A Deeper Look at HABs

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Cyanobacteria that have the potential to cause HABs can be found in a diverse array of aquatic systems, from the highly visible planktonic blooms to less conspicuous benthic mats. The potential risks and detrimental effects of planktonic blooms have been well studied in recent years. Most alert-level framework monitoring programs and guidelines are based on planktonic cyanobacteria and their associated toxins (EPA).

To date, benthic cyanobacteria that grow on substrates in aquatic ecosystems have been overlooked in risk assessments. Toxin production in benthic cyanobacteria mats has been documented worldwide and linked to dog and livestock deaths in various countries. Despite the potential detrimental effects they present, benthic populations have been largely overlooked because they are less visible and therefore, more difficult to detect. This article aims to bring awareness to those who manage aquatic systems to look deeper, beyond the water's surface, when evaluating and responding to HABs in their systems.

Benthic communities in lakes and rivers

The term "periphyton" refers to the complex communities of phototrophs attached to submerged surfaces in aquatic ecosystems, which can include benthic cyanobacteria. Environmental controls that can influence the periphytic communities and the benthic cyanobacteria within include physical disturbances, light, temperature, nutrients, and grazing. The influence each environmental factor has on the communities can vary and depends on the habitat.

Benthic cyanobacteria have been found to inhabit all ecological niches within the riverine system, from slow-moving backwater locations to swift water riffle and cascade habitats. In some instances, a river reach can contain several different habitats containing dozens of cyanobacteria species with the potential to release several cyanotoxins at the same time. Periods of stable flow, temperature, and light availability provide an environment conducive to the proliferation of periphytic communities that may lead to benthic HABs.

Benthic cyanobacteria in lakes are commonly found in the periphyton of shallow near-shore waters or littoral zone where light penetrates to sediments. They frequently form mat communities that exhibit complex ecological interactions among the diverse assemblage of organisms. The spatial distribution of cyanobacteria mats in lakes is largely dependent on light availability, which in turn is affected by lake size, morphometry, and water clarity. The taxonomic composition of these mats is also influenced by light availbility; for example some potentially harmful genera of cyanobacteria, like *Phormidium* spp., can be found under low-light conditions due to the presence of phycobilins, photosynthetic pigments that can capture longer wavelengths of light.

Planktonic blooms, common in eutrophic lakes, can reduce water clarity and limit light penetration to the benthos. Water clarity in oligotrophic lakes is high compared to eutrophic lakes and favors deeper growth of potentially toxigenic cyanobacteria mats. Lake managers should not assume that oligotrophic lakes with seemingly high water quality cannot be a source of HABs.

Toxins within

Benthic cyanobacteria are capable of producing several cyanotoxins such as hepatotoxins, neurotoxins, and dermatoxins. These toxins are known to contribute to human and animal illness and, in the worst case scenario, death. Reports of benthic HABs contributing to animal poisonings have increased in recent years. In Northern California's rivers, several dog deaths have been attributed to benthic cyanotoxin poisonings since 2000. Due to the inconspicuous nature of benthic cyanobacteria, there has been a lack of research into the health risks associated with benthic cyanobacteria. The ability to quantify the health risks requires new research and the development of new tools for risk assessment.

Despite these challenges, there are countries (e.g., Scotland, New Zealand, Cuba) that are responding to these needs. Periphytic communities are complex, composed of numerous organisms and substrates. They are also less accessible than the planktonic community and, therefore, more difficult to observe and sample.

Only two countries, Cuba and New Zealand, have introduced guidelines for monitoring benthic cyanobacteria. In both cases, the action triggers are based upon percent coverage of the benthos by potentially toxigenic cyanobacteria species. This type of guidance requires the determination of the toxigenic potential of cyanobacteria assemblages, which can be difficult, requiring time-consuming microscopy or DNA analysis and potentially cost-prohibitive toxin analysis.

Benthic cyanobacteria have been shown to produce toxins that are harmful to humans, animals, and aquatic life. It is important that water managers work together with regulators to develop protocols and establish water quality criteria that protects the public, animals and aquatic life. There are several documented cyanotoxins released by benthic cyanobacteria, but draft water quality criteria developed by the EPA for recreational water and health advisories for drinking water focus on just microcystin and cylindrospermopsin (EPA Document Number: 822-P-16-002). These criteria were developed in response to research conducted on planktonic species. The lack of research into the various other toxins produced by benthic species and potential associated health risks leaves individual States to determine criteria on their own or to ignore the risks associated with exposure to these toxins either singly or synergistically.

Recent research (Anderson et al. 2018) suggests that cyanotoxins may have a deleterious effect on macroinvertebrates. Anderson found that anatoxin (a neurotoxin) can be lethal to invertebrates in the laboratory setting at environmentally relevant concentrations. This can have far-reaching management implications by interrupting the base of the aquatic food web or altering the way we evaluate water quality conditions or impairments when macroinvertebrate population data may be the criteria of determination.

Sampling benthic mats

Many of the tools utilized in planktonic toxin detection and analysis can be employed for benthic cyanobacteria with some modification. These include the development and calibration of visual cues for determining benthic species present and bloom size, and toxin testing of both ambient water and benthic mats to evaluate the overall risk. In addition, passive samplers, like solid phase adsorption toxin tracking (SPATT) samplers, may be useful in determining the presence of low-level cyanotoxin concentrations and in documenting seasonal trends.

Unless mats are detaching from the substrate and floating to the surface, benthic cyanobacteria can be difficult to detect. Sediment samplers such as the PONAR grab sampler allows for the recovery of soft sediment benthic material, but this sampling method is like taking a shot in the dark when trying to find benthic mats. Scuba divers can be an effective means of surveying and monitoring benthic cyanobacterial mats (Figure 1). The divers can collect grab samples and make observations on percent coverage of potentially toxigenic mats.

The location and spatial extent of rivers can pose a hindrance to the detection and evaluation of benthic cyanobacteria mats. Whereas a lake is a contained body of water with a finite location and often complete accessibility, rivers and streams often flow through private lands or other areas that may be otherwise inaccessible. In a single watershed, this may account for hundreds of miles of habitat in which toxic benthic HABs can proliferate unnoticed, affecting water quality conditions for many miles downstream of a benthic bloom. Limitations such as this may require the development of a susceptibility framework to determine environmental factors and conditions that may be conducive to bloom development.

Guidelines generally lacking

In general, HABs are increasing in spatial extent, frequency, and severity as well as temporally as blooms persist throughout the year. It is critical that water managers have good guidance to aid them in protecting the public from HABs, whether planktonic or benthic. While guidance regarding planktonic HABs exists, it is lacking for benthic HABs. Additionally, benthic cyanobacteria have been linked to numerous animal deaths worldwide, increasing pressure and need for the development of such guidance. Unfortunately, at the time of this publication, no federal or state guidelines, water quality criteria or regulations exist to provide recommendations to water managers (e.g., government agencies, local authorities, drinking water suppliers) regarding the appropriate response to or management of benthic HABs.

A few countries (e.g., New Zealand and Cuba) have developed guidelines for mitigating human risks associated with benthic cyanobacteria. Guidelines in New Zealand have been developed for both recreation and drinking water supplies. These guidelines include recommendations on agency roles and responsibilities, a monitoring and action plan and sampling advice. The guidelines are intended to help agencies develop monitoring protocols and encourage a consistent national approach to managing

Figure 1. Metropolitan Water District of Southern California SCUBA diver Kelly Lorenz collecting benthic samples.

risk in recreational water. The most advanced action level (red mode) is triggered when there is greater than fifty percent coverage by potentially toxigenic cyanobacteria or when potentially toxigenic cyanobacteria are detaching from the substrate. Actions taken during the red mode include notifying the public health unit, testing for cyanotoxins, and notifying the public to the health risks.

Establishing water quality regulatory guidelines for benthic cyanobacterial toxins is challenging for several reasons. These reasons include the variability of toxin production by a given taxon, limited understanding of the environmental triggers of toxin production, and the diversity of toxigenic cyanobacterial taxa. Compounding these challenges is the fact that cyanotoxins produced by benthic cyanobacteria can travel far downstream of their source. Additionally, benthic algal mats can become buoyant when dislodged, increasing the risk of accidental ingestion as the liberated mats float in the water column or collect along the shoreline (Figure 2).

The importance of integrating research on benthic HABs into models that will aid predictions related to the occurrence of HABs cannot be understated given the potential risks they pose. The development of guidance and effective management approaches is needed in North America. Collaborative workgroups like the international benthic HABs discussion group, coordinated by Christine Joab, Jade L. Young, Margaret Spoo-Chupka, and Lesley D'Anglada, https://www.epa.gov/nutrient-policy-data/benthic-habs-discussion-group, aim to facilitate the sharing of data, experiences and lessons learned from both an academic and water-management point of view. These collaborative workgroups and partnerships will become more important as global warming and anthropogenic activities are likely to increase in the occurrence of HABs in the future.

Figure 2. Benthic mat of anatoxin-producing cyanobacteria (Phormidium sp.) *in the Eel River.*

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