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Harmful algae in benthic systems: A GEOHAB core research program

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Abstract – Harmful events caused by benthic microalgae have recently garnered a high level of attention in temperate areas, upon reports of *Ostreopsis* species causing fauna damage, food intoxication and respiratory illness. A resurgence of interest has also occurred in ciguatera fish poisoning (CFP), a syndrome associated with the consumption of reef fish contaminated by ciguatoxins produced by the dinoflagellate genus *Gambierdiscus* in tropical and subtropical areas. To foster research on events caused by benthic microalgae, the SCOR-IOC Global Ecology and Oceanography on Harmful Algal Blooms (GEOHAB) program started a Core Research Project on Benthic Harmful Algal Blooms (BHABs). During an Open Science Meeting (OSM) in 2010, scientists studying benthic and planktonic microalgae identified the main gaps of knowledge and the research, technology and infrastructure needs in the field of the ecology and oceanography of BHABs. The issues addressed during the OSM covered the state of taxonomy, sampling methods, biogeography, genetic diversity, ecology and ecophysiology of BHABs, along with the identification of research priorities and approaches to be taken in order to improve understanding and prediction of BHABs.

GEOHAB / HABs / harmful algae/ *Ostreopsis* / *Gambierdiscus* / ecology

INTRODUCTION

The SCOR-IOC programme Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) was initiated in 1999 to develop research on the ecological and oceanographic mechanisms underlying the dynamics of harmful algal blooms (HABs, www.geohab.info). To achieve its objective, the GEOHAB

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Science Plan (GEOHAB, 2001) and the GEOHAB Implementation Plan (GEOHAB, 2003) specified, among other activities, the formation of Core Research Projects (CRPs) to address comparative, integrative, multi-faceted and international research on HABs. In the beginning, four CRPs related to four ecosystems types (fjords and coastal embayments, upwelling, eutrophic and stratified systems) were established through focused open science meetings (OSM) with a wide international participation. It became evident, mid-way through the programme, that it was important to start a new CRP within GEOHAB that addressed benthic microalgae. The increased attention to HAB outbreaks made clear that the ecology of microphytobenthos was almost unknown as compared to our knowledge of phytoplankton. Although the organisms involved in BHABs may not greatly differ from the planktonic ones in terms of morphology, taxonomy and phylogeny, the two realms are clearly distinct regarding the lifestyle (biological cycle and life strategies), relationships with the physical and biological environment and relevant spatial and temporal scales. The intrinsic characteristics of the planktonic and benthic HABs also imply that different approaches and methodologies need to be applied in their study. Another important reason to start a new core project is that experience and expertise have been accumulated during the past decade on tropical and subtropical benthic HABs, namely those related to *Gambierdiscus* spp. in the Pacific Ocean and subtropical and tropical Atlantic Ocean, and on the consequent ciguatera outbreaks. This experience can be particularly useful considering the recent expansion of BHAB problems to temperate areas. The establishment of an international program that can coordinate these different science communities is a main goal of the BHAB CRP, which perfectly fits the main goals of GEOHAB.

The BHAB CRP was initiated during an Open Science Meeting (OSM) in 2010 at Honolulu (Hawaii, USA), where scientists studying benthic and planktonic microalgae reviewed the current knowledge on benthic microalgae and discussed the main gaps of knowledge and the research, technology and infrastructure needs in the field of the ecology and oceanography of BHABs.

During the meeting several fundamental knowledge gaps were identified regarding the distribution and abundance of harmful benthic microalgae. Distribution maps so far compiled (e.g. Litaker *et al.*, 2010; Rhodes, 2010; Parsons *et al.*, 2012), show places where the species in question were detected. However, the absence of a record does not imply the absence of the species. The available information on presence should be considered in comparison with that of the actual absence of a species. This will allow to gain a clear picture of the environmental factors that promote or prevent the expansion of the geographic range of individual harmful benthic microalgae along the coasts of the world's seas. It is also clear that, with the exception of few areas and genera (*i.e. Gambierdiscus*, e.g. Litaker *et al.* 2010; *Ostreopsis* in the Mediterranean Sea, e.g. Mangialajo *et al.*, 2011), data on benthic harmful microalgae abundance is extremely sparce. Toward the end of the 20th century, the insufficient and at times confounding information on species taxonomy represented a hindrance to the construction of spatial distribution of individual species. However, studies conducted during the last few years (e.g. Litaker *et al.*, 2009; Penna *et al.*, 2005; Penna *et al.*, 2010) demonstrate the importance of molecular information in order to identify several species, and tools are under development to allow the easy application of such methods. During the OSM, scientists noted the need for a centralized location where information concerning *Gambierdiscus*, *Ostreopsis* and other benthic species could be accessed. Thus, a new tool was recently developed: the Wiki (http://gambierdiscuswiki.wikispaces.com/). It is a forum aimed to help keep the designation of *Gambierdiscus* ribotypes from becoming confusing until the new species are described.

Another problem preventing a clear understanding of BHAB distribution and dynamics is the lack of a single, intercalibrated and widely applied method for their sampling and abundance estimation. Benthic harmful algal bloom species occupy structurally complex and diverse environments, which greatly complicates the design of quantitative sampling regimes for these organisms. At present, the existing sampling methods fall into three categories: substrate sampling (Carlson, 1984), vacuum collection (Parsons *et al.*, 2010) and the use of artificial substrates (Kibler *et al.*, 2010). Each of these approaches has advantages and disadvantages. Cell abundance is expressed most frequently as cells per gram wet weight of substrate. Because the substrates are characterized by complex morphologies with a wide range of surface area to mass ratios, cell abundances among different substrates are not comparable. Finally, the patchiness of benthic organisms indeed poses a major problem for the sampling design. The gaps appear even wider in our knowledge of the adaptive strategies of BHAB species, *i.e.* their responses to the biotic and abiotic environmental factors. The responses may not be unique to these species but still differ considerably from those shown by planktonic species. Indeed benthic and planktonic habitats differ considerably in terms of substrate, light regimes, relationship with nutrients, grazers and effects of mucilage production. So far, a number of studies on the role of nutrients, macroalgal substrates and other environmental parameters on the development of BHABs have been initiated. At times these studies show contradictory results, clearly demonstrating the need for further investigations. While the life cycles of BHAB species have been attributed a primary relevance to species distribution and initiation of blooms, to date the life cycles of neither *Ostreopsis* nor *Gambierdiscus* species have been completely elucidated.

In the next section, we follow the GEOHAB strategic design to develop and implement research in BHABs by formulating specific key questions within five main elements that are relevant to HAB development. The questions listed below were identified based on the fruitful discussion that took place at the Honolulu OSM.

KEY QUESTIONS TO BE ADDRESSED IN UNDERSTANDING THE ECOLOGY AND OCEANOGRAPHY OF HABS IN BENTHIC SYSTEMS

The GEOHAB Science Plan (GEOHAB, 2001, free download at www.geohab.info) established five elements to develop and implement research on HABs in general (Fig. 1). Within each element, specific questions regarding benthic HABs have been formulated.

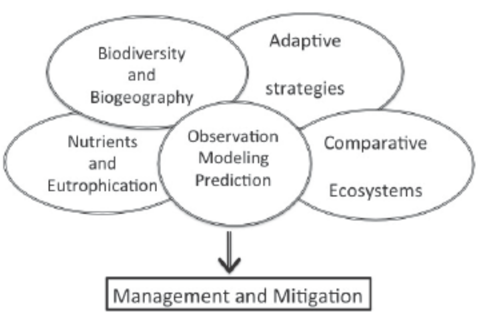

Fig. 1. The five Programme Elements of GEOHAB that serve as framework to guide priorities and research. The elements are individually defined and justified, but the goals of GEOHAB (*i.e.*, understanding the factors underlying BHABs and thus improving prediction and helping management and mitigation) will only be attained through the linkages between these Programme Elements (redrawn from GEOHAB, 2001).

Programme element 1: biodiversity and biogeography

Overall Objective: To determine the distributions of BHAB species, their biodiversity, and their responses to environmental changes.
Specific objectives are:
1) Characterise the genetic variability of *Gambierdiscus* and *Ostreopsis* species, specifically related to toxicity, population dynamics and biogeography, using existing and new molecular tools.
2) Determine the changes in the biogeographical range of *Gambierdiscus* and *Ostreopsis* species caused by natural and/or anthropogenic mechanisms. Studies will focus on the environmental factors that contribute to mesoscale distribution including climate change, ocean acidification, and global warming. Research will also consider the dispersion of BHAB species facilitated by human activities (e.g. ship ballast, transport *via* plastics, oil platforms).
3) Investigate the relevance of substrate specificity of *Gambierdiscus* and *Ostreopsis*, at small scale (see also Program Element 2).

Programme element 2: nutrients and eutrophication

Overall Objective: To determine the significance of nutrients and eutrophication on benthic HAB species.
Specific objectives are:
1) Investigate whether nutrient inputs affect BHAB outbreaks or the development of macroalgal substrates.
2) Investigate the mixotrophic capacities of BHAB species.
3) Investigate the nutritional links between BHAB species and their macroalgal substrates, as sources of dissolved organic compounds.
4) Determine the effects of nutrients on the growth rates and toxicity of BHABs.
5) Consider the potential rôle of groundwater discharges in BHABs.

Programme element 3: adaptive strategies

Overall Objective: To define the particular characteristics and adaptations of BHAB species that determine when and where they occur and what harmful effects they produce.
Specific objectives are:
1) Define the ecophysiological characteristics of BHAB species that determine their intrinsic potential for growth and persistence. Research would include the adaptations to fluctuating light and temperature; induction of resting stages, rôle of resting stages in the outbreaks and the existence of endogenous clocks *versus* external triggers for cell proliferation.
2) Investigate biological-physical interactions on benthic assemblages and their substrates at local and regional scales (including wave exposure, desiccation and oxygen supply).
3) Describe and quantify chemical and biological processes affecting species interactions, including the rôle of the mucous production, the potential role of toxins on marine animals at sublethal levels, the trophic transfer processes (fish, shellfish and other potential vectors grazing on macroalgae), parasite infections and competition and/or succession with other benthic microalgae. Investigate how anthropogenically driven changes in the ecosystem structure (jellyfish outbreaks,

fishing pressure, coral reef destruction) may affect trophic dynamics at the level of benthic microalgal assemblages.
4) Investigate the biological and environmental factors that affect toxin production, including nutrients, light intensity and quality, physiological state and/ or growth phase of the organisms and strain specificity.

Programme element 4: comparative ecosystems

Overall Objective: To identify mechanisms underlying BHAB population and community dynamics across ecosystem types through comparative studies.
Interestingly, *Gambierdiscus* and *Ostreopsis* are not typically found in the other systems identified by GEOHAB (upwelling, stratified, eutrophied). The comparative approach can help ascertain the environmental characteristics that favor BHABs. Possible comparisons would include:
1) Compare the occurrence of BHAB species in different habitats. Examine the differences in BHAB abundance in carbonate (coral) *vs* volcanic islands, and in mangrove and sea grass habitats.
2) Compare the food webs resulting in ciguatoxic fish in the Caribbean and in the Pacific, to determine if they are similar or have different routes of toxin bioaccumulation.
3) Identify and quantify the effects of physical processes on accumulation and transport of harmful algae, including seasonal and small scale variability in water motion and circulation. The important factors to consider are the covariance of depth and light as well as wave action and exposure.

Programme element 5: observation, modelling and prediction

Overall Objective: To improve the detection and prediction of BHABs by developing capabilities in observation and modeling.
At present we have not developed yet capabilities to observe BHAB organisms *in situ*. Further, we need to develop and evaluate systems for long term monitoring of BHAB species. As explained above, there is a major need to establish a standardized sampling protocol and to define the best expression for cell abundances. This is fundamental to learning the actual distribution of the harmful organisms and their relationship with toxicity outbreaks. In addition, we must improve our understanding of the biology and ecophysiology of benthic dinoflagellates related to different physical forcings. Major comprehension can be achieved by experiments under controlled conditions. However, it is necessary to integrate the physico-chemical dynamics with the natural conditions of BHAB species. Altogether, results of the research outlined above may provide basic parameters to develop models to describe and quantify the biological, chemical and physical processes related to BHABs.

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