Background

Blue-green algae (i.e., cyanobacteria) (Figure 1) are the most important freshwater algae associated with the degradation of water quality in lakes and reservoirs. Cyanobacterial toxins, including the hepatotoxin microcystin, which is prevalent in waterbodies across the United States (USEPA 2009), have been implicated in the poisoning of drinking water supplies, food webs, pets, and humans. Furthermore, cyanobacteria are often responsible for taste and odor issues (i.e., off-flavor compounds such as 2-methylisoborneol (MIB) and geosmin) in drinking water and aquaculture-raised organisms. Therefore, cyanotoxins and off-flavor compounds are a serious concern for a variety of water users and industries ranging from water utilities, livestock production (Wilson et al. 2014), and zoos (Doster et al. 2014) (Figure 2A), to aquaculture and subsistence fisheries (Figure 2B). Recent headlines in the national media (e.g., Lake Erie – drinking water in Toledo, OH; nitrogen pollution litigation – Iowa water utilities) have highlighted the severity of these issues and have made the general public more aware of their access to high quality freshwater resources. The purpose of this article is two-fold: (1) to highlight some readily available methods for understanding cyanobacteria and associated water quality issues (including a rapid, pigment-based method developed by our lab to easily quantify cyanobacterial biomass) and (2) to briefly discuss ecological interactions related to these issues, with a focus on several experiments that we have conducted in aquaculture ponds at Auburn University.

Cyanobacterial detection

Given the economic, human health, and ecological concerns associated with harmful blooms of freshwater cyanobacteria (i.e., HABs), there is considerable interest by water resource managers in tools that can rapidly (and accurately) detect risks associated with cyanobacterial toxins and/or off-flavors. While there are several basic tools that can be used to aid in these risk assessments, it is important to understand what each can (and cannot) tell you about your system. First and foremost, Secchi disks (Figure 3) have been used since the 19th century to measure water transparency and can be used to examine trends in algal abundance and productivity over the course of a growing season. However, one limitation of the Secchi disk is that it is difficult to distinguish between the effects of algal abundance vs. sediments and other sources of turbidity in ponds.

As algae are important primary producers, they contain a variety of pigments including chlorophylls (all algae and plants) and phycobilins (e.g., phycocyanin – cyanobacteria) to capture light for photosynthesis. Chlorophyll a is a widely used estimate of algal biomass, and numerous techniques are available for measuring chlorophyll a (e.g., HPLC, spectrophotometry, fluorometry). Similar to chlorophyll a as an estimate of algal biomass, phycocyanin (the blue pigment present in cyanobacteria) can be used to quickly estimate cyanobacterial biomass (Kasinak et al. 2014). Phycocyanin is a fairly good surrogate for cyanobacterial biomass both within a pond and across ponds that...
Figure 2. (A) Aquaculture ponds, (B) zoo watering moats, and ponds providing water for livestock often contain high concentrations of nutrients, and are often affected by cyanobacterial blooms and hypoxia, especially during the summer months. Water resource managers and water users need to be aware of the risks posed by water sources contaminated with cyanobacterial toxins.

vary in algal species composition and productivity. Each of the above methods can be used to determine the presence of algal blooms. However, what is essential for management is to distinguish between potentially toxic (or off-flavor causing) algal blooms and blooms of relatively benign species. The term blue-green algal (cyanobacteria) bloom often receives a negative connotation due to perceived risks of toxins and off-flavors. However, only certain genera/species (and sometimes genotypes within a species) are potent producers of these compounds (e.g., Anabaena, Cylindrospermopsis, Microcystis, Lyngbya, Oscillatoria/

managing algal community composition (and associated cyanotoxins) given that nitrogen-fixing cyanobacterial species should dominate under relatively low N:P. However, nitrogen-fixing cyanobacteria are predicted to be outcompeted by non-nitrogen fixing species at higher N:P.

We tested the hypothesis that nitrogen-fixing cyanobacteria should dominate under low nitrogen-to-phosphorus (N:P) (7:1, by atoms) but are outcompeted by non-nitrogen fixing species under high N:P (122:1, by atoms) using a limnocorral experiment in a eutrophic pond with a diverse algal community (Figure 4). Initially, the algal community was dominated by a mixture of chlorophytes (i.e., green algae) and cyanobacteria (including Anabaena, Cylindrospermopsis, and Microcystis species). In contrast to predictions, the algal community in all N:P treatments became entirely composed of the nitrogen-fixing cyanobacterium, Cylindrospermopsis raciborskii by the conclusion of the study. Furthermore, levels of the cyanobacterial neurotoxin, saxitoxin, were actually enhanced under the two highest N:P conditions (Chislock et al. 2014).

Another alternative for improving water quality in nutrient-rich systems has been biomanipulation: the manipulation of higher trophic levels (adding piscivorous fishes that eat other fish or removing planktivorous fish) to increase the size, abundance, and grazing pressure of herbivorous zooplankton to reduce algal abundance. While large-bodied zooplankton such as Daphnia (Figure 5A) are well-known to dramatically reduce the abundance of algae in lakes, whether they can ultimately control harmful blooms of cyanobacteria is a topic of considerable debate. Recent mesocosm research in two hypereutrophic aquaculture ponds (S9 and S10), with dense blooms of Microcystis, has demonstrated that populations of Daphnia can have large effects on reducing algal abundance, even in systems with abundant toxic cyanobacteria (Figure 5B). Management of Daphnia populations capable of consuming toxic cyanobacteria may provide a potential sustainable alternative for the control of freshwater HABs in systems where planktivorous
fish populations can be controlled. While there is clearly no “silver bullet” for detecting and controlling toxic cyanobacterial blooms, management programs focused on prevention and early detection/identification are recommended. While the acute effects of cyanotoxins are well-studied, the direct and indirect effects of long-term, chronic exposure are less studied. Awareness of these potential effects is important, and future studies of the chronic effects of blue-green algal secondary metabolites are necessary. Fortunately, there are a wide variety of tools and management options available to reduce these risks.

References


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Figure 4. Limnocorrals used in a eutrophic pond to test the hypothesis that nitrogen-fixing cyanobacteria should dominate under low nitrogen-to-phosphorus ratios.

Figure 5. (A) The “water flea” *Daphnia* can exert considerable grazing pressure on phytoplankton and cyanobacteria, associated cyanotoxins, and overall water quality. (B) Results of mesocosm experiment evaluating the effects of *Daphnia pulex* on phytoplankton abundance (measured as chlorophyll a). Closed symbols represent no *Daphnia* controls, and open symbols represent enclosures for the *Daphnia* treatment, for ponds S9 (circles) and S10 (triangles).