Environmental Science & Technology

Viewpoint

pubs.acs.org/est

Climate Change at a Crossroad for Control of Harmful Algal Blooms

Karl E. Havens*,† and Hans W. Paerl‡

†University of Florida, Institute of Food and Agricultural Sciences and Florida Sea Grant, Gainesville, Florida 32611, United States

‡Instutute of Marine Sciences, University of North Carolina—Chapel Hill, Morehead City, North Carolina 28557, United States

Because of climate change, we are at a crossroad with regard to control of harmful algal blooms, and must aggressively tackle the problem before it becomes so difficult that in many ecosystems we are faced with the option of allowing these micro-organisms to go unchecked.

Many lakes and estuaries around the world, which provide drinking water for millions of people, and support a myriad of ecosystem services, already have toxic, food web-altering, hypoxia-generating blooms of cyanobacteria. The occurrence is driven by high inputs of nitrogen (N) and phosphorus (P) to the ecosystems from human sources.[1] To reduce the frequency and intensity of noxious and sometimes toxic cyanobacteria blooms, sizable reductions of both N and P are urgently needed.[2] Yet, Climate change will severely affect our ability to control blooms, and in some cases could make it near impossible.

The longer we wait to take actions to control blooms, and the more time that climate change has to exert synergistic effects with nutrients,[3] the less likely it becomes that controls will be attained. A climate-driven change in water temperature, including both a general warming and more extremes, can modify phytoplankton community by favoring bloom-forming cyanobacteria, which are able to take advantage of warmer conditions and increasing hydrologic extremes (drier droughts, increased storm activity and greater episodic nutrient loads).[3] Further, rising temperatures are expected to increase the rate of mineralization of soil nutrients and favor more deoxygenation at the lake sediment surface, so that more nutrients are released into the water column in summer.[4] This means that for the many lakes and estuaries in agricultural watersheds, with legacy P in their soils and sediments, conditions could become much worse—again, increasing the urgency for nutrient input reductions.

Hence, climate change poses a serious, additional challenge to formulating nutrient-based bloom thresholds as part of a strategy for controlling blooms. With warmer water, achieving a desired low level of blooms in the future will require greater reductions in the inputs of N and P to lakes than is needed under the current climate conditions. Yet to date, climate change has not been factored into mitigation strategies for algal blooms.

Complicating the problem is the fact that some lakes that are not currently being targeted for nutrient reductions, because of the absence of blooms, could develop dominance by cyanobacteria and experience blooms in a warmer future, even without a further rise in nutrient inputs. As an example, using data from 143 lakes along a latitudinal gradient from Europe to South America, at lower levels of total N (TN), the frequency of occurrence of cyanobacteria is below 30% over a wide range of water temperatures, and it rises very slowly. In contrast, at a high concentration of TN, there is a rapid and nonlinear increase in cyanobacteria frequency with temperature—indicating not only a change in the composition of phytoplankton, but one that happens in a discontinuous and therefore unpredictable manner.[5] This makes anticipating a bloom threshold, and controlling blooms much more challenging.

Conditions may sometimes become so unwieldy that no currently used management strategy can handle the synergistic effects of human nutrient enrichment and warming. Nutrient reduction strategies may be overwhelmed by climate change impacts on these ecosystems, unless costly and aggressive approaches are employed. Therefore, it is our view that the U.S. Environmental Protection Agency, the EU, and other bodies responsible for water quality of lakes and estuaries must: (1) develop a better understanding about how those ecosystems will respond to warming, and (2) implement nutrient reduction standards now that will be effective in achieving desired algal bloom control goals in the future. This needs to include remediation of in-lake sources of P and N where they have the ability to influence the water column, and more aggressive strategies for dealing with legacy nutrients on the landscape. This is a major change from the current overarching principle of reducing nutrient levels to address contemporary levels of blooms.

A major decision that resource managers must address when spending public or private funds to mitigate blooms is to

Received: August 17, 2015

DOI: 10.1021/acs.est.5b03990
Environ. Sci. Technol. XXXX, XXX, XXX−XXX

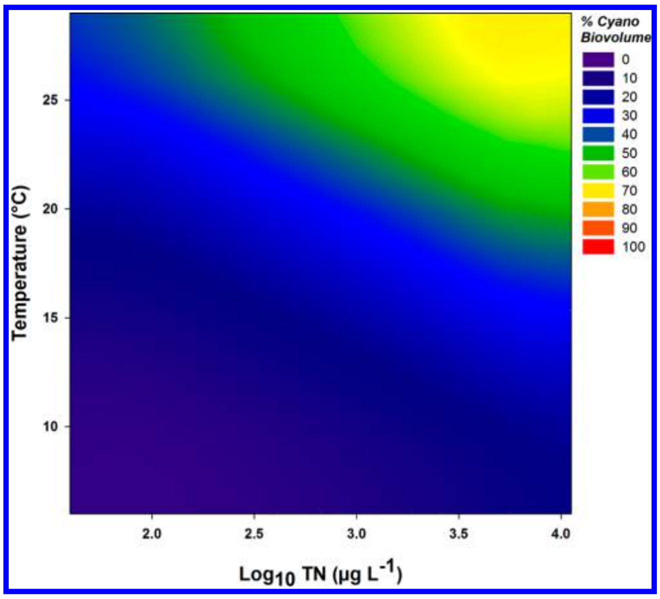

Figure 1. Relationship between percent occurrence of cyanobacteria in total phytoplankton biomass with water temperature and total N concentration. This figure was developed from data provided to the authors by Sarian Kosten. Details on the sampling methods used to collect the TN and temperature data may be found in Kosten et al. 2011.[5]

determine whether there is a realistic chance that a reduction can be achieved. Over 2 billion years ago, cyanobacteria created the environmental conditions that allowed biological diversification and ultimately the establishment of mankind. Perhaps they will reclaim waters that we failed to protect during our short time on Earth, unless we act quickly to reduce nutrient loads before the synergistic effects of climate change make it exceedingly difficult.

AUTHOR INFORMATION

Corresponding Author

*Phone: +352-392-5870; e-mail: khavens@ufl.edu.

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

H.P. was supported by U.S. National Science Foundation projects DEB 9815495, CBET 0826819, 1230543, and Dimensions of Biodiversity 1240851.

REFERENCES

(1) Conley, D. J.; Paerl, H. W.; Howarth, R. W.; Boesch, D. F.; Seitzinger, S. P.; Havens, K. E.; Lancelot, C.; Likens, G. E. controlling eutrophication: nitrogen and phosphorus. *Science* **2009**, *323*, 1014−1015.

(2) Grantz, E. M.; Haggard, B. E.; Scott, J. T. stoichiometric imbalance in rates of nitrogen and phosphorus retention, storage, and recycling can perpetuate nitrogen deficiency in highly-productive reservoirs. *Limnol. Oceanogr.* **2014**, *59*, 2203−2216.

(3) Moss, B.; Kosten, S.; Meerhoff, M.; Battarbee, R. W.; Jeppesen, E.; Mazzeo, N.; Havens, K.; Lacerot, G.; Liu, Z.; De Meester, L.; Paerl, H.; Scheffer, M. allied attack: climate change and eutrophication. *Inland Waters* **2011**, *1*, 101−105.

(4) Kosten, S.; Huszar, V. L. M.; Bécares, E.; Costs, L. S.; van Donk, E.; Hansson, L. A.; Jeppesen, E.; Kruk, C.; Lacerot, G.; Mazzeo, N.; De Meester, L.; Moss, B.; Lürling, M.; Nõges, T.; Romo, S.; Scheffer, M. warmer climates boost cyanobacterial dominance in shallow lakes. *Global Change Biology* **2012**, *18*, 118−126.

(5) Paerl, H. W.; Otten, T. G. harmful cyanobacterial blooms: causes, consequences and controls. *Microb. Ecol.* **2013**, *65*, 995−1010.

DOI: 10.1021/acs.est.5b03990
Environ. Sci. Technol. XXXX, XXX, XXX−XXX