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Invited Editorial

IN SOME PLACES, IN SOME CASES, AND AT SOME TIMES, HARMFUL ALGAL BLOOMS ARE THE GREATEST THREAT TO INLAND WATER QUALITY

The summer season brings surges in outdoor recreational activities each year, with increased visitor attendance to National Parks and protected areas and annual peaks in fishing and swimming in many rivers, lakes, and beaches. The warmer months routinely bring field sampling campaigns for environmental scientists, time for academics to catch up following final exams, and vacations with family or friends. Unfortunately, headlines in North America during summer 2016 reminded us that the incidence of harmful algal blooms (HABs), particularly of cyanobacteria, also tends to increase in summer months and cause impairment to inland recreational waterbodies. In addition to the highly publicized issues in Lake Erie and the HAB event stretching hundreds of miles in the Ohio River, other inland water bodies were impacted by HABs from the east to west coasts of the United States. A state of emergency was declared in 4 Florida counties, Utah closed access to Utah Lake, and California responded to multiple HAB events from the southern to northern parts of the state. Similarly, HABs severely impacted water quality of inland systems in many other regions of the world [1]

These highly publicized examples of HAB impacts on water resources highlight the need for robust data for HAB toxins from environmental surveillance and monitoring programs to identify the prevalence and severity of such problems and thus achieve management goals of reducing HAB risks to public health and to the environment. These programs in turn are critical to ensure effectiveness of management efforts and to support decision-making by resource managers, particularly when HAB events affect public health and economies buoyed by tourism. Earlier in 2016 [1] we considered a seemingly simple question: Are HABs becoming the greatest threat to inland water quality? We specifically identified research needs associated with global environmental assessment and management of HAB impacts to water quality. For example, although monitoring activities for HABs in inland waters are ongoing in a number of locations [2], these activities are not occurring in all states, tribes, and territories of the United States and another countries; are haphazardly coordinated; and almost never evaluate the full suite of potential HAB impacts to terrestrial and aquatic habitats. In fact, monitoring activities, if they occur, are routinely limited to microscope-based evaluation of some algae or chlorophyll *a* as a result of limited resources available for more sophisticated instrumental analyses, training programs for practitioners, and environmental monitoring in general. Such microscopic observations cannot identify the presence of toxins during field assessments, if they are performed, and rarely examine picoplankton; then they are simply compared to HAB thresholds for algal cell density (e.g., from the World Health Organization [3]). Other efforts employ molecular tools (e.g., quantitative polymerase chain reaction) and remote sensing to identify water bodies more likely to present risks to surface waters.

Microscope and satellite-based (including light detection and ranging, or LIDAR) monitoring efforts are critical and must be greatly expanded; however, these approaches fail to determine whether algal toxins are present and subsequently increase the possibility that an impaired water quality situation will be missed that would compromise aquatic organisms and associated aquatic life uses, recreational and commercial/sport fishing, and swimming activities. For example, the biologically active chemicals produced by different *Cylindrospermospis raciborskii* morphotypes, which vary across the Americas and environmental gradients, are generally not well understood [4]. Unfortunately, water quality criteria do not exist for algal toxins in many countries, including the United States, although some efforts are underway to derive aquatic species sensitivity distributions for some of these toxins and the US Environmental Protection Agency (USEPA) is developing recreational ambient water quality criteria for some cyanotoxins. Following a review by the US Government Accountability Office in 2014 [5], the USEPA's Unregulated Contaminant Monitoring Rule (UCMR 4) for Public Water Systems was revised to include 10 toxins produced by various cyanobacteria [6]. Monitoring efforts like this are beneficial for understanding the extent of algal toxins present and will proceed to examine select potable water systems over the next few years. Similar efforts are absent in most of the world, particularly in developing countries.

In the United States, parallel federal and state efforts to determine the extent of exposure to HAB toxins during recreational activities, however, are not consistently occurring, although some States have implemented monitoring programs. For example, many lakes and reservoirs have designated swimming areas where public use increases during summer months, when cyanobacterial blooms are more likely to occur. Whereas these areas may be monitored for bacterial water quality to assure swimmability, they are not being evaluated for HAB species or exposure to their toxins. Although federal and state programs have been developed to examine exposure to HABs in marine and coastal beaches, monitoring efforts for algal species or the toxins they produce are limited in freshwater swimming areas across states, tribes, and territories. Even more challenging is determining the extent to which exposure occurs during recreational contact in lakes and ponds on private lands, or in public or private swimming pools where local environmental health services are differentially delivered, because here again surveillance efforts for algal toxins are routinely absent. In the United States, the Centers for Disease Control and Prevention recently released the Model Aquatic Health Code (MAHC), which provides an excellent resource to improve the safety of swimming activities [7]. However, the MAHC does not yet consider algal toxins in swimming pools and was not

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developed to specifically address swimming areas in lakes and reservoirs.

Similarly, the extent to which fisheries and public health may be affected by HAB toxins from recreational and commercial/sport fishing in inland waters is not well understood. Although governmental efforts have increased to examine select HAB toxins in marine fish and shellfish in some countries, determination of algal toxins in edible fish and shellfish from freshwater systems does not exist in most states, tribes, and territories. Evaluation of ecological and human health risks from exposure to HAB toxins across trophic levels and through recreational and commercial fishing in lakes and reservoirs is warranted, particularly during seasons when various HABs occur in inland waters. Further, food safety evaluation of HAB toxins and other emerging contaminants in agricultural products remains a challenge because of funding limitations and the changing universe of anthropogenic chemicals in commerce. Herein, HAB risks to freshwater aquaculture and crops irrigated with surface waters affected by algal toxins deserve attention for food crops, particularly when non-traditional waters (e.g., reused wastewater) are employed for agriculture.

In the United States, limited state and federal funding has been provided for environmental monitoring, and basic and applied research on inland HABs, compared with extramural resources committed to understand, assess, and manage toxicological implications of conventional chemical contaminants to public health and the environment. As one example, the National Institutes of Health (NIH), with an annual budget of over $32 billion USD [8], is the most important extramural supporter of basic research for public health and the biomedical sciences. A recent search of NIH projects with the key words "algae," "algal," or "HAB" yielded only 107 results out of approximately 84 000 active NIH research grants [9]. Of these grants, most awards are not focused algal toxins toxicity. Those projects that are conducting research on the HAB topic primarily target marine systems. In fact, the few studies (totaling $916,353) examining freshwater HABs represent a small percentage ($< 0.003\%$) of the annual NIH budget. Similar observations apply for limited funding for environmental toxicology and chemistry of freshwater algal toxins research from the National Science Foundation. Funding across other federal and state agencies, with more modest research budgets, are comparatively limited for inland HABs. In 2014, President Obama signed the Harmful Algal Bloom and Hypoxia Research and Control Amendments Act (HABHRCA) to law, yet this has not received financial support from the US Congress. The extent to which funding authorization for HABHRCA will occur or the partitioning of such potential resources to address HABs among states or regions in inland lakes and reservoirs beyond the Great Lakes is unknown. However, 47 bipartisan members of the US Congress recently sent a letter to President Trump requesting "robust funding" for HAB science and research [10].

Despite such funding uncertainties and limited resources, the USEPA, the National Oceanic and Atmospheric Administration, and other US agencies are attempting to increase communication among stakeholders. Although extramural funding support for basic science of HAB species has been lacking for some time, the lack of effort on this issue likely also results from the contemporary nature of HABs—we simply must endeavor to catch up with a rapidly evolving phenomenon. For some time, it was thought by some that the worst eutrophication problems in the United States had been dealt with through nutrient management under the Clean Water Act [11]; however, implementation and enforcement of nutrient criteria remains absent in most states, tribes, and territories. In developing countries, inland HABs continue to present even more palpable challenges when environmental management efforts are comparatively limited or absent [1]. But here again, the issue of HABs has become publically visible over the last decade, in part because of some very recent events in North America [12] and because multi-stressor responses from climate change combined with anthropogenic contaminants including nutrients from land and atmospheric sources are now being observed [13].

Current federal extramural funding levels in the United States suggest that inland HABs are not a top research priority; whether HAB research for freshwater systems should be prioritized for federal funding is debatable. Yet, we've been recently reminded by events in California, Florida, Ohio, and Utah—states with a total population of 73.2 million people representing almost 23% of the USA population—that in some places, in some cases, and at some times, HABs are clearly the most important threat for inland water quality impairment, even in developed countries. Clearly, increased development of predictive models associated with algal toxins production; basic and applied environmental chemistry and toxicology research on toxins to define risks to aquatic life and human health; and global implementation of monitoring, assessment, and management strategies to address HAB toxins are necessary for inland waters.

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REFERENCES

1. Brooks BW, Lazorchak JM, Howard MDA, Johnson MV, Morton SL, Perkins DAK, Reavie ED, Scott GI, Smith SA, Steevens JA. 2016. Are harmful algal blooms becoming the greatest inland water quality threat to public health and aquatic ecosystems? *Environ Toxicol Chem* 35:6–13.
2. US Environmental Protection Agency. 2016. States with Freshwater HABs Monitoring Programs. [cited 2017 March 29]. Available from: https://www.epa.gov/nutrient-policy-data/states-freshwater-habs-monitoring-programs
3. World Health Organization. 2003. Guidelines for Safe Recreational Water Environments, Vol 1: Coastal and Fresh Waters. [cited 2017 March 29]. Available from: http://www.who.int/water_sanitation_health/publications/srwe1/en/.
4. Lind O, Davalos-Lind L, Lopez C, Lopez M, Dyble Bressie J. 2016. Seasonal morphological variability in an in situ Cyanobacteria monoculture: Example from a persistent Cylindrospermospsis bloom in Lake Catemaco, Veracruz, Mexico. *J Limnol* 75:66–80.
5. Government Accountability Office. 2014. Drinking Water: EPA has improved its Unregulated Contaminant Monitoring program, but additional action is needed. Report to Congressional Requesters. GAO-14-103. [cited 2017 March 29]. Available from: http://www.gao.gov/assets/670/660067.pdf
6. US Environmental Protection Agency. 2015. Revisions to the Unregulated Contaminant Monitoring Rule (UCMR 4) for public water systems and announcement of a public meeting. 40 CFR Part 121. Fed Reg 80:76897–76923. [cited 2017 March 29]. Available from: https://federalregister.gov/a/2015-30824
7. Centers for Disease Control and Prevention. 2016. The Model Aquatic Health Code (MAHC): An All-inclusive Model Public Swimming Pool and Spa Code. [cited 2017 March 29]. Available from: http://www.cdc.gov/mahc
8. National Institutes of Health. 2017. Budget. [cited 2017 March 29]. Available from: https://www.nih.gov/about-nih/what-we-do/budget
9. US Department of Health and Human Services. 2017. NIH Research Portfolio Online Report Tools (RePORT). [cited 2017 March 29]. Available from: projectreporter.nih.gov
10. US Congress. 2017. Algal bloom research letter to President-elect Donald Trump. [cited 2017 March 29]. Available from: http://auburnpub.com/algal-bloom-research-letter-to-president-elect-donald-trump/pdf_82eb8feb-9a04-58d0-abea-f382be777b55.html
11. Andreen WL. 2004. Water quality today—Has the Clean Water Act been a success? *Ala L Rev* 55:537–593.
12. Michalak AM, Anderson EJ, Beletsky D, Boland S, Bosch NS, Bridgeman TB, Chaffin JD, Cho K, Confesor R, Daloğlu I, DePinto JV. 2013. Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. *Proc Nat Acad Sci U S A* 110:6448–6452.
13. Taranu ZE, Gregory-Eaves I, Leavitt PR, Bunting L, Buchaca T, Catalan J, Domaizon I, Guilizzoni P, Lami A, McGowan S, Moorhouse H. 2015. Acceleration of cyanobacterial dominance in north temperate-subarctic lakes during the Anthropocene. *Ecol Lett* 18:375–384.