Cyanobacterial Harmful Algal Blooms

ADVANCES IN EXPERIMENTAL MEDICINE AND BIOLOGY

H. Kenneth Hudnell
Editor

Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs

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Interagency ISOC-HAB Symposium Introduction

This symposium was held to assess the state-of-the-science and identify research needed to address the increasing risks posed by freshwater harmful algal blooms to human health and ecosystem sustainability. Information obtained through the symposium will help form the scientific basis for developing and implementing strategies to reduce these risks.

All chapters in this book are based on platform sessions or draft workgroup reports that were presented at ISOC-HAB. All chapters were completed after the conclusion of ISOC-HAB. Each chapter was critically reviewed by at least two peers with expertise in the subject matter, revised based on those reviews, and reviewed by the editor before being accepted for publication.

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Chapter 1: An Overview of the Interagency, International Symposium on Cyanobacterial Harmful Algal Blooms (ISOC-HAB): Advancing the Scientific Understanding of Freshwater Harmful Algal Blooms

H Kenneth Hudnell, Quay Dortch, Harold Zenick

Abstract

There is growing evidence that the spatial and temporal incidence of harmful algal blooms is increasing, posing potential risks to human health and ecosystem sustainability. Currently there are no US Federal guidelines, Water Quality Criteria and Standards, or regulations concerning the management of harmful algal blooms. Algal blooms in freshwater are predominantly cyanobacteria, some of which produce highly potent cyanotoxins. The US Congress mandated a Scientific Assessment of Freshwater Harmful Algal Blooms in the 2004 reauthorization of the Harmful Algal Blooms and Hypoxia Research and Control Act. To further the scientific understanding of freshwater harmful algal blooms, the US Environmental Protection Agency (EPA) established an interagency committee to organize the Interagency, International Symposium on Cyanobacterial Harmful Algal Blooms (ISOC-HAB). A theoretical framework to define scientific issues and a systems approach to implement the assessment and management of cyanobacterial harmful algal blooms were developed as organizing themes for the symposium. Seven major topic areas and 23 subtopics were addressed in Workgroups and platform sessions during the symposium. The primary charge given to platform presenters was to describe the state of the science in the subtopic areas, whereas the Workgroups were charged with identifying research that could be accomplished in the short- and long-term to reduce scientific uncertainties. The proceedings of the symposium, published in this monograph, are intended to inform policy determinations and the mandated Scientific Assessment by describing the scien-

tific knowledge and areas of uncertainty concerning freshwater harmful algal blooms.

Background

There is growing concurrence among scientists, risk assessors, and risk managers that the incidence of harmful algal blooms (HABs) is increasing in spatial and temporal extent in the US and worldwide. HABs occur in marine, estuarine, and freshwater ecosystems. A National Plan that primarily targets HABs and their toxins in marine and estuarine waters has been developed, Harmful Algal Research and Response: A National Environmental Science Strategy 2005-2015, (HARNESS 2005), but an analogous plan for freshwater HABs has not been developed. Although many algal groups form HABs within a range of salinity levels, dinoflagellates comprise the majority of marine and estuarine HABs, whereas cyanobacteria are the predominant source of freshwater HABs. The Interagency, International Symposium on Cyanobacterial Harmful Algal Blooms (ISOC-HAB) focused on cyanobacterial HABs (CHABs) because characterization of the state of the science and identification of research needs is essential for the development of a freshwater research and response plan. CHABs and their highly potent toxins, collectively known as cyanotoxins, pose a potential risk to human health. Ecosystem sustainability is compromised by CHABs due to toxicity, pressures from extreme biomass levels, and the hypoxic conditions that develop during CHAB die offs and decay. Some of these risks are described in the World Health Organization's guidelines for CHABS (WHO 1999). However, current data in the US are insufficient to unequivocally confirm an increased incidence or to fully assess the risks of CHABs, thereby complicating Federal regulatory determinations and the development of guidelines, Water Quality Criteria and Standards, and regulations. As a result, state, local, and tribal authorities are placed in the quandary of responding to CHAB events by developing and implementing risk management procedures without comprehensive information or Federal guidance. This dilemma was recognized by the US Congress and expressed in the 2004 reauthorization and expansion of the 1998 Harmful Algal Blooms and Hypoxia Research and Control Act (HABHRCA). Whereas HABHRCA originally targeted harmful algal blooms in the oceans, estuaries and the Great Lakes, the reauthorized Act mandated a Scientific Assessment of Freshwater Harmful Algal Blooms, which will: 1) examine the causes, consequences, and economic costs of freshwater HABs throughout the US; 2) establish priorities and guidelines for a research program on freshwater HABs; and 3) improve coordination among Federal agencies with respect to research on HABs in freshwater environments.

The US Environmental Protection Agency (EPA) is authorized to protect human health and the environment from contaminants in drinking and recreational waters through the mandates of the Safe Drinking Water Act, last amended in 1996 (SDWA 1996), and the Clean Water Act, last amended in 2002 (CWA 2002). The National Oceanographic and Atmospheric Administration (NOAA), EPA and other Federal agencies recognize that cyanotoxins in freshwaters may present a risk to human health through the potential for exposure from recreational waters, drinking water, fish and shellfish consumption, and other vectors. The Federal agencies also recognize that cyanobacteria and cyanotoxins threaten the viability of aquatic ecosystems through alteration of the habitats that sustain plants, invertebrates and vertebrates. EPA's Office of Water listed cyanobacteria and cyanotoxins on the first drinking water Contaminant Candidate List (CCL) of 1998 and the second, CCL2, of 2005 (CCL 2006). Risk assessments, regulatory determinations, and risk management procedures can be informed by research that further clarifies: 1) the spatial extent and temporal frequency of freshwater CHABs, both toxic and non-toxic; 2) dose-response relationships describing the effects of individual cyanotoxins and commonly occurring cyanotoxin mixtures in humans and other species at risk; and 3) cost effective means to prevent, control, and mitigate CHABs in surface waters.

EPA's National Health and Environmental Effects Research Laboratory, a component of the Office of Research and Development, invited other Federal and state entities to co-sponsor a CHAB symposium, ISOC-HAB. The purpose of the Symposium was to characterize the state of the science and to identify research needs, thereby informing EPA's Office of Water and the HABHRCA-mandated Scientific Assessment of Freshwater Harmful Algal Blooms. NOAA and seven other Federal entities, the Food and Drug Administration, Department of Agriculture, Centers for Disease Control and Prevention, Army Corps of Engineers, US Geological Survey, National Institutes of Health, and National Institute of Environmental Health Sciences, as well as the University of North Carolina Institute of Marine Sciences joined EPA in co-sponsoring ISOC-HAB. An interagency organizing committee of 32 members and a five member executive advisory committee (see Organizing Committee page) were assembled to develop an operational structure for ISOC-HAB.

Theoretical Framework for Cyanobacterial Harmful Algal Blooms

The ISOC-HAB Organizing Committee developed a theoretical framework of interrelationships between factors that may influence the development of CHABs and be impacted by CHABs to help identify the major topic areas and subtopics of the symposium (Fig. 1). Both natural forces and human activities may be promoting CHABs through habitat alteration (Causes, Prevention and Mitigation Workgroup Report this volume). The natural forces may include an upswing in temperature cycles that allow tropical genera of cyanobacteria to flourish in subtropical regions, the evolution of new strains of cyanobacteria that can better compete for survival and dominance, a decline in predatory populations that limit cyanobacteria growth, and age-related eutrophication of surface waters. Anthropogenic pressures may be major sources of ecological change that promote CHABs. There is evidence that greenhouse gasses are increasing global temperatures, thereby allowing temperature limited genera and species to expand spatially and temporally (Paul this volume). Excessive levels of nitrogen and phosphorus in surface waters from point and non-point sources promote the development of CHABs, and their ratios may determine which species dominate blooms (Paerl this volume). Waters that are high in phosphorus and relatively low in nitrogen are typically dominated by species that contain heterocysts, specialized cells to collect and fix nitrogen into useable forms. Non-heterocyst containing species often dominate blooms in waters that are high in nitrogen. The incidence of CHABs may be increased by pollutants, such as pesticides and metals in storm-water runoff and other sources that disrupt the balance between cyanobacteria and their predators, or lead to the rise of more resilient strains of cyanobacteria through natural selection. The introduction of non-native organisms into surface waters also may promote CHABs. The recent resurgence of CHABs in the Great Lakes is associated with the invasion of Asiatic Zebra muscles, *Dreissena polymorpha,* that may selectively filter-feed non-toxic phytoplankton (Occurrence Workgroup Report this volume). The combined pressures from natural forces and human activities on surface waters may provide a competitive advantage to cyanobacteria over their predators, leading to an increase in the spatial and temporal extent of CHABs.

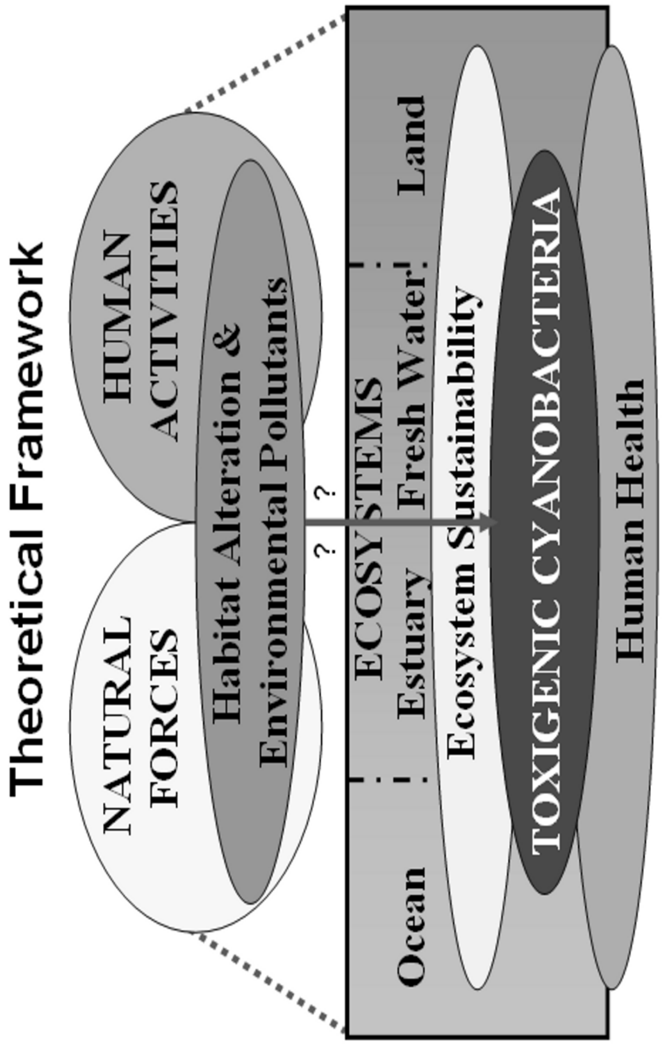

Fig. 1. Both natural forces and human activities may alter habitats in ways that promote the occurrence of cyanobacterial harmful algal blooms, increasing the potential for adverse effects on ecosystem sustainability and human health.

Although CHABs primarily occur in fresh and estuarine waters, there is increasing recognition that cyanobacteria blooms in oceans are threatening the sustainability of some marine ecosystems (Ecosystem Effects Workgroup Report this volume). The recent and unprecedented decline in viable coral reefs worldwide is due in part to marine CHABs (Paul this volume). Species of toxigenic *Lyngbya* adapted to high salinity environments can form benthic mats that expand over an area equivalent to a football field within an hour, causing ecological damage and endangering human health (Australian Environmental Protection Agency 2003).

Cyanotoxins also are found in terrestrial environments where they may pose a risk to human and animal health. Surface waters are increasingly used for field irrigation in agricultural production. Water drawn from sources experiencing toxigenic CHABs is sprayed on crops, producing cyanotoxin-containing aerosols that may be inhaled by humans and other animals, and absorbed by crops. Cyanobacteria can form a symbiotic relationship with terrestrial plants which may biomagnify cyanotoxins. Cyanobacteria of the genus *Nostoc* form colonies on the roots of cycad plants in Guam where for more than 30 years scientists have tried to unravel the genesis of the mysterious neurodegenerative disease that afflicts the native Chamorro population. An amino acid cyanotoxin produced by *Nostoc*, beta methylamino-alanine (BMAA), accumulates in cycad seeds. The seeds are eaten by a species of bat that accumulates high levels of BMAA in its tissues. The bat is a traditional food source for the Chamorro. Analyses detected BMAA in brain tissues of Chamorro victims, leading to the hypothesis that BMAA causes neurodegeneration that may manifest with features of amyotrophic lateral sclerosis, Parkinson’s disease, and Alzheimer’s dementia. Recent evidence indicates that BMAA is produced by most types of cyanobacteria, and that it may be associated with neurodegenerative diseases elsewhere (Human Health Effects Workgroup Report this volume).

Cyanobacteria and cyanotoxins are clearly hazardous to human health and ecosystem sustainability, but the degree of risk they present is unclear (Risk Assessment Workgroup Report, this volume). Research is needed to accurately assess the risks and provide risk managers with cost effective options for reducing the risks as warranted. A Scientific Assessment of Freshwater HABs can describe a comprehensive approach toward understanding the interconnections between the causes of blooms and toxin production, the characteristics and magnitude of the risks they pose, and the means for reducing the risks through prevention and mitigation strategies. Meeting these objectives requires that relationships between CHABs, humans, and the environment be viewed as a system of interconnected components.

A Systems Approach to Cyanobacterial Harmful Algal Blooms

The concept of a systems approach can be traced back to ancient Greece when Aristotle proclaimed that "The whole is more than the sum of its parts." A system is generally defined today as a dynamic process that provides the functionality required by users of the system. In engineering, a systems approach integrates multidisciplinary groups into a unified team that develops and implements a process from concept to operation. The application of a systems approach to risk assessment and management issues requires several fundamental components.

- Integration of discovery (i.e., descriptive) science with hypothesis-driven science
- A cross-disciplinary team to develop and implement the system
- Development of new approaches and technologies coupled with tools for data acquisition, storage, integration, and analysis

Whereas a systems approach to CHABs is appropriate, a broad perspective is required to accommodate the stochastic nature of biological and ecological processes. That is, the causes, occurrences, production of hazardous materials, routes of exposure, dosage of hazardous materials, and effects of a CHAB can be viewed as an ordered collection of random variables whose values change over space and time. These components and their interconnections, the processes by which one component at least partially determines the qualities of the next component, form the CHAB pathway. The combination of the CHAB pathway, risk assessment, policy determination, and risk management forms a systems approach to CHABs. A systems approach to CHABs provides the perspective that ecosystems partially determine human well-being, and that humans partially determine ecosystem well-being. To produce the tools required to manage the risks that CHABs impose on humans and ecosystems, it is necessary to characterize the components and their interconnections. Successful risk management tools may target the components and interconnections of the CAHB pathway for disruption to reduce risk.