnesins) production after the addition of 0.1 N sulfuric acid (Prosser et al. 2012). Place (A. Place, unpubl. data) has examined the effects of sulfuric acid additions to reduce pH of surface waters surrounding local HABs temporarily, thereby increasing phytoplankton susceptibility to flocculation and settling to the bottom.

7.3.4.4 Potassium permanganate

Potassium permanganate has been employed in wastewater treatment plants for decades as a potent oxidizing agent to reduce biological and chemical oxygen demands in effluents (reviewed by Scott and Ollis 1995). Use in the natural environment is a concern due to its generic ability to oxidize all organic matter, i.e., HAB cells and all other biota. It has, however, been used to control *Karlodinium veneficum* (an ichthyotoxin-producing dinoflagellate) and its toxin in brackish hybrid striped bass ponds in Eastern Maryland, USA (Deeds et al. 2004). In another spring-fed pond, near-bottom cold water anatoxin-producing *Planktothrix prolifera* populations were effectively removed or severely reduced with bottom water $KMnO_4$ additions, thereby freeing the pond of detectable toxin, with only low cell abundances (K. Sellner, unpubl. data) and no apparent impact on metazoans in the system. The *P. prolifera* population has since been found at bloom levels under ice seven years post-treatment.

7.3.4.5 Chlorination

Chlorination, through addition of NaOCl or other chloride compounds, is commonly used to remove cyanobacteria and cyanotoxins from drinking water supplies, with the degree of toxin degradation being toxin-specific (Zamyadi et al. 2012). Following experimental work with electrolysis of seawater (yielding hypochlorite) and several marine dinoflagellates (*Gymnodinium catenatum*, *Cochlodinium polykrikoides*, *Akashiwo sanguinea*, *Lingulodinium polyedrum*, *Prorocentrum micans*, *Alexandrium affine*, and *Gymnodinium impudicum*), Jeong et al. (2002) suggested effective NaOCl doses of 300-500 ppb for 10 min or 200-400 ppb for 1 h could minimize HAB exposures; however, free radicals may stress other biota in the system (Brungs 1973). Chlorination to eliminate HAB toxins is discussed in Chapter 2.

7.3.5 Biological additions

7.3.5.1 Microbes

Viral and bacterially induced lysis (cell breakdown) are natural processes that regulate phytoplankton communities and carbon flux (e.g., Fuhrman and Azam 1980; Salomon and Imai 2006). Making use of this natural pathogenicity seems like a logical, cost-effective solution to HAB control; however, the scientific community is skeptical of experiments that introduce foreign, potentially invasive species, or have the potential to restructure natural assemblages in an ecosystem irreversibly (Sanders et al. 2003; Secord 2003). Despite the many laboratory studies demonstrating the harmful effects of heterotrophic bacteria on algal species, Mayali and Azam (2004) argue that most field studies have failed to show conclusively the causal relationship between the decline of a bloom in natural ecosystems and the behavior of an introduced algicidal bacterium. Another major issue is that the conversion from laboratory conditions to the natural environment is inherently complex given the flexibility of predator-prey dynamics mediated by the presence or absence of other algal species (Mayali and Azam 2004).

There are at least two studies indicating the benefit of natural plant-associated bacteria in reducing HABs. Imai et al. (2012) and Onishi et al. (2014; Figure 1.6) noted lytic bacteria for *M. aeruginosa* as well as *H. akashiwo* and *Alexandrium tamarense* in submersed angiosperms and macroalgae, respectively, indicating potential natural control in several Japanese bays (see Imai et al. 2014) and Puget Sound (Inaba et al. 2015).

HAB parasites are increasingly studied as bloom control agents, with *Amoebophyra* spp. the most well-documented natural dinoflagellate control. The seminal work by Coats and colleagues (e.g., Coats 1999) has stimulated other research, resulting in the identification of several taxon-specific parasites that some suggest could be applied routinely to nearshore zones where host dinoflagellates might be increasing, detected through satellite or other remote detection systems (see Chapter 4). Jeong et al. (2003) have proposed using heterotrophic dinoflagellates for control of natural HABs. Routine use of most biological agents seems impractical at this time due to the costs associated with maintenance of the parasite in culture, mass cultivation, manpower, and the diversity of HABs that could frequent an area.

Although not identified for marine species, chytrid fungi have been shown to infect a wide variety of phytoplankton in freshwater lakes, and while not necessarily host-specific, they appear to prefer larger phytoplankton species (Kagami et al. 2007). These eukaryotic parasites are ubiquitous in coastal marshes, and so far, only two genera of infecting fungi have been studied for marine taxa (diatoms only), with little known regarding the magnitude of their pathogenicity (Park et al. 2004). Interestingly, the major eukaryotic parasites infecting marine dinoflagellates are *other* dinoflagellates (rather than fungi), such as *Amoebophyra* spp. mentioned above. Jia et al. (2010) examined the effect of "white rot fungus" (*Trichaptum abietinum*), a non-aquatic, wood-decay fungus often used to degrade industrial pollutants, on several cyanobacterial cultures. Not only were the cultures destroyed within 48 h, but it appeared that the fungus actively preyed on the algal cells and did not seem to discriminate between species. Even more tantalizing is the complete degradation after 12 h of microcystin in test *M. aeruginosa* cultures inoculated with mycelial pellicles. It is important to note that white rot fungus has not been applied to larger reservoirs or drinking water systems nor evaluated for environmental safety (Jia et al. 2012), although it has been used to increase barley straw decomposition and inhibition of the cyanobacterium (Sellner et al. 2015).

7.3.5.2 Competitors

Biological diversity may also be an important factor for keeping HAB species from gaining dominance. Cardinale (2011) demonstrated that more diverse communities are naturally buffered against nutrient enrichment relative to less diverse communities due to the enhanced niche partitioning by benthic diatoms which increased nitrogen uptake. The promotion of higher algal biodiversity and habitat preservation may thus be one method for facilitating greater nutrient uptake capacity, particularly in protected environments where physical advection processes do not dominate phytoplankton turnover rates. Allelopathic interactions (e.g., Pratt 1966; Tang and Gobler 2011; Lim et al. 2014; Tang et al. 2014) introduced when algae exude dissolved secondary metabolites (sometimes phycotoxins) into the environment are an indicator of inter-specific competition for limiting resources (Graneli and Hansen

2006). It may also be that as species diversity increases, the ability of a given toxic species to dominate its competitors is suppressed by the wider array of competitive strategies present in the community. As marine ecosystem models become more sophisticated and include realistic phytoplankton biodiversity (Follows et al. 2007; Goebel et al. 2010), varying management strategies can be assessed in relation to the physical environment, community composition, competitive interactions, and nutrient dynamics.

7.3.5.3 Grazers and trophic cascades

Algal proliferation is heavily regulated by grazing pressure from zooplankton, with grazing and trophic cascades representing an often overlooked component of bloom development and persistence (e.g., Verity and Smetacek 1996; Gobler et al. 2002; Turner and Graneli 2006; Smayda 2008). There is evidence that eutrophication (i.e., nutrient enrichment) exerts an indirect effect on zooplankton grazing efficiency. At higher nutrient levels, phytoplankton are no longer suppressed by grazers (Kemp et al. 2001) and actually increase the production of grazing deterrents (Mitra and Flynn 2006), a positive feedback that intensifies negative impacts of HABs (Sunda et al. 2006). This idea of indirect effects is also consistent with a simulation study by Daskalov (2002) who found that the increase in algal blooms in the Black Sea was the result of intense overfishing of top predators, such as cetaceans and large migratory fish. The overfishing resulted in decreased predator control of planktivorous fish, thereby depleting zooplankton stocks and allowing phytoplankton to flourish. This 'trophic cascade' was assisted by anthropogenic eutrophication that significantly relieved resource limitation from the bottom-up (Daskalov 2002) and likely further suppressed grazing. Another simulation study (Walsh et al. 2011) used a coupled physical-biological model of the Chukchi/Beaufort Seas to illustrate that "fishing down of the food web" (*sensu* Pauly et al. 1998) and increased eutrophication in a scenario similar to that of the Black Sea supports hypotheses of a regime shift favoring N_2-fixers and HAB-forming dinoflagellates like the saxitoxin-producing *Alexandrium tamarense*. Ultimately, the solution to this ecologically complex interplay is similar to that discussed in Section 7.2.1, whereby reduction in nutrient loads not only provides bottom-up regulation of blooms, but can lead to unexpected consequences for other ecosystem components essential to bloom control.

7.3.6 Combined methods/redundancy

There are some examples of combinations of multiple interventions in bloom control. Sellner et al. (2015) document the combined effects of hydraulic flushing and barley straw additions in limiting growth of *M. aeruginosa* and toxin accumulation in a freshwater lake in Maryland, USA. Flocculation, sedimentation, capping of bottom sediments, and additions of toxin-utilizing *Pseudomonas* sp. in bloom control have been suggested for blooms of *M. aeruginosa* in China (Li et al. 2015). As noted above, seawater electrolysis followed by clay flocculation is an effective removal strategy for *C. polykrikoides* populations that threaten fish pen mariculture in Korean (Park et al. 2013). Practical use of approaches like these near SWRO intakes remains to be determined.

7.4 SUMMARY

There are numerous techniques to prevent and control HABs, though many remain experimental or are practical only on a small scale. Most preventative measures involve factors beyond the control of desalination plant operators, such as nutrient reduction from regional watersheds or other point and non-point sources of nutrient discharge to the coastal zone that can stimulate HABs. The increasing development of desalination plants should serve to provide pressure on governmental entities (or favor government-private partnerships) responsible for monitoring and controlling nutrient pollution given the need for safe, clean drinking water. As covered in Chapter 3, monitoring methods that include satellite-based bloom detection, and advanced models of HAB initiation and transport provide early warning of delivery of potential toxins or bloom biomass to a plant's intake system. While these monitoring and modeling programs require significant financial investment to develop and maintain, they allow operators to prepare for HAB events and potentially adjust intake operations and plant pre-treatment technologies accordingly.

Fortunately, options remain for the control of HABs that have already entered a desalination plant, and these are described in detail in Chapter 9. For plants with holding ponds or reservoirs, intervening with physical disturbance techniques, oxidizing compounds (H_2O_2, $KMnO_4$) or clay minerals to remove HAB particles via flocculation are possibilities. Care must be taken, however, as some turn particulate algal biomass (which is relatively easy to remove with pretreatment) into dissolved organic compounds, which are much harder to remove. Other post-intake technologies for SWRO include the application of copper sulfate (cell lysis but little toxin degradation) followed by, or by themselves, the use of techniques that generate oxidizing conditions (again peroxide or permanganate as well as chlorination, electrolysis, ozonation, perhaps ultrasound), but post-treatment of these waters might be required to mitigate possible damage to plant membranes.

High costs will likely prohibit the frequent use of these methods for mitigation, but several could also be considered as options for minimizing HAB entry into a desalination plant, particularly in the case of methods that are applicable to coastal environments or embayments, such as hydrogen peroxide application or electrolysis-clay addition. The majority of methods suggested in this chapter, however, are meant to give desalination operators an understanding of the challenges associated with HAB prevention and control. Many are not practical, given desalination–specific factors such as the high-volume intake requirements of plants, but others may be of use, and may contribute to a suite of adaptive strategies to mitigate HAB impacts on desalination operations.

7.5 REFERENCES

Anderson, D. M. 1997. Turning back the harmful red tide. Nature 388, 513-514.

Anderson, D. M. 2004. Prevention, control and mitigation of harmful algal blooms: Multiple approaches to HAB management. Hall, S., Etheridge, S., Anderson, D., Kleindinst, J., Zhu, M., and Zou, Y. (Eds.), *Harmful Algae Management and Mitigation*, Asia-Pacific Economic Cooperation (Singapore): APEC Publication #204-MR-04.2. pp. 123-130.

Anderson, D. M., Glibert, P. M., and Burkholder, J. M. 2002. Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences. *Estuaries* 25, 704–726.

Archambault, M. C., Bricelj, V. M., Grant, J., and Anderson, D. M. 2004. Effects of suspended and sedimented clays on juvenile hard clams, *Mercenaria mercenaria*, within the context of harmful algal bloom mitigation. *Marine Biology* 144, 553-565.

Body, A. 2011. Stable pond blooms through phosphate and pH control. *Infofish International* 1/2011, 22-25.

Brownlee, E. F., Sellner, S. G., and Sellner, K. G. 2003. Effects of barley straw (*Hordeum vulgare*) on freshwater and brackish phytoplankton and cyanobacteria. *Journal of Applied Phycology* 15, 525–531.

Brungs, W. A. 1973. Effects of residual chlorine on aquatic life. *Journal of the Water Pollution Control Federation* 45, 2180-2193.

Budd, J. W., Drummer, T. D., Nalepa, T. F., and Fahnenstiel, G. L. 2001. Remote sensing of biotic effects: Zebra mussels (*Dreissena polymorpha*) influence on water clarity in Saginaw Bay, Lake Huron. *Limnology and Oceanography* 46(2), 213-223.

Bullock, G., Blazer, V., Tsukuda, S., and S. Summerfelt. 2000. Toxicity of acidified chitosan for cultured rainbow trout (*Oncorhynchus mykiss*). *Aquaculture* 185, 273-280.

Burson, A., Matthijs, H. C., de Bruijne, W., Talens, R., Hoogenboom, R., Gerssen, A., Visser, P. M., Stomp, M., Steur, K., and van Scheppingen, Y. 2014. Termination of a toxic *Alexandrium* bloom with hydrogen peroxide. *Harmful Algae* 31: 125–135.

Cardinale, B. J. 2011. Biodiversity improves water quality through niche partitioning. *Nature* 472, 86–89.

Coats, D. W. 1999. Parasitic life styles of marine dinoflagellates. *Journal of Eukaryote Microbiology* 46, 402-409.

Conley, D. J., Paerl, H. W., Howarth, R. W., Boesch, D. F., Seitzinger, S. P., Havens, K. E., Lancelot, C., and Likens, G. E. 2009. Controlling eutrophication: Nitrogen and phosphorus. *Science* 323, 1014-1015.

Cuker, B. E. 1993. Suspended clays alter trophic interactions in the plankton. *Ecology* 74, 944-953.

Daskalov, G. M. 2002. Overfishing drives a trophic cascade in the Black Sea. *Marine Ecology Progress Series* 225, 53–63.

Deeds, J. R., Mazzaccaro, A. P., Terlizzi, D. E., and Place, A. R. 2004. Treatment options for the control of an ichthyotoxic dinoflagellate in an estuarine aquaculture facility: A case study. Hall, S., Anderson, D., Kleindinst, J., Zhu, M., and Zou, Y. (Eds.), *Proceedings of the Second International Conference on Harmful Algae Management and Mitigation*, Asia-Pacific Economic Cooperation, APEC Publ. #204-MR-04.2, Singapore, pp. 177-181.

Elder, J. F., and Horne, A. J. 1978. Copper cycles and CuSO4 algicidal capacity in two California lakes. *Environmental Management* 2, 17–30.

Elmgren, R., and Larsson, U. 2001. Nitrogen and the Baltic Sea: managing nitrogen in relation to phosphorus. *The Scientific World Journal* 1, 371–377.

Ferrier, M. D., Butler, B. R., Terlizzi, D. E., and Lacouture, R. V. 2005. The effects of barley straw (*Hordeum vulgare*) on the growth of freshwater algae. *Bioresource Technology* 96, 1788–1795.

Fisher, T. R., Gustafson, A. B., Sellner, K., Lacouture, R., Haas, L. W., Wetzel, R. L., Magnien, R., Everitt, D., Michaels, B., and Karrh, R. 1999. Spatial and temporal variation of resource limitation in Chesapeake Bay. *Marine Biology* 133, 763-778.

Follows, M. J., Dutkiewicz, S., Grant, S., and Chisholm, S. W. 2007. Emergent biogeography of microbial communities in a model ocean. *Science* 315, 1843–1846.

Frank, D., Ewert, L., Shumway, S., and Ward, J. E. 2000. Effect of clay suspensions on clearance rates in three species of benthic invertebrates. *Journal of Shellfish Research* 19, 663.

Fuhrman, J. A., and Azam, F. 1980. Bacterioplankton secondary production estimates for coastal waters of British Columbia, Antarctica, and California. *Applied and Environmental Microbiology* 39, 1085–1095.

Geller, W., Klapper, H., and Schultze, M. 1998. Natural and anthropogenic sulfuric acidification of lakes. Geller, W., Klapper, H., and Salomons, W. (Eds.), *Acidic Mining Lakes*. Springer, Berlin Heidelberg, pp. 3–14.

Ghafari, S., Aziz, H. A., Isa, M. H., and Zinatizadeh, A. A. 2009. Application of response surface methodology (RSM) to optimize coagulation–flocculation treatment of leachate using poly-aluminum chloride (PAC) and alum. *Journal of Hazardous Materials* 163, 650–656.

Gobler, C. J., Renaghan, M. J., and Buck, N. J. 2002. Impacts of nutrients and grazing mortality on the abundance of *Aureococcus anophagefferens* during a New York brown tide bloom. *Limnology and Oceanography* 47, 129–141.

Goebel, N. L., Edwards, C. A., Zehr, J. P., and Follows, M. J. 2010. An emergent community ecosystem model applied to the California Current System. *Journal of Marine Systems* 83, 221–241.

Graneli, E., and Hansen, P. J. 2006. Allelopathy in harmful algae: A mechanism to compete for resources? Granéli, E. and Turner, J. T. (Eds.), *Ecology of Harmful Algae*, Springer. pp. 189–201.

Hagström, J. A., Sengco, M. R., and Villareal, T. A. 2010. Potential methods for managing *Prymnesium parvum* blooms and toxicity, with emphasis on clay and barley straw: a review. *Journal of the American Water Resources Association* 46, 187–198.

Hakata, Y., Roddick, F., and Fan, L. 2011. Impact of ultrasonic pre-treatment on the microfiltration of a biologically treated municipal effluent. *Desalination* 283, 75–79.

Heisler, J., Glibert, P., Burkholder, J., Anderson, D., Cochlan, W., Dennison, W., Dortch, Q., Gobler, C., Heil, C., Humphries, E., Lewitus, A., Magnien, R., Marshall, H., Sellner, K., Stockwell, D., Stoecker, D., and Suddleson, M. 2008. Eutrophication and harmful algal blooms: A scientific consensus. *Harmful Algae* 8, 3-13.

Henry, T. 2013. Carrol Township's scare with toxin a "wake-up call." *Toledo Blade* 15.

Ho, K. C. and Wong, Y. K. 2004. A study on the effectiveness of using ozone to mitigate harmful algal blooms. Hall, S., Anderson, D., Kleindinst, J., Zhu, M., and Zou, Y. (Eds.), *Proceedings of the Second International Conference on Harmful Algae Management and Mitigation*, Asia-Pacific Economic Cooperation, APEC Publ. #204-MR-04.2, Singapore, pp. 185-188.

Huang, H., Xiao, X., Ghadouani, A., Wu, J., Nie, Z., Peng, C., Xu, X., and Shi, J. 2015. Effects of natural flavonoids on photosynthetic activity and cell integrity in *Microcystis aeruginosa*. *Toxins* 7, 66-80.

Hudnell, H. K., Jones, C., Labisi, B., Lucero, V., Hill, D. R., and Eilers, J. 2010. Freshwater harmful algal bloom (FHAB) suppression with solar powered circulation (SPC). *Harmful Algae* 9, 208–217.

Imai, I., Imai, Y., Toda, T., Noda, M., and Miyamura, K. 2015. Manipulating phytoplankton flora to harmless diatoms through germination of resting stage cells by sediment-lift to euphotic layer in coastal sea. *Proceedings of the 16th International Conference on Harmful Algae*, Abstract and presentation, Wellington, NZ.

Imai, I., Shimada, H., Shinada, A., Baba, K., Kanamori, M., Sato, M., Kuwahara, Y., Miyoshi, K., Tada, M., Hirano, K., Miyazono, A., and Itakura, S. 2014. Prediction of toxic algal bloom occurrences and adaptation to toxic blooms to minimize economic loss to the scallop aquaculture industry in Hokkaido, Japan. Trainer, V.L. and Yoshida, T. (Eds.). *Proceedings of a Workshop on Economic Impacts of Harmful Algal Blooms on Fisheries and Aquaculture*, PICES Scientific Report Number. 47, pp. 7-16.

Imai, Y., Ohgi, K., Mizuhara, S., Yamaguchi, A., and Kaerlyama, M. 2012. Experimental study on control of *Microcystis aeruginosa* bloom by using of microorganisms in waters of a reed community and a water plant zone. Abstract and presentation, *15th International Conference on Harmful Algae*, Gyeongnam, Korea.

Inaba, N., Onishi, Y., Ishii, K., Trainer, V. L., Wylie-Echeverria, S., Hatch, M. B. A., and Imai, I. 2015. High density of algicidal and growth-inibiting bacteria against harmful algal species detected from seagrass and macroalgae in Puget Sound. Abstract and presentation, 16th *International Conference on Harmful Algae,* Wellington, NZ.

Iredale, R. S., McDonald, A. T., and Adams, D. G. 2012. A series of experiments aimed at clarifying the mode of action of barley straw in cyanobacterial growth control. *Water Research* 46, 6095–6103.

Jeong, H. J., Kim, J. S., Yoo, Y. D., Kim, S. T., Kim, T. H., Park, M. G., Lee, C. H., Seong, K. A., Rang, N. S., and Shim, J. H. 2003. Feeding by the heterotrophic dinoflagellate *Oxyrrhis marina* on the red-tide raphidophyte *Heterosigma akashiwo*: A potential biological method to control red tides using mass-cultured grazers. *Journal of Eukaryotic Microbiology* 50, 274-282.

Jeong, H. J., Kim, H. R., Kwang, I. K., Kwang, Y. K., Park, K. H., Seong, T. K., Yoo, Y. D., Song, J. Y., Kim, J. S., Seong, K. A., Pae, W. H. S. E., Lee, C. H., Huh, M. D., and Lee, S. H. 2002. NaOCl produced by electrolysis of natural seawater as a potential method to control marine red-tide dinoflagellates. *Phycologia* 41, 643-656.

Jia, Y., Han, G., Wang, C., Guo, P., Jiang, W., Li, X., and Tian, X. 2010. The efficacy and mechanisms of fungal suppression of freshwater harmful algal bloom species. *Journal of Hazardous Materials* 183, 176–181.

Jia, Y., Du, J., Song, F., Zhao, G., and Tian, X. 2012. A fungus capable of degrading microcystin-LR in the algal culture of *Microcystis aeruginosa* PCC7806. *Applied Biochemistry and Biotechnology* 166, 987–996.

Juhel, G., Davenport, J., O'Halloran, J., Culloty, S. C., O'Riordan, R. M., James, K. F., Furey, A., and Allis, O. 2006. Impacts of microcystins on the feeding behaviour and energy balance of zebra mussels, *Dreissena polymorpha*: A bioenergetics approach. *Aquatic Toxicology* 79, 391–400.

Kagami, M., de Bruin, A., Ibelings, B. W., and Van Donk, E. 2007. Parasitic chytrids: their effects on phytoplankton communities and food-web dynamics. *Hydrobiologia* 578, 113–129.

Kemp, W. M., Brooks, M. T., and Hood, R. R. 2001. Nutrient enrichment, habitat variability and trophic transfer efficiency in simple models of pelagic ecosystems. *Marine Ecology Progress Series* 223, 73–87.

Kim, H. G. 2006. Mitigation and controls of HABs. Granéli, E. and Turner, J.T. (Eds.), *Ecology of Harmful Algae*, Springer. pp. 327–338.

Li, L. and Pan, G. 2013. A universal method for flocculating harmful algal blooms in marine and fresh waters using modified sand. *Environmental Science and Technology* 47, 4555–4562.

Li, L., Zhang, H., and Pan, G. 2015. Influence of zeta potential on the flocculation of cyanobacteria cells using chitosan modified soil. *Journal of Environmental Sciences* 28, 47–53.

Lim, A. S., Jeong, H. J., Jang, T. Y., Jang, S. H., and Franks, P. J. 2014. Inhibition of growth rate and swimming speed of the harmful dinoflagellate *Cochlodinium polykrikoides* by diatoms: Implications for red tide formation. *Harmful Algae* 37, 53–61.

Lu, G., Song, X., Yu, Z., Cao, X., and Yuan, Y. 2015. Environmental effects of modified clay flocculation on *Alexandrium tamarense* and paralytic shellfish poisoning toxins (PSTs). *Chemosphere* 127, 188–194.

Lürling, M. and Faassen, E. J. 2012. Controlling toxic cyanobacteria: Effects of dredging and phosphorus-binding clay on cyanobacteria and microcystins. *Water Research* 46, 1447–1459.

Lürling, M., Meng, D., and Faassen, E. J. 2014. Effects of hydrogen peroxide and ultrasound on biomass reduction and toxin release in the cyanobacterium, *Microcystis aeruginosa*. *Toxins* 6, 3260-3280.

Lürling, M., Waajen, G., and de Senerpont Domis, L. N. 2016. Evaluation of several end-of-pipe measures proposed to control cyanobacteria. *Aquatic Ecology* 50, 499-519.

Maier, H. R., Kingston, G. B., Clark, T., Frazer, A., and Sanderson, A. 2004. Risk-based approach for assessing the effectiveness of flow management in controlling cyanobacterial blooms in rivers. *River Research Applications* 20, 459-471.

Mattheiss, J., Sellner, K. G., and Ferrier, D. 2017. Lake Anita Louise Peroxide Treatment Summary – December 2016. CCWS Contribution #17-01, Center for Coastal and Watershed Studies, Hood College, Frederick, MD. 9 pp.

Matthijs, H. C., Visser, P. M., Reeze, B., Meeuse, J., Slot, P. C., Wijn, G., Talens, R., and Huisman, J. 2012. Selective suppression of harmful cyanobacteria in an entire lake with hydrogen peroxide. *Water Research* 46, 1460–1472.

Mayali, X., and Azam, F. 2004. Algicidal bacteria in the sea and their impact on algal blooms. *Journal of Eukaryotic Microbiology* 51, 139–144.

McKnight, D. M., Chisholm, S. W., and Harleman, D. R. 1983. CuSO4 treatment of nuisance algal blooms in drinking water reservoirs. *Environmental Management* **7**, 311–320.

Miller, M. A., Kudela, R. M., Mekebri, A., Crane, D., Oates, S. C., Tinker, M. T., Staedler, M., Miller, W. A., Toy-Choutka, S., and Dominik, C. 2010. Evidence for a novel marine harmful algal bloom: cyanotoxin (microcystin) transfer from land to sea otters. *PLoS One*, 5: e12576.

Mitra, A., and Flynn, K. J. 2006. Promotion of harmful algal blooms by zooplankton predatory activity. *Biology Letters* 2, 194–197.

Nelson, L. A. 2015. Community assessment for public health emergency response (CASPER) following detection of microcystin toxin in a municipal water system, Ohio, September 2014. *Proceedings of the 2015 CSTE Annual Conference. Cste*.

Oemcke, D. J. and Van Leeuwen, J. H. 2005. Ozonation of the marine dinoflagellate alga *Amphidinium* sp.—implications for ballast water disinfection. *Water Research* 39, 5119–5125.

Onishi, Y., Mohri, Y., Tuji, A., Ohgi, K., Yamaguchi, A., and Imai, I. 2014. The seagrass *Zostera marina* harbors growth inhibiting bacteria against the toxic dinoflagellate *Alexandrium tamarense*. *Fisheries Science* 80, 353–362.

Padilla, L., San Diego-McGlone, M. L., and Azanza, R. 2007. Preliminary results on the use of clay to control *Pyrodinium* bloom-a mitigation strategy. *Science Diliman* 18(1), 35-42.

Paerl, H. W. 2014. Mitigating harmful cyanobacterial blooms in a human- and climatically-impacted world. *Life* 4, 988-1012.

Paerl, H. W., Hall, N. S., and Calandrino, E. S. 2011. Controlling harmful cyanobacterial blooms in a world experiencing anthropogenic and climatic-induced change. *Science of the Total Environment* 409, 1739–1745.

Pan, G., Dai, L., Li, L., He, L., Li, H., Bi, L., and Gulati, R. D. 2012. Reducing the recruitment of sedimented algae and nutrient release into the overlying water using modified soil/sand flocculation-capping in eutrophic lakes. *Environmental Science and Technology* 46, 5077–5084.

Park, M. G., Yih, W., and Coats, D. W. 2004. Parasites and phytoplankton, with special emphasis on dinoflagellate infections. *Journal of Eukaryotic Microbiology* 51, 145–155.

Park, T. G.,Lim, W. A., Park, Y. T., Lee, C. K., and Jeong, H. J. 2013. Economic impact, management and mitigation of red tides in Korea. *Harmful Algae* 30S, S131-S143.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., and Torres, F. 1998. Fishing down marine food webs. *Science* 279, 860–863.

Pratt, D. M. 1966. Competition between *Skeletonema costatum* and *Olisthodiscus luteus* in Narragansett Bay and in culture. *Limnology and Oceanography* 11, 447–455.

Prosser, K. N., Valenti, T. W., Hayden, N. J., Neisch, M. T., Hewitt, N. C., Umphres, G. D., Gable, G. M., Grover, J. P., Roelke, D. L., and Brooks, B. W. 2012. Low pH pre-empts bloom development of a toxic haptophyte. *Harmful Algae* 20, 156–164.

Randhawa, V., Thakkar, M., and Wei, L. 2012. Applicability of hydrogen peroxide in brown tide control - culture and microcosm studies. PLOS One https://doi.org/10.1371/journal.pone.0047844

Rensel, J. E. J. and Anderson, D. M. 2004. Effects of phosphatic clay dispersal at two divergent sites in Puget Sound, Washington. In: Steidinger, K.A., Landsberg, J.H., Tomas, C.R., and Vargo, G.A. (Eds.), *Harmful Algae 2002*. Florida Fish and Wildlife Conservation Commission, Florida Institute of Oceanography and Intergovernmental Ocenographic Commission of UNESCO, St. Petersburg Beach, Florida, pp. 522-524.

Rivera, P. P. L. 2015. Removal of harmful algal bloom (HAB)-forming organisms using ball clay: Factors and effects of clay addition. University of Philippines. pp. 101.

Rounsefell, G. A., and Evans, J. E. 1958. Large-scale experimental test of copper sulfate as a control for the Florida red tide. *U.S. Fish and Wildlife Service Special Scientific Report.*

Salomon, P. S. and Imai, I. 2006. Pathogens of harmful microalgae. Granéli, E. and Turner, J.T. (Eds.), *Ecology of Harmful Algae*, Springer. pp. 271–282.

Sanders, N. J., Gotelli, N. J., Heller, N. E., and Gordon, D. M. 2003. Community disassembly by an invasive species. *Proceedings of the National Academy of Sciences USA*, 100, 2474–2477.

Schneider, K. R., Pierce, R. H., and Rodrick, G. E. 2003. The degradation of *Karenia brevis* toxins utilizing ozonated seawater. *Harmful Algae* 2, 101-107.

Scott, J. P. and Ollis, D. F. 1995. Integration of chemical and biological oxidation processes for water treatment: review and recommendations. *Environmental Progress* 14, 88–103.

Secord, D. 2003. Biological control of marine invasive species: cautionary tales and land-based lessons. *Biological Invasions* 5, 117–131.

Seger, A., Body, A., and Hallegraeff, G. M. 2014. Exploration of Phoslock™ clay in mitigating *Prymnesium parvum* fish-killing algal blooms in aquaculture ponds. *Proceedings of the 15th International Conference on Harmful Algae*, Changwon, South Korea, October.

Sellner, K. G., Place, A. R., Paolisso, M., Gao, Y., Williams, E. and VanDolah, F. M. 2013. Options in mitigating cyanobacterial blooms. *Proceedings of the 7th U.S. Harmful Algal Bloom Symposium,* Abstract and presentation.

Sellner, K. G., Place, A. R., Williams, E., Gao, Y., VanDolah, E., Paolisso, M., Bowers, H. A., and Roche, S. 2015. Hydraulics and barley straw (*Hordeum vulgare*) as effective treatment options for a cyanotoxin-impacted lake. L. MacKenzie (Ed.), *Proceedings of the 16th International Conference on Harmful Algae*, Cawthron Institute and International Society for the Study of Harmful Algae, Vawthron, NZ. pp. 218-221.

Sengco, M. R., Li, A., Tugend, K., Kulis, D., and Anderson, D. M. 2001. Removal of red-and brown-tide cells using clay flocculation. I. Laboratory culture experiments with *Gymnodinium breve* and *Aureococcus anophagefferens*. *Marine Ecology Progress Series* 210, 41–53.

Sengco, M. R., and Anderson, D. M. 2004. Controlling harmful algal blooms through clay flocculation1. *Journal of Eukaryotic Microbiology* 51, 169–172.

Seo, K. S., Lee, C. K., Park, Y. T., and Lee, Y. 2008. Effect of yellow clay on respiration and phytoplankton uptake of bivalves. *Fisheries Science* 74, 120-127.

Shumway, S. E., Frank, D. M., Ewart, L. M., and Ward, L. E. 2003. Effect of yellow loess on clearance rate in seven species of benthic, filter-feeding invertebrates. *Aquaculture Research* 34, 1391-1402.

Smayda, T. J. 2008. Complexity in the eutrophication–harmful algal bloom relationship, with comment on the importance of grazing. *Harmful Algae* 8, 140–151.

Smith, V. H. and Schindler, D. W. 2009. Eutrophication science: where do we go from here? *Trends in Ecology & Evolution* 24, 201–207.

Song, W., Teshiba, T., Rein, K., and O'Shea, K. E. 2005. Ultrasonically induced degradation and detoxification of microcystin-LR (cyanobacterial toxin). *Environmental Science and Technology* 39, 6300–6305.

Sunda, W. G., Granéli, E., and Gobler, C. J. 2006. Positive feedback and the development and persistence of ecosystem disruptive algal blooms. *Journal of Phycology* 42, 963–974.

Tang, Y. Z., and Gobler, C. J. 2011. The green macroalga, *Ulva lactuca*, inhibits the growth of seven common harmful algal bloom species via allelopathy. *Harmful Algae* 10, 480–488.

Tang, Y. Z., Kang, Y., Berry, D., and Gobler, C. J. 2014. The ability of the red macroalga, *Porphyra purpurea* (Rhodophyceae) to inhibit the proliferation of seven common harmful microalgae. *Journal of Applied Phycology* 27, 531–544.

Terlizzi, D. E., Ferrier, M. D., Armbrester, E. A., and Anlauf, K. A. 2002. Inhibition of dinoflagellate growth by extracts of barley straw (*Hordeum vulgare*). *Journal of Applied Phycology* 14, 275–280.

Tian, F., Zhou, J., Sun, Z., Cai, Z., Xu, N., An, M., and Duan, S. 2014. Inhibitory effects of Chinese traditional herbs and herb-modified clays on the growth of harmful algae, *Phaeocystis globosa* and *Prorocentrum donghaiense*. *Harmful Algae* 37, 153–159.

Turner, J. T. and Granéli, E. 2006. "Top-down" predation control on marine harmful algae, Granéli, E. and Turner, J.T. (Eds.), *Ecology of Harmful Algae*, Springer. pp. 355–366.

Verity, P. G., and Smetacek, V. 1996. Organism life cycles, predation, and the structure of marine pelagic ecosystems. *Marine Ecology Progress Series* 130, 277–293.

Walsh, J. J., Dieterle, D. A., Chen, F. R., Lenes, J. M., Maslowski, W., Cassano, J. J., Whitledge, T. E., Stockwell, D., Flint, M., and Sukhanova, I. N. 2011. Trophic cascades and future harmful algal blooms within ice-free Arctic Seas north of Bering Strait: A simulation analysis. *Progress in Oceanography* 91, 312–343.

Wang, L., Liang, W., Yu, J., Liang, Z., Ruan, L., and Zhang, Y. 2013. Flocculation of *Microcystis aeruginosa* using modified larch tannin. *Environmental Science and Technology* 47, 5771–5777.

Wu, X., Joyce, E. M., and Mason, T. J. 2011. The effects of ultrasound on cyanobacteria. *Harmful Algae* 10, 738–743.

Xiao, X., Huang, H., Ge, Z., Rounge, T. B., Shi, J., Xu, X., Li, R., and Chen, Y. 2013. A pair of chiral flavonolignans as novel anti-cyanobacterial allelochemicals derived from barley straw (*Hordeum vulgare*): Characterization and comparison of their anti-cyanobacterial activities. *Environmental Microbiology* doi:10.1111/1462-2920.12226.

Zamyadi, A., MacLeod, S. L., Fan, Y., McQuaid, N., Dorner, S., Sauvé, S., and Prévost, M. 2012. Toxic cyanobacterial breakthrough and accumulation in a drinking water plant: A monitoring and treatment challenge. *Water Research* 46, 1511–1523.

Zhang, G., Zhang, P., and Fan, M. 2009. Ultrasound-enhanced coagulation for *Microcystis aeruginosa* removal. *Ultrasonics Sonochemistry* 16, 334–338.

Zillén, L., Conley, D. J., Andrén, T., Andrén, E., and Björck, S. 2008. Past occurrences of hypoxia in the Baltic Sea and the role of climate variability, environmental change and human impact. *Earth Science Reviews* 91, 77–92.

Zou, H., Pan, G., Chen, H., and Yuan, X. 2006. Removal of cyanobacteria blooms in Taihu Lake using local soils. II. Effective removal of *Microcystis aeruginosa* using local soils and sediments modified by chitosan. *Environmental Pollution* 141, 201-205.