Harmful Algal Blooms in a Changing World

by Mark Wells

There are projections that climate change will lead to increases in the frequency and severity of harmful algal blooms (HABs). Indeed, there is evidence that climate change already may be causing shifts in phytoplankton community composition, but the projections of a climate-increasing HAB impact remain speculative. Although there are many intuitive linkages, these scenarios are founded on limited and often conflicting experimental data. Moreover, the few longer-term datasets that exist on HAB events in almost all cases lack the oceanographic data essential for statistical assessment. So scientific debate cannot establish a link between HABs and climate change at this time, let alone forecast regional HAB changes in the future. It is critical that HAB scientists proactively identify the fundamental parameters and research infrastructure required to effectively address this important question if we are to inform when called upon to forecast or explain changing HAB patterns.

PICES, ICES (International Council for the Exploration of the Sea; http://www.ices.dk), GEOHAB (IOC/SCOR Global Ecology and Oceanography of Harmful Algal Blooms Research Program; http://www.geohab.info/) and NOAA (U.S. National Oceanic and Atmospheric Administration), with funding provided through PICES, GEOHAB and NOAA, convened a workshop of invited international experts (11 participants from 5 countries; Fig. 1) to develop an assessment of where the field of HAB research stands in terms of addressing HAB/climate change linkages, and what research is needed to move forward on these questions over the next decade. This workshop was held on March 18–22, 2013, at the Whiteley Center, Friday Harbor Laboratories, University of Washington (Figs. 2 and 3), and co-chaired by Mark Wells (PICES), Bengt Karlson (ICES) and Raphael Kudela (GEOHAB).

Three broad classes of HABs were considered: *toxic* HABs that impact human health, *fish-killing* HABs where the causative organisms affect both wild and aquaculture fish populations, and *high-biomass* HABs, whether derived by natural or anthropogenic processes leading to hypoxia, foam causing bird deaths, and other negative impacts. The key underlying consideration surrounding changes in the distribution of HABs is three-pronged: HAB species "getting there", being adapted well enough to "remain there" over the course of the season, and ultimately "staying there" for multiple seasons.

The deliberations focused on the observed and predicted climate changes in the physical and chemical conditions in aquatic systems identified in the AR4 IPCC Synthesis Report on climate change, and what is known about these effects on the physiology of HAB species as well as general phytoplankton. The core questions were:

- What do we know about how the given parameter affects HAB species?
- What do we not know of importance in terms of these parameters impacts? and
- Which of these unknowns are the most pressing questions and how should we go about addressing them?

The factors considered included: temperature, with its effects on cellular growth rates, nutrient uptake rates, toxin production and cellular lipid compositions, and stratification, with its impact on vertical nutrient flux, physical and chemical stability of the system, and the prolonging of HAB windows of opportunity. Similarly, the effect of ocean acidification was examined in terms of success of HAB species and cellular toxin synthesis and accumulation, as well as consideration of the effects from altered nutrient inputs associated with changing precipitation characteristics (*e.g.*, pulsed terrestrial riverine flows) and facilitated transport of culturally-derived nutrients. While each of these four broad parameters have known impacts on HAB species, it will be the synergistic interactions among these drivers that will determine the overall impact on HAB species success in phytoplankton communities.

The participants felt that there was insufficient current insight on how climate change may influence grazing and light effects on HAB species. Many HABs species are both grazers and prey, but there is very limited information on how the balance of these processes might deviate as the ocean environment changes. The second factor is the effect of changing light fields resulting from broad-scale alterations in cloud cover. While light is a key environmental parameter affecting phytoplankton communities, and different species are known to be better light- or shade-adapted candidates, there is little indication so far that HAB species will be affected differently than non-HAB species.

An important aspect of the deliberations was consideration of how HAB science has progressed over the last few decades. The participants recognized that much of the research to date has focused on two fronts: observations of HAB events and the study of HAB organisms. Although when combined, these approaches provide some understanding of the ecophysiology of HAB organisms, but there is only limited insight on how HAB organisms interact within the broader phytoplankton communities. One of key findings of the workshop was that HAB research needs to move towards more comparative investigations that inform on the thresholds for shifting balance among HAB and non-HAB species in the context of climatically-driven changes in coastal and oceanic environments.

The participants contemplated what new research tools would help move the science forward most quickly. The primary need at this time is initiating the long-term collection of HAB-relevant datasets across diverse geographical and oceanographic regimes. While there exists numerous long-term HAB monitoring efforts, none are sufficient to provide the data streams required to assess climate-related changes in HABs. It was agreed that the most productive means to initiate these data collection streams is to collaborate with existing coastal and offshore oceanographic and climate-based monitoring sites to add a limited list of parameters (*e.g*., phytoplankton speciation, toxins, *etc*.) to establish HAB "observer sites". Recognizing that there are very limited laboratory facilities and expertise in many areas of interest, a shorter list of key parameters that are easily obtained with simple sampling approaches was developed to facilitate new monitoring sites in waters where HABs are not a persistent problem.

Fig. 1 The participants of the PICES/ICES/GEOHAB/NOAA workshop on "Harmful algal blooms in a changing world", March 18–22, 2013, at the Whiteley Center, Friday Harbor Laboratories, University of Washington. Left to right: Stuart Benard (South Africa), Donald Anderson (U.S.A.), Vera Trainer (U.S.A.), Angela Wulff (Germany), Charles Trick (Canada), Bengt Karlson (Co-Chairman, ICES/Sweden), Ted Smayda (U.S.A.), Raphael Kudela (Co-Chairman, GEOHAB/U.S.A.), Mark Wells (Co-Chairman, PICES/U.S.A.; author of this article), Akira Ishikawa (Japan) and William Cochlan (U.S.A.).

Fig. 2 Friday Harbor Laboratories, San Juan Island, Washington State, U.S.A.

Fig. 3 One of the group dinners prepared by participants in the Whiteley Center, Friday Harbor Laboratories.

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