GEOHAB

GLOBAL ECOLOGY AND OCEANOGRAPHY
OF HARMFUL ALGAL BLOOMS

AN INTERNATIONAL PROGRAMME SPONSORED BY THE SCIENTIFIC COMMITTEE ON OCEANIC RESEARCH (SCOR) AND THE INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (IOC) OF UNESCO

GEOHAB Synthesis Open Science Meeting

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This report is based on contributions and discussions by the organizers and participants of the workshop, and the GEOHAB Scientific Steering Committee.

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Cover images:
Top left: Microphotograph of Ostreopsis cf. ovata bloom in the NW Mediterranean, courtesy of Dr. Magda Vila (Institut de Ciències del Mar, CSIC, Barcelona).
Top right: Artificial substrate method for sampling benthic dinoflagellates in Malaysian coastal waters, courtesy of Patricia A. Tester.
Bottom left: Detection of an extensive high biomass dinoflagellate bloom in the southern Benguela in April 2012, using the Equivalent Algal Population algorithm and the MERIS sensor, courtesy of Hayley Evers-King (University of Cape Town).
Bottom right: Microphotograph of the marine benthic cyanobacterium Lyngbya majuscula, courtesy of Michele A. Burford.


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EXECUTIVE SUMMARY

I. AN INTRODUCTION TO THE MEETING

II. OVERVIEW OF GEOHAB ACTIVITIES

III. OUTCOMES OF THE BREAKOUT SESSIONS

IV. CONCLUDING REMARKS SESSION

APPENDIX 1 – Open Science Meeting Program

APPENDIX 2 – Meeting Participants

APPENDIX 3 – Poster Abstracts

APPENDIX 4 – Concept papers

LIST OF ACRONYMS
EXECUTIVE SUMMARY

An international workshop held in Havrehølm, Denmark, in October 1998 marked the first step towards developing the international research programme on the Global Ecology and Oceanography of Harmful Algal Blooms, GEOHAB. At this meeting, thirty-seven scientists from twenty countries affirmed the need for a coordinated international scientific programme on the ecology and oceanography of harmful algal blooms (HABs). The coordination of individual and national research efforts was considered essential to advance the understanding of HABs dynamics, and thus to find tools for their prediction, management, and if possible, mitigation. With the sponsorship of the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO the GEOHAB program was launched in 2000.

In the intervening years GEOHAB has established Core Research Projects in five areas, has promoted international research and cooperation, and has hosted a series of meetings and workshops focusing on a comparative approach to understand the ecology of harmful algae. In April 2013, fifty-one scientists from twenty-two countries gathered at an Open Science Meeting (OSM) in Paris, with the goal to highlight GEOHAB accomplishments. Furthermore, the OSM offered the opportunity to bring the community together to develop the next stage of international HAB research activities. In this spirit, the OSM included plenary presentations by invited speakers, concept papers contributed by the participants and lively discussions to review past activities and explore future research themes and opportunities.

Participants agreed on the main successful aspects of GEOHAB:

- GEOHAB helped establish and sustain global research groups on core research topics, focusing on sound science leading to better understanding and prediction of HABs;
- the GEOHAB OSMs, Reports, and Workshops were highly successful and valuable, particularly HabWatch and the GEOHAB Modeling Workshop;
- a process for endorsing programs and projects from the community was also highly valuable; and
- sponsorship of framework activities with emphasis on technology development, capacity building, and training of young scientists.

The GEOHAB Science Plan (GEOHAB, 2011), implemented through core research programs and the comparative approach, was recognized as a solid basis for another ten years of HAB research. The future programme should be addressed with new structures and mechanisms defined with clear goals, of relatively short duration, and able to produce useful documents for a broad scientific community and the society. Thus, a revised Implementation Plan would include new strategic research targets and approaches non present in the former GEOHAB, such as:

- inclusion of societal goals: ecosystem services and human health consequences of HABs,
- attention to human activities that could lead to the different HAB events,
- studies on toxins and freshwater HABs,
- to be part of the “blue economy” and involve managers/stakeholders from the outset,
• establish and reinforce long-term sentinel sites to ascertain the effect of climate change on HABs trends,
• develop and consolidate training and modelling workshops,
• three main platforms or themes:
  - Benthic HABs
  - Technology and scientific exchanges for HAB detection and research
  - Transitioning science to application

These aspects were proposed to be included as an Addendum to the GEOHAB Science Plan, while a specific Implementation Plan will be developed. Focusing on HABs in a Changing World, the name of the new program was proposed to be GlobalHAB.

On 29 October 1998, John Cullen, the chair of the first GEOHAB workshop wrote: "The five days of the GEOHAB Workshop were characterised by hard work, a clear sense of purpose, good humour, and a remarkable convergence of opinions on the needs for an international research programme on the ecology and oceanography of harmful algal blooms."

Similarly, on April 2013 in Paris the participants of the GEOHAB Synthesis OSM opined: “We all came to Paris because we recognize a fundamental problem (HABs), and cannot solve this problem in our individual laboratories. This requires an international approach.”

The GEOHAB Scientific Steering Committee is grateful to SCOR and IOC/UNESCO for sponsoring the 2013 OSM and for providing excellent staff support.

Participants at the GEOHAB OSM in Paris, April 2013
I. AN INTRODUCTION TO THE MEETING

Purpose of Meeting
This meeting had special relevance not only for the GEOHAB programme, but also for the entire international scientific community of researchers and managers engaged in the advancement of harmful algal bloom research and mitigation of impacts.

The meeting had two objectives. The first was to review the scientific advances accomplished under GEOHAB since its inception. The second was to identify a near-future roadmap of GEOHAB-like activities to be pursued beyond 2013. To achieve these objectives, active involvement of meeting participants, representing the global HAB community, was essential. For this reason, the OSM was structured somewhat differently from a typical science meeting, along four main axes (see also Appendix 1. Open Science Meeting Program):

1. Invited presentations that covered:
   - Review of GEOHAB’s past and present through its 5 Core Research Projects, Regional Programmes, and Targeted Activities.
   - Some relevant topics that provided a general framework for future research on HABs.

2. Concept papers: Participants were encouraged to provide 2-page concept papers (i.e., proposals for specific activities, such as research projects, training sessions, or comparisons among ecosystems) that could be implemented between 2014 and 2018. The papers were to be based on GEOHAB planning documents, such as the GEOHAB Science and Implementation Plans, and the Core Research Project reports (www.geohab.info). The concept papers were briefly presented at the meeting and discussed during a breakout session.

3. Poster sessions broadened the number of topics that could be considered during the meeting and encouraged the widest possible scientific participation.

4. Breakout discussion sessions among the participants based on both the invited presentations and the concept papers. The purpose of the breakout groups was to provide an opportunity for participants to discuss the impact of GEOHAB and new ideas for post-GEOHAB international HAB research. Three breakout sessions took place:
   - BREAKOUT SESSION #1: What has GEOHAB accomplished and what project objectives have not been accomplished?
   - BREAKOUT SESSION #2: What Concept Paper ideas should move forward and how?
   - BREAKOUT SESSION #3: What would the next iteration of GEOHAB-like activities look like, and what ideas should be presented to IPHAB?

Participants were split into three separate groups during each breakout session, working in parallel. Each group was assigned a chair and rapporteur. The output from the three parallel groups in each session is synthesized in this report.

It was hoped that with this diverse approach, a synthesis document regarding a near-future international collaboration on HAB research would arise from this OSM. The results of the OSM discussions and recommendations were presented to IOC’s Intergovernmental Panel on Harmful
Algal Blooms (IPHAB), one of the GEOHAB sponsors, at its 11th Session, immediately following the OSM.

This report is the first synthesis product expected from GEOHAB. Other products planned include a special issue of a peer-reviewed journal that summarizes the work of GEOHAB and a Scientific Summary on HABs for Policymakers.
II. OVERVIEW OF GEOHAB ACTIVITIES

The GEOHAB SSC invited presentations on specific topics to stimulate discussion at the OSM. These invited presentations broadly represented the range of work undertaken as part of GEOHAB. The abstracts are given in alphabetic order of the first authors (see Appendix 1 for agenda).

* GEOHAB EARTH OBSERVATION ACTIVITIES AND PARTNERSHIPS: PAST AND FUTURE

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A review is presented of GEOHAB’s past, ongoing, and future activities concerning earth observation applications for harmful algal blooms. A key aspect is the partnerships between GEOHAB and other international programmes, specifically the International Ocean Colour Coordinating Group (IOCCG) and the Group on Earth Observations (GEO). The first major GEOHAB activity in this domain was the HabWatch workshop and accompanying monograph and material in 2003. Entitled “real time coastal observing systems for ecosystem dynamics and harmful algal blooms”, HabWatch was a ten day workshop for 90 people, supported and endorsed by a wide range of sponsors and international programmes. Providing a review of the theory and state-of-the-art in real-time sensing systems for observation, modelling and prediction of HABs and phytoplankton dynamics, HabWatch was a major undertaking, and workshop content and subsequent impact are reviewed.

Another ongoing activity is the combined IOCCG/GEOHAB Working Group on Ocean Colour and Harmful Algal Blooms. The Working Group, comprised of international HAB and ocean colour scientists, is working towards the publication of a monograph in 2013. Example output of the group is presented as a current summary of ocean colour application to HAB observation. These include: conceptual models and limitations for ecologically-contextualised ocean colour application; sensitivity of ocean colour to phytoplankton functional types in coastal and inland waters; available ocean colour algorithms and HAB-focused products; and several case studies examining HAB application for various bloom types across representative ecosystems.

Detection of an extensive high biomass dinoflagellate bloom in the southern Benguela in April 2012, using the Equivalent Algal Population algorithm and the MERIS sensor (Hayley Evers-King).
Some discussion of future direction is presented in the context of a new generation of ocean colour missions, and their use for HAB applications as part of GEO. The GEO Blue Planet and Global Water Quality tasks have strong HAB components, and these are summarized as a GEOHAB contribution to the Global Earth Observation System of Systems (GEOSS). Potential future GEOHAB contributions to these large programmatic and space agency-related activities are presented as mechanisms to realize broader impact of GEOHAB core research initiatives.

*HINDCASTS AND FUTURE OUTLOOKS OF GLOBAL RIVER EXPORT AND NUTRIENT RELEASE FROM AQUACULTURE*

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A model was developed to estimate nitrogen (N) and phosphorus (P) budgets for aquaculture production using country production data for the 1950-2010 period from the Food and Agriculture Organization, and scenarios based on the Millennium Ecosystem Assessment for 2010-2050. Global production of crustaceans (18% yr\textsuperscript{-1}), molluscs (7.4%), seaweed (8%) and finfish (8.5%) rapidly increased in the past decades. In freshwater, the N and P release from global shellfish aquaculture will increase from current 1% of river export to up to 6% in 2050. Freshwater finfish aquaculture contributes 2.5% N (1.1 Tg) and 1.3% P (0.1 Tg) to global river nutrient export at present. However, our results for South and East Asia indicate that current nutrient release from freshwater finfish production is 9% of the river N and 5% of the river P load, with local hotspots. Scenarios show that nutrient release from global aquaculture may increase considerably. Compared to chicken meat and egg production, freshwater aquaculture is a rapidly growing and important cause of the anthropogenic acceleration of the N and P cycles in many parts of the world, especially so in Asia. Aquaculture production causes changes in nutrient stoichiometry and increasing reduced and organic N forms, which are of concern because of their preferential use by some harmful algae. To overcome effects of increasing nutrient release from aquaculture production, integrated systems that include seaweed may play an important role in reducing this nutrient load.

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*DYNAMICS OF HARMFUL ALGAL BLOOMS IN SEMI-ENCLOSED COASTAL EMBAYMENTS – PROCESSES AND MECHANISMS DEFINED BY THESE ECOSYSTEMS*

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Many models of HAB dynamics are predicated as physical descriptions of water mass characteristics and then incorporate biological parameters, such as growth rate, cell loss terms, life history transitions and behaviour. Based upon their geomorphological configuration affecting hydrodynamics, freshwater input and influence by adjacent coastal waters, coastal embayments have special features that determine the regime within which HABs can develop. Within a GEOHAB core research project we have attempted to determine the relative importance of biological, chemical and physical processes driving the HAB bloom dynamics. For example, recent evidence suggests that chemical ecological interactions among planktonic members of marine food webs may affect and even regulate “top down” processes such as competition, predator-prey relationships and chemical communication within and among certain species. Such allelochemical interactions may be more acute in confined systems where blooms can develop. We argue that the physical constraints on advection and dispersion of blooms in semi-enclosed systems such as
fjords and coastal embayments offer maximum potential for expression and transduction of chemical signals in natural plankton assemblages. Furthermore, we expect that life history transition strategies, such as cyst formation and excystment dynamics, may be rather different in semi-enclosed than in open coastal systems. In enclosed systems, stationary seed beds of cysts may serve as persistent repositories and inoculum for successive annual blooms. Sub-mesoscale processes related to advection and mixing of HABs can be approached via in situ bio-optical instrumentation deployed within embayment. We present recent evidence from comparative field projects, in the form of case studies, including from GEOHAB target sites in close proximity to aquaculture sites for maximal relevance. Integrative studies of chemically mediated phenomena, coupled with physically determined features such as stratification and water retention in the GEOHAB comparative framework, assist in determining the magnitude of these effects on co-evolutionary processes and HAB dynamics.

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* INTEGRATIVE APPROACH TO THE STUDY OF CIGUATERA FISH POISONING: THE EXAMPLE OF FRENCH POLYNESIA
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The Louis Malardé Institute (ILM) of French Polynesia has been engaged in ciguatera research for more than 5 decades and has contributed to several of the milestone discoveries in this field of research. Recently, the current strategy applied by ILM in collaboration with the Institut de Recherche pour le Développement is an integrative pragmatic approach to the study of ciguatera for a more efficient survey and management of this food-borne illness and its impacts on human health. Current research efforts focus on: i) the implementation of a CFP case reporting program and database with the Public Health Directorate of FP, most useful for the survey of emerging hot-spots of ciguatera and future modelling efforts on CFP epidemiology; ii) the conduction of large-scale algal- and toxin-based field monitoring campaigns for a better understanding of differences observed between French Polynesian archipelagos with respect to the genetic diversity and toxic potential of benthic HAB species (Gambierdiscus, Ostreopsis, cyanobacteria), and fish species most prone to ciguatera; iii) the implementation of detection and field-monitoring tools best suited to our islands, taking into account their geographic dispersion and complex epidemiological context; iv) the study of the potential contribution of traditional knowledge and practices regarding CFP treatment and the detection of toxic fish among island communities. Some of the major outcomes of ongoing programs will be presented while outlining their potential significance to the recently endorsed GEOHAB “HABs in benthic systems” core plan.

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CLOSING THE GAP: SPECIES-SPECIFIC STUDIES OF HARMFUL ALGAL BLOOMS
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Since the establishment of GEOHAB, our knowledge of harmful algal blooms has evolved. However, while general concepts and paradigms continue to guide our investigations they often fail to consider the multifaceted aspects of blooms and the producing organisms, especially the complexities of the biological traits of several congeneric species. Precise characterizations and more focused research efforts are needed to close the remaining gaps in our understanding of species. Here, we summarize the lessons learned from species-specific studies, carried out by our group over the last several decades, of near-shore microalgal blooms. Data acquired from research and monitoring programs greatly enhanced our knowledge of species composition, the conditions that trigger bloom events and those that determine both their recurrence and their intensity. Our own efforts consisted of: i) descriptions of new species; ii) first-time detections in the investigated areas; iii) blooms of rare species; iv) the identification of introduced species; and v) insights into species dispersal mechanisms. Most importantly, our studies opened up novel areas of research, focusing on previously unrecognized life-cycle pathways and the reversibility of the sexual stage in dinoflagellates. Thus, new paradigms of bloom dynamics are conceivable, e.g., the formation and maintenance of small-scale coastal blooms despite physical constrains. Accordingly, interpretations of bloom dynamics, persistence, and recurrence require a renewed examination of the biological behaviors of organisms and their environmental interactions, based on detailed taxonomy and appropriately scaled studies of growth rates, life cycles, and adaptive strategies, in an approach that distinguishes between broad concepts and species-specific characteristics.

HABS AND NUTRIENTS: PROGRESS OF THE CORE RESEARCH PROGRAMME
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Increased nutrient loading from anthropogenic activities is considered to be one of the important reasons why HABs have been expanding in frequency, duration, and harmful properties worldwide. Not all nutrient loads promote the growth of HABs; when and why do some nutrient loads lead to HABs and others to non-HAB algal accumulations? The GEOHAB Nutrients and Eutrophication Core Project has addressed this broad question and associated specific questions through two Open Science meetings and a SCOR/LOICZ Working Group. Addressing the relationships between nutrients and HAB expansion has required advancements in the quantification of nutrient loads by form and source, and advancements in understanding the physiology of nutrient acquisition by both HAB and non-HAB species. Models of global nutrient loads have been advanced and, using a linked modeling approach, predictive scenarios for HAB habitat change in relation to nutrient loading and predicted climate change have been developed for various regions of the world. Through comparative studies, much has been learned about nutritional strategies of various HAB organisms, including the importance of mixotrophy. However, there is much that is still not understood regarding linkages between specific types of nutrient loads and specific clusters or types of HAB species, as well as the multiple complex physiological processes of nutrient acquisition by HAB compared to non-HABs, and feedbacks and interactions that occur between HABs and the components of the microbial food web that may impact their detrimental effects. This talk will summarize key successes of the Core Project and important remaining challenges.
Global climate change is adding a new level of uncertainty to many seafood safety and HAB monitoring programs. Increasing temperature, enhanced surface stratification, alteration of ocean currents, intensification or weakening of local nutrient upwelling, stimulation of photosynthesis by elevated CO$_2$, and heavy precipitation and storm events causing changes in land runoff and micronutrient availability may all produce contradictory species- or even strain-specific responses. We can expect: (i) Range expansion of warm-water species at the expense of cold-water species; (ii) Species-specific changes in abundance and seasonal window of growth of HAB taxa; (iii) Increased toxin content of some harmful algal cells; and (iv) Secondary effects for marine food webs, when individual zooplankton and fish grazers are differentially impacted by climate change. Some species (e.g. toxic *Alexandrium* dinoflagellates benefitting from land runoff and/or water column stratification, tropical benthic *Gambierdiscus* dinoflagellates responding to increased water temperatures and coral reef disturbance) may become more successful, while others may diminish in areas currently impacted. Carefully designed mesocosm experiments are required with due consideration for the complex multivariate interactive effects on the long-term responses of HABs. Extensive investment in global ocean observation systems, improved ocean sensor capabilities and integrated data management are called for in order to define management options and better forecast risks to human health and seafood safety. The greatest problems for human society will be caused by being unprepared for significant HAB range expansions or the increase of algal biotoxin problems in currently poorly monitored areas.

In the conception of the GEOHAB science program, a conscientious effort was made to focus on strategic science that would lead to the understanding of the ecology of harmful and toxic algae and the dynamics leading to their development. Such studies were necessary for the effective modeling, and ultimately forecasting, of harmful algal events. However, only 12 out of 168 (7%) studies formally assigned to GEOHAB dealt with toxin detection, algal toxin profiles or allelopathy. Hence, further work will be necessary to improve our comprehension of toxin biosynthesis and the ecological effect and function of toxins.

Therefore, this literature review focused on aspects of algal toxinology from detection and biosynthesis over chemotaxonomy (profiling) to effects and transformation of toxins in the marine food web. While studies on biosynthesis were restricted to microalgae, the review of detection of toxins could be further subdivided into sections on different matrices, i.e. seawater and passive samplers, microalgae and other marine organisms. The review of toxins in the marine food web investigated transport phenomena as well as transformation of toxins.

Finally, the discussion part of this paper attempts to inspire a future strategy, including aspects of toxinoology that cover ecology of microalgae as well as the ecotoxicology and mammalian toxicology of algal metabolites, including toxins.
* DANCING WITH THE TIDES: HOW TO PREDICT COMPLEX DYNAMICS IN PLANKTON COMMUNITIES?
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Plankton communities often consist of hundreds of different species, while only a handful of them are potentially harmful. In this presentation, I will argue that this “multi-species problem” may complicate the predictability of harmful algal blooms considerably, and will discuss approaches that may help to improve our forecasts.

First, I will show that interactions between multiple species can generate non-equilibrium dynamics with continuous ups and downs in species abundances, even in a constant environment. This is illustrated by mathematical models and controlled laboratory experiments. Next, I will discuss possible underlying mechanisms that may generate these complex dynamics, such as multispecies competition, predator-prey interactions, and host-virus networks. Finally, I will consider the interplay between intrinsic community dynamics and environmental variation. For instance, data obtained from high-resolution monitoring illustrate that fluctuations of coastal phytoplankton can become entrained by the tidal cycle.

One important implication of these complex dynamics is that changes of individual species abundances within plankton communities may have a high predictability in the short term, but a low predictability in the long run. In other words, there is a time horizon for accurate prediction, quite similar to the time horizon in weather predictions. The daily weather forecast might therefore serve as a useful paradigm approach for the prediction of harmful algal blooms. In particular, prediction of the rise and fall of harmful algal species will necessitate the development of extensive monitoring programs and data assimilation techniques that enable regular updates of predictive models with observed changes in species composition.

* THE QUEST FOR BIOLOGICAL AND PHYSICAL MEASUREMENTS OF HABS: PROGRESS AND PROSPECTS
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A fundamental impediment to understanding the formation, evolution, and ultimate dissipation of Harmful Algal Blooms has been a lack of suitable instrumentation for in situ observation. Spatial scales ranging from millimeters to tens of kilometers define both the micro and macroscopic features of the bloom, while temporal scales of cell growth, grazing, and physical transport can span the range of hours to weeks. Although shipboard sampling programs with traditional instruments like CTD-fluorometers and bottle casts can answer a variety of questions, increased sensing ability is paramount for sufficient understanding. In this talk, Dr. Jaffe will document both past, present, and envisioned work in developing ocean-sensing systems for sampling the euphotic zone. This includes the past development of a large autonomous profiler that was equipped with a laser imaging fluorometer used along with a host of other instruments. Presently, his group is developing an inexpensive miniature vehicle, to be deployed in swarms, that has many of the properties of its predecessor, however, can be localized in 3-dimensions to track internal waves and mimic larval transport. Additional efforts in the acoustic tracking of zooplankton and the optical imaging of organisms from centimeters to microns are aimed at gaining a better understanding of the statics and dynamics of both plants and animals in the top 100 meters of the ocean. Examples of previous and recent work (performed in the last few months!), as well as intended future developments will be described.
The Core Research Project: HABs in upwelling systems was initiated by means of an Open Science Meeting in Portugal in November 2003. Eight key questions were formulated to address our understanding of the ecology and oceanography of HABs in upwelling systems. These questions related to the identification of adaptive strategies that characterize HAB species in upwelling systems, including seeding strategies, the influence of small-scale physical processes and nutrient supply in affecting HAB population dynamics, the role of genetic predisposition versus environmental conditions in toxin production, the influence of coastal morphology and bathymetry in determining the distribution of HABs, the relative importance of cross-shelf and along-shore advection for HABs, and the linkages of HAB events and climate. Following a comparative review of the ecology and oceanography of HABs in upwelling systems through publication of a special issue of Progress in Oceanography in 2010 we highlight further advances in addressing the above questions. We specifically examine achievements in terms of the overall goal of GEOHAB of prediction supported by observation and modelling systems. The comparative approach, as endorsed by GEOHAB, is considered to have added value to regional or national science programmes. Furthermore the CRP is deemed to have provided effective direction to HAB research in upwelling systems over the past decade which has improved the availability of comparable data. Prediction of HABs nevertheless remains limited by ecological complexity. However increasingly realistic hydrodynamic models with high spatial resolution now lay the groundwork for better prediction through incorporation of better resolved ecological properties and processes.
Can we imagine a HAB population in an ocean realm without layering? HAB events are usually associated with some kind of thermal/haline stratification. The Core Research Project “HABs in Stratified Systems” was established to promote our understanding of the conditions underlying the initiation, maintenance and dissipation of high density HAB populations in stratified systems. The main focus was on small scale hydrographic features which may be encountered in any environment, with formation of thin layer (TL) as the extreme scenario. Some overarching questions leading this CRP were: i) Are these layers formed by passive accumulation, aggregation, or physical-biological interactions? ii) What are the advantages of living in a TL? iii) Are the local changes in viscosity and secretory product levels caused by plankton key to understanding thin layers properties? iv) What are the key parameters/scales and the appropriate instruments to measure them?

Progress in advanced instruments to obtain vertical distributions of physical properties has increased their resolution from meters to centimeters. Still the main bottleneck lies in our acquisition of biological observations (rates and interactions) on similar scales, and many observations of dramatic thin layers have been more serendipitous events than results of planned field experiments. Promising developments in the last few years for in situ data acquisition will play a key role in this issue. Here we summarize activities carried out concerning HABs in stratified systems in the last 10 years, and the main advances. We also identify issues that chart future progress.

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* BHABS – THE NEW HAB IN GEOHAB WITH THE BIG BACK STORY: A RETROSPECTIVE TO INFORM THE FUTURE
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From Alexander the Great (800 B.C.) and the T’ang Dynasty (618-907), the ancients were aware of the dangers of eating some types marine fishes. Peter Martyr’s 1511 description of people who ‘eat those fish were attacked by divers and strange maladies’ is considered the first published account of ciguatera fish poisoning (CFP). Similar descriptions of maladies followed from the Gulf of Guinea (1525), Mauritius (1601) and the New Hebrides (1606) scattered through 17th and 18th century naval logs from tropical expeditions. A number of regional observations of toxic fish, some of which were associated with clinical accounts of CFP symptoms, were reported in the early 19th century. By the late 19th-early 20th centuries compilations of these reports into atlases or global summaries marked the progress of ciguatera knowledge. These static summaries helped inspire more systematic inquiries of ecological conditions associated with CFP outbreaks. By the mid-20th century landmark discoveries of the toxins were followed quickly by description of the causative organisms (Gambierdiscus) and hypotheses about toxin transfer in marine food webs. Refinement of analytical methods for ciguatoxins in the last decade of the century
paved the way for pharmacological studies depicting cellular mechanisms and provided cell-based detection methods. The 21st century has witnessed a resurgence of interest in ciguatera research including a revision of the genus *Gambierdiscus*, descriptions of new species, and molecular assays for their detection and quantification. The field is well positioned to address questions about the consequences of ecological changes on the future occurrences of CFP.

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GEOHAB Asia was formally established in 2010 following two open science meetings in 2007 and 2008. The primary aim of GEOHAB Asia is to facilitate and promote exchange of information and cooperative research among people working on HABs in Asia based on the GEOHAB comparative model. The program would also complement existing regional HAB projects that operate under the IOC umbrella or otherwise. Many studies on HABs have been carried out in East and Southeast Asia even before the formation of GEOHAB Asia. Some countries in the region also have national HAB programs that are endorsed by GEOHAB or formulated based on the GEOHAB model. A wide range of HAB species affect Asian countries including *Prorocentrum* spp., *Cochlodinium polykrikoides*, *Karenia mikimotoi*, *Noctiluca scintillans*, *Pyrodinium bahamense* var. *compressum*, *Alexandrium* spp., *Dinophysis* spp., and benthic dinoflagellates. In 2012 the IOC was able to secure some funding from the South Korea government for GEOHAB Asia to implement a comparative regional project on benthic HABs in Southeast Asia for a period of two years. A training workshop on the ecology and taxonomy of benthic HAB species was conducted in Malaysia in 2012 as part of the project. Ideally several more projects outlined in the GEOHAB Asia Implementation Plan should be conducted to meet the trained manpower, management and mitigation needs of countries affected by HABs in the region. Efforts to promote funding for these projects from the respective governments and other sources should be continued regardless of whether or not GEOHAB continues to exist.

![Intensive bloom of Noctiluca in a fish cage-farming coastal inlet in Sabah, Malaysia in April 2014. The Noctiluca bloom preceded intensive blooms of Cochlodinium polykrikoides that resulted in massive fish kills in the area.](image)

*Photo: Gires Usup*
*SELECTED TOPICS ON OCEAN CHANGE IN THE WIDER CONTEXT OF SUSTAINED OCEAN OBSERVATIONS AND CLIMATE VARIABILITY*

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The ocean plays a key role on the climate system. Ocean observations and ocean reanalysis systems have shown that 90% of the climate change induced heating of the plant is found in the ocean. Similarly large scale changes in the hydrological cycle of the atmosphere imprint themselves in changes in the upper ocean salinity. However, both the warming and changes in salinity are not uniform and moderated by the wind driven ocean dynamics.

The mean and time variable ocean circulation plays an essential role in the regional redistribution of heat, fresh water, carbon, oxygen and nutrients. On the largest scale, in addition to the wind driven forcing, arguably the global overturning circulations regulate many aspects of the global climate. New observations in the North Atlantic Subpolar Subtropical gyre demonstrate the inherent variability of the Atlantic Meridional Overturning Circulation (AMOC) and the challenge to fully observe and understand its dynamics. In the southern hemisphere the cross Antarctic Circumpolar Current flows are thought to play a substantial role in the ocean’s uptake of heat and carbon. Recent observations and model studies suggest that local eddy dynamics need to be taken into account to estimate meridional fluxes.

All cases demonstrate that the rich spectrum of ocean dynamics need to be considered when estimating changes in regional ocean heat uptake, CO2 budgets and possibly even more so for estimates of future ocean acidification, freshwater budgets and associate changes in the subpolar stratification. The complexity of the challenge demands large scale global coordination of ocean observations, research activities and efforts to inform the public on sustainability issues in the marine realm.

*MODELING PYRODINIUM BLOOMS IN SEVERAL BAYS IN THE PHILIPPINES*

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As part of an on-going Department of Science and Technology-University of the Philippines-Marine Science Institute (DOST-UPMSI) program on the ecology and oceanography of Harmful Algal Blooms in the Philippines, models of *Pyrodinium bahamense* blooms in several bays in the country have been developed to serve as diagnostic and prognostic tools. Two-dimensional cyst-based advection models have previously been created for Manila Bay, where massive blooms of the organism were recorded from 1986 to about 2000. Recently three other embayments i.e., Sorsogon, Matarinao and Murcielagos Bays have been the subject of interdisciplinary studies on *Pyrodinium* toxic blooms.

We present progress in the development of integrated model/s of the bloom dynamics of *P. bahamense* var. *compressum* with focus on Sorsogon Bay. The data collected from periodical field work were used to parameterize and validate simulations. The hydrodynamic model was developed using the DELFT-3D platform and integrated with a 3-dimensional individual-based model made primarily for the study of the bloom dynamics of *P. bahamense* var. *compressum*. The main factors affecting bloom dynamics were identified and represented in the model mechanistically. The different life cycle processes of *Pyrodinium* within its cyst and cell stages are represented through the synthesis of laboratory and field studies. Future directions including possible application of the models to the management of *Pyrodinium* blooms in the country are discussed.
III. OUTCOMES OF THE BREAKOUT SESSIONS

III.1. BREAKOUT SESSION #1: What has GEOHAB accomplished and what project objectives have not been accomplished?

Both general and specific achievements of GEOHAB were identified. The strategic framework of GEOHAB has been very useful, particularly with respect to interdisciplinary scientific activities. The comparative approach was also very productive in terms of facilitating interactions among scientists from different regions. The scientific guidance provided by GEOHAB has been particularly beneficial to early-career and less-experienced scientists. In terms of the greatest achievement by each Core Research Project (CRP), the discussion group developed the following list:

- **Upwelling Systems**: This CRP undertook a review, resulting in a set of papers in the journal *Progress in Oceanography*. Ultimately, the group was highly beneficial, particularly for questions regarding bathymetry, physical factors, circulation, and for establishing the comparative approach that was carried forward by other CRPs.

- **Eutrophied Systems**: This CRP developed a global approach to develop a consensus of ideas about the relationship of eutrophication to HABs. The highly cited papers in the journal *Harmful Algae* reflect substantial impact of this CRP. These papers also effectively communicated larger concepts of the CRP to the scientific community.

- **Stratified Systems**: This CRP encouraged significant progress in this field of study and the CRP influenced the direction and execution of research. Significant progress was made in development of technologies for sampling and observations with fine resolution and on thin layers.

*Summary of the main gains achieved and future challenges of the research of HABs in Stratified Systems*
• **Coastal Embayments and Fjords**: Significant progress was made in understanding and observations of cell life cycle and strategies. The group helped identify mechanisms that may be common to coastal embayments and fjords in different regions.

• **Benthic HABs**: Smaller workshops were useful to focus on particular topics and concepts. This CRP was successful in terms of the comparative approach.

The greatest GEOHAB achievements, outside the CRP activities, were the HabWatch workshop and subsequent events enabled by this workshop (see http://hab.ioc-unesco.org/index.php?option=com_oe&task=documentSearch&field=general&searchText=HabWatch). GEOHAB has been strong in education and presentation of technology utilization. The Modelling Workshop also was considered an important accomplishment (http://hab.ioc-unesco.org/index.php?option=com_oe&task=viewDocumentRecord&docID=6659).

In terms of highest priority topics not yet achieved by GEOHAB, the following topics were identified:

• Data sharing is needed, as is a higher level of integration among endorsed projects and creation of associated infrastructure.

• GEOHAB output is not utilized enough at the government decision-making level.

• In addition to scientific impact, a greater programmatic impact (with potential metrics for its assessment) should have been achieved;

• Greater emphasis on international educational programs is needed (e.g., similar to the GEOHAB modelling workshop held in Ireland). There has been a failure to introduce research to students and to create a common language across labs (through exchange of students, workshops as well as more formalized structure). In part, this is because it is difficult to fund such activities.

• Need for development of more accurate modeling frameworks (which requires financial support).

• Need for research to improve parameterization of key processes so support more accurate models; this requires a tight communication of modelers with non-modelling researchers

• Need for more sustained and distributed modeling capability (with different scales of models), which should be seen as an endpoint.

• Failure to connect physical oceanography and biology (especially for low-biomass species), partly due to problems of resolution (spatial/temporal under-sampling).

• There has been no comparative research on benthic/planktonic cyanobacteria blooms, due to the focus of GEOHAB primarily on marine species.

• Eutrophication/climate change: have not leveraged the sedimentary record to inform current activities.

• Technological advances: high-throughput sequencing has generated a tremendous amount of observational data, sometimes in the absence of questions, thus contributing to the underutilization of these data. What is feasible with these new techniques and what kinds of questions could be addressed?

The greatest impediments to achieving GEOHAB goals include the following:
• Lack of a program office that would have fostered and reinforced GEOHAB implementation and visibility (besides the effort done by the different SSC members along GEOHAB lifetime).
• Failure to connect with other international programs (e.g., GOOS).
• Lack of participation by physical oceanographers; perhaps a function of focus on small-scale phenomena and differences in sampling resolution.
• GEOHAB was active solely in the research arena. Better communication and emphasis of economic benefits of research is needed. Socioeconomic impacts were not included/emphasized in the GEOHAB approach, yet impact information is frequently required for proposals.
• Ocean observing systems: better consideration and integration of HABs.
• There was emphasis on comparative approaches by GEOHAB, but there is a lack of international funding for these types of ecosystem comparison projects.

*Lively discussion during one of the breakout sessions*
III.2. BREAKOUT SESSION #2: What Concept Paper ideas should move forward and how?

The concept papers were not ranked, but the topics below were selected as promising for implementation. Some criteria for selection include the following:

- Does it fit into existing GEOHAB activities?
- Does it answer fundamental objectives from Breakout #1?
- Could it be accomplished within the next 10 years?
- Does it require international cooperation?
- Does it lead to improved prediction, management, or better human/ecosystem health?

The specific topics recommended from among the concept papers submitted (see Appendix 4) include the following:

- **Cyanobacteria**: Knowledge could be gained by comparing cyanobacterial blooms in brackish and freshwater systems. The Baltic Sea, Australia, and South Africa are obvious study locations due to the cyanobacterial bloom issues. There are several large projects that should be considered, such as NERC GloboLakes ([http://www.globolakes.ac.uk/](http://www.globolakes.ac.uk/)) and Netlake ([http://www.cost.eu/domains_actions/essem/Actions/ES1201](http://www.cost.eu/domains_actions/essem/Actions/ES1201)) and linking with the Global Lake Ecological Observation Network (GLEON) ([http://www.gleon.org/](http://www.gleon.org/)). Funding may be derived from sources that invest in environmental issues in developing countries.

- **HABs in a changing world**. For example, does stratification increase HABs? Can we attribute increases in HABs to climate? There should be a quantitative workshop to get consensus among different experts. The Earth observing community and long-term datasets, for example from the Continuous Plankton Recorder, should be considered. It might be possible to add a couple of parameters to existing observing programs.

- **Links between blooms and anoxia**. High-biomass blooms often occur in upwelling areas. Oxygen parameters are changing the most, for example, in the Benguela Current system. A project on this topic could include the Benguela, Humboldt, and other upwelling systems. The microbial loop is important in these areas and perhaps cyanobacterial blooms. This topic would not include permanent “dead zones”, only the temporary ones. It would focus on high-biomass, short-term events. There is a modelling challenge in these systems.

- **Sea-cage fish farming and HABs**. Is there causality between fish farming and HABs, particularly, fish-killing toxic HABs? There should be good funding available for such research, for example from regional governments because they want to know where to place farms, and from marine insurance companies.
III.3. BREAKOUT SESSION #3: What would the next iteration of GEOHAB-like activities look like, and what ideas should be presented to IPHAB?

The discussions in this session built on the previous two sessions. Much was learned from the CRPs, but they should be restructured. GEOHAB needs to move away from the CRP structure and from the comparative approach. Any working group formed needs to have clear goals and clear deliverables and be of relatively short duration. They should produce useful documents (such as IOCCG monographs). The mission and goal of GEOHAB needs to be refocused – it must include societal goals, ecosystem services and human health, be part of the “blue economy” and involve managers/stakeholders from the start.

Three “platforms” or themes were envisioned:

1. BHABs. This would be the one CRP that would be continued in much the same way that it has been operating, since it was only recently established and BHABs are a major public health issue worldwide.
2. Technology and scientific exchanges for HAB detection and research. This theme would be a cross-cutting application and comparison of tools and methods, instruments, and measuring techniques (e.g., hydrographic tools, tools to measure biological rates/fluxes, genetic tools, modelling).
3. Transitioning science to application. This theme would focus on enhanced monitoring, development of new technologies, mitigation, and translation of research results into practical applications.

An important role of GEOHAB has been the so-called “Framework Activities”. GEOHAB follow-on should continue with this approach. Some of the approaches to enhancing HAB-related framework activities include the following:

- Coordination with international research projects to apply GEOHAB approaches to research questions of related projects.
- More focus on creating global databases related to HABs, including expanding HAEDAT (working together with ICES, PICES, and other organizations).
- Open Science Meetings focused on specific HAB-related science issues. Ocean Science Meetings should focus on narrow achievable goals (change perhaps to format such as Gordon Conferences – cover more global issues such as climate change and HABs, fish farming etc.).
- New attention to climate change effects on HABs.
- New attention to the effects of agriculture on both high-biomass HABs that lead to hypoxia and low-biomass toxic HABs.
- New attention on socio-economic consequences of HAB. How do we engage the socio-economic research community and the health specialists?
- The new program should elaborate status reports (IPCC like).
- Training workshops (“common garden” experiments, exchange programmes or summer schools).
- Modelling workshops.
- Establish long-term sentinel sites (with endorsement to empower their continuation).
- Workshops on inter-comparison and standardization of methods.
• Technological developments (cell, life stage or toxin detection, in situ observations).
• Infrastructure to disseminate the information (applications for tablets, iPhones, etc.) and reach the younger generation.

*New integrative multidisciplinary technology is already contributing to monitor the biological processes in situ. Environmental Sample Processor (EPS, from MBARI).*
Two main initiatives arose as the primary outcome of the OSM. These were presented and discussed at the Concluding Remarks session.

**A) Implementation of the BHAB Core Research Programme or platform**

Advances on benthic HAB (BHAB) research will require reaching a wider scientific community and stakeholders. Thus, beyond BHAB researchers, the creation of a BHAB focused platform would allow drawing the attention of, for example, fisheries scientists, sociologists, physicians, and toxicologists. People with such expertise could be incorporated in a Steering Committee to continue work on BHABs.

The BHAB platform would foster research activities to address the questions and priorities identified by the BHAB Report (GEOHAB 2012)*. In addition it would foster some of the following framework activities:

- capacity enhancement: creation of an outreach program, training through active research workshops, elaborate manuals in different languages (including French and Spanish)
- implementation of a database including risk areas maps; and
- development of models to identify outbreak triggers, species and toxin profiles, ecotoxicology, and epidemiology.

The BHAB platform research plans and activities would be implemented through working groups, facilitated by the IPHAB and ISSHA events (which could be opportunistic meetings), and reinforced through publicity (announcements) within the countries of the involved researchers.

B) Establishment of a new programme, GlobalHAB, to be implemented over the next 10 years

The international community is aware that our planet is experiencing:
- globally changing drivers and pressures;
- globally changing HAB biogeography;
- globally improving infrastructure for observations; and
- globally changing HAB impacts.

Conceptual diagram that illustrates ongoing changes that the planet is experiencing and which are linked to HABs. This draft figure was presented and discussed in the Concluding Remarks session. The image, provided by Patricia Glibert at the meeting, also suggests how the new GlobalHAB program would integrate future needs on HAB research.
The future steps on HAB research should integrate these global challenges with a new perspective, as illustrated for instance in the image above. The new programme, so-called GlobalHAB, will aim to address the science and societal challenges of HABs through the application of advanced technologies, training and capacity building. It will also build linkages with broader science domains and emphasize social science communications.

In order to start to move forward with GlobalHAB in 2015, there was a general agreement and a recommendation to:

1. Maintain the basic GEOHAB Science Plan, with an addendum that could integrate new aspects and specific objectives;
2. Include freshwater HABs;
3. Develop a new Implementation Plan including BHABs, a list of milestones, deliverables and a time line;
4. Enhance contact with other partners (e.g. GEO, GEOSS, ICES, PICES, GLEON);
5. Continue as an independent science programme under the auspices of SCOR and IOC UNESCO.
**APPENDIX 1 – Open Science Meeting Program**

**DETAILED PROGRAMME**

**WEDNESDAY, 24 APRIL**

8:30-8:45 Welcome – *Wendy Watson-Wright*, Assistant Director General of UNESCO, and Executive Secretary of IOC

8:45-9:00 Goals of the meeting – *Elisa Berdalet*, Vice-Chair, GEOHAB

9:00-9:30 Overview of GEOHAB – *Raphael Kudela*, Chair, GEOHAB

**GEOHAB Past/Present**

**Session Chair:** *Stewart Bernard*

9:30-10:00 Core Research Project: Harmful Algal Blooms In Upwelling Systems – *Grant Pitcher*, Fisheries Research and Development, South Africa

10:00-10:30 HABs and Nutrients: Progress of the Core Research Programme – *Patricia Glibert*, University of Maryland, USA

10:30-11:00 Break

11:00-11:30 Roles of Stratification in Harmful Algal Bloom Ecology – *Beatriz Reguera*, Instituto Español de Oceanografía, Spain

11:30-12:00 Dynamics of Harmful Algal Blooms in Semi-Enclosed Coastal Embayments – Processes and Mechanisms Defined By These Ecosystems – *Allan Cembella*, Alfred Wegener Institute for Polar and Marine Research, Germany

12:00-12:30 BHABs – The New HABs In GEOHAB With The Big Back Story: A Retrospective to Inform the Future – *Patricia Tester*, National Oceanic and Atmospheric Administration, USA

12:30-14:00 Lunch

Poster Set up

14:00-16:00 BREAKOUT SESSION #1: What has GEOHAB accomplished and what project objectives have not been accomplished?

16:00-18:00 Poster Session
THURSDAY, 25 APRIL

Regional GEOHAB

Session Chair: Suzanne Roy

8:30-9:00 GEOHAB Asia: Past, Present and Future – Gires Usup, Universiti Kebangsaan Malaysia

9:00-9:30 GEOHAB Earth Observation Activities and Partnerships: Past and Future – Stewart Bernard, Earth Systems Earth Observation, CSIR – NRE, South Africa

9:30-10:00 Modeling Pyrodinium Blooms In Several Bays in the Philippines – Rhodora Azanza, University of the Philippines

10:00-10:30 Closing the Gap: Species-Specific Studies of Harmful Algal Blooms – Esther Garcés, Institut Ciències del Mar, CSIC, Spain

10:30-11:00 Break

11:00-11:30 Integrative Approach to the Study of Ciguatera Fish Poisoning: The Example of French Polynesia – Mireille Chinain, Institut Louis Malardé, UMR, French Polynesia

11:30-12:00 Review on Algal Toxins, Chemotaxonomy, Ecological Function and Effects, Trophic Transformations – Philipp Hess, Ifremer, France

12:00-13:30 Lunch

Moving Into The Future

Session Chair: Michele A. Burford

13:30-14:00 Hindcasts and Future Outlooks of Global River Export and Nutrient Release From Aquaculture – Lex Bouwman, PBL Netherlands Environmental Assessment Agency and Utrecht University, Netherlands

14:00-14:30 Dancing With the Tides: How to Predict Complex Dynamics in Plankton Communities? – Jef Huisman, University of Amsterdam, Netherlands

14:30-15:00 Report backs from Breakout Session #1

15:00-15:15 Introduction of concept papers – Raphael Kudela

15:15-17:00 BREAKOUT SESSION #2: What Concept Paper ideas should move forward and how?

17:00-18:00 Poster Session
Session Chair: Gires Usup

8:30-9:00  The Quest for Biological and Physical Measurements of HABs: Progress and Prospects – Jules Jaffe, Scripps Institution of Oceanography, USA

9:00-9:30  Harmful Algal Blooms and Climate Change: Monitoring, Prediction and Management – Gustaaf Hallegraeff, University of Tasmania, Australia

9:30-10:00  Selected Topics on Ocean Change in the Wider Context of Sustained Ocean Observations and Climate Variability – Martin Visbeck, GEOMAR, Germany

10:00-10:30  Report backs from BREAKOUT SESSION #2

10:30-11:00  Break

11:00-13:00  BREAKOUT SESSION #3: What would the next iteration of GEOHAB-like activities look like, and what ideas should be presented to IPHAB?

13:00-14:30  Lunch

14:30-15:00  Report backs from Breakout Session #3

15:00-15:30  Break

15:30-16:45  Discussion of post-2013 activities – Patricia Tester

16:45-17:00  Concluding remarks – Raphael Kudela
APPENDIX 2 – Meeting Participants

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SEEDING OF GYMNODINIUM CATENATUM BLOOMS ON THE IBERIAN SHELF: TESTING THE CYST BED HYPOTHESIS

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Dinoflagellate blooms in upwelling areas are characterized by a high long-term (decadal) and short-term (upwelling cycle) irregularity despite their recurrence. Knowledge on the autecology and bloom dynamics of HAB species, namely the dinoflagellate Gymnodinium catenatum, has progressed enormously in the last decades. However, in the Iberian upwelling system very little is known on the origin of the seed population and the factors that trigger the initiation of G. catenatum blooms.

Cyst surveys along the shelf have shown that viable cysts, despite in low concentrations (<25 cysts.cm⁻³), occur mainly in muddy patches at mid-shelf, motivating the study of the hydrological processes needed for the successful benthic-pelagic coupling of seeding. Here, a Lagrangian model was used to test if cysts re-suspended near the bottom may be passively transported to the photic zone where the environmental conditions may trigger their germination. The particle-tracking experiments were performed using the solutions of a 3D hydrodynamic model configured to realistically reproduce shelf circulation off Aveiro-F.Foz, where blooms are frequently recorded. The results show that bottom cysts released at the positions of the mid-shelf muddy patches (~100 m depth), can frequently be transported to the photic zone (< 20 m) in less than 10 days. This contrasts with periods when the cysts are maintained below the photic zone for up to two months. Results also indicate a high inter-annual variability on cyst re-suspension probability. These results look promising but future research is needed in other shelf areas if we aim at a realistic forecast of G. catenatum blooms in W Iberia.

EMERGENT MARINE TOXINS IN THE TEMPERATE NORTH ATLANTIC COAST

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The occurrence of toxins typical from tropical environments in waters from the north Atlantic coast has been sporadically reported in the past years. However, these infrequent reports have been preceded by human intoxication episodes. For this reason it became evident that the analysis of coastal water needed a more detailed survey of marine toxins.

First reports on the occurrence of ciguatoxin (CTX), of tetrodotoxin (TTX) and its analogues, of Spirolides (STX), and of β-methylamino-L-alanine (BMAA) in temperate north Atlantic coast, and in the Portuguese coast in particular, have come to light in recent years.

The presence of these toxins has been shown, in levels high enough to affect human beings, such as one intoxication due to the consumption of the gastropod Charonia lampas collected in the south of Portugal (and positive for TTX and its analogue 5,6,11-TrideoxyTTX) or the intoxication due to consumption of fish caught off the Madeira archipelago, which revealed the presence of CTX and analogues.
Moreover, organisms capable of producing such toxins have been found. A bloom of Ostreopsis spp. (a potential producer of palytoxin) occurred on the south coast of Portugal. BMAA production by a diverse number of strains in three major Portuguese estuaries was found. And the presence of SPX in Portuguese coastal waters has also been ascertained. The detection of new vectors, particularly those potentially used as food by human beings, suggests that monitoring of marine toxins should be extended to other species and that regulated limits of toxin should be closely monitored.

TURECOTOX AND ECOALFACS PROJECTS: CONTRIBUTIONS OF TWO GEOHAB ENDORSED PROJECTS

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From 2009 to 2013, the TURECOTOX (CTM2006-13884-C02-00/MAR) and ECOALFACS (CTM2009-09581) projects, endorsed by GEOHAB, focused on the interactions between small-scale turbulence and the biology of toxigenic dinoflagellates (toxin-producing HABs). Research included ecophysiological experiments and fieldwork in two contrasting areas: the Galician Rías Baixas (upwelling systems, Atlantic coast) and the microtidal estuary of Alfacs bay in the Ebro Delta (coastal embayment, stratified system, Mediterranean Sea).

Laboratory experiments with cultures showed how small-scale turbulence can modulate different ecophysiological processes including growth rate, cell cycle patterns, asexual encystment, nucleic acids, toxin and DMSP cell quota and infection by parasites. However, the cellular mechanisms underlying the observed responses are still unknown.

In the Rias, the population dynamics (division rate, viability, mortality) of Dinophysis spp. and their behavior (vertical migration, mixotrophy) were studied with the same spatio-temporal scale than the fine-scale hydrodynamical processes (water velocities, shear, vertical diffusion, turbulence). For the first time, data on the formation, maintenance and dissipation of thin layers of Pseudo-nitzschia spp. were obtained in this area.

In Alfacs bay, several modeling approaches (3D hydrodynamic model combined with a Lagrangian particle-tracking module) validated by continuous records of physical and meteorological data have been implemented to understand how the complex circulation dynamics may facilitate water retention and thus phytoplankton biomass accumulation in the inner part of the bay. We hope that most undergoing efforts will improve the understanding of the link between physical dynamics and biological and ecological processes (growth, mortality, migration) of selected HAB taxa and/or functional groups in the bay.
DANCING WITH THE TIDES: FLUCTUATIONS OF COASTAL PHYTOPLANKTON ORCHESTRATED BY DIFFERENT OSCILLATORY MODES OF THE TIDAL CYCLE

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Population fluctuations are often driven by the interplay between intrinsic population processes and extrinsic environmental forcing. To investigate this interplay, we analyzed fluctuations in coastal phytoplankton concentration in relation to the tidal cycle. Time series of chlorophyll fluorescence, suspended particulate matter (SPM), salinity and temperature were obtained from an automated measuring platform in the southern North Sea, covering 9 years of data at a resolution of 12 to 30 minutes. Wavelet analysis showed that chlorophyll fluctuations were dominated by periodicities of 6 hours 12 min, 12 hours 25 min, 24 hours and 15 days, which correspond to the typical periodicities of tidal current speeds, the semidiurnal tidal cycle, the day-night cycle, and the spring-neap tidal cycle, respectively. During most of the year, chlorophyll and SPM fluctuated in phase with tidal current speed, indicative of alternating periods of sinking and vertical mixing of algal cells and SPM driven by the tidal cycle. Spring blooms slowly built up over several spring-neap tidal cycles, and subsequently expanded in late spring when a strong decline of the SPM concentration during neap tide enabled a temporary “escape” of the chlorophyll concentration from the tidal mixing regime. Our results demonstrate that the tidal cycle is a major determinant of phytoplankton fluctuations at several different time scales. These findings imply that high-resolution monitoring programs are essential to capture the natural variability of phytoplankton in coastal waters.

TECHNICAL COOPERATION PROGRAM TO ENHANCE DEVELOPING NATIONS’ CAPACITY FOR HARMFUL ALGAE MANAGEMENT AND MITIGATION

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Harmful algal may produce potent toxins that are transferred through marine food webs, threatening wildlife diversity and, when accumulating in seafood, human health, international trade and sustainable coastal fisheries development. In the context of climate change, blooms of harmful algae appear to be more frequent and widespread globally, drastically impacting developing nations including numbers of vulnerable small islands.

The IAEA Technical Cooperation Program has been supporting technology transfer and capacity building to assist member states in managing harmful algae through toxigenic species surveillance, toxin monitoring, and historical bloom reconstruction. Technologies involve the radioligand receptor binding assay (RBA) for toxins associated with Paralytic Shellfish Poisoning (PSP), a method recently adopted as AOAC First Action Official Method (2011.27), and with Ciguatera. Other methods include radiometric sediment core dating combined with fossil cyst abundance to allow reconstruction of the prior history of blooms and their relationship to climate. Following a successful project in Southeast Asia, implementation of these technologies has been initiated in Africa, the Caribbean and Latin America.
**PSEUDO-NITZSCHIA (PERAGALLO) AND DOMOIC ACID IN LOCH EWE, A SEA LOCH ON THE WEST COAST OF SCOTLAND**

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The diatom *Pseudo-nitzschia* (Peragallo) is routinely observed throughout the year in Scottish waters. Enforced closures of offshore beds of *Pecten maximus* as a result of high concentrations of domoic acid (DA) during the late 1990s had a severe impact on the scallop fishing industry in this region. Loch Ewe, a sealoch on the west coast of Scotland (57° 50.14' N 5° 36.61’ W), is part of a network of monitoring sites operated by Marine Scotland Science. A detailed study of the uptake/depuration of DA in *Mytilus edulis* and *P. maximus* over a two year period was performed to investigate differences between the two shellfish species. This study revealed that *M. edulis* can take up and depurate up to 7 µg DA g\(^{-1}\) during one week. DA concentrations in *M. edulis* never exceeded the closure limit of 20 µg DA g\(^{-1}\) during the study. In contrast, uptake of DA in *P. maximus* continued over a 6 week period, with DA concentrations of up to 66 µg DA g\(^{-1}\) recorded in gonad tissue. DA concentrations in *P. maximus* remained over the closure limit for 12 weeks during this event. The *Pseudo-nitzschia* population at the site was observed to be diverse with seven species recorded including DA producers *P. australis* and *P. seriata*. A study revealed copepods from this site can contain up to 9 ρg DA individual\(^{-1}\). This confirms the potential for DA to be vectored up the food web to higher trophic levels in this region.

**DETECTING HARMFUL ALGAL BLOOMS USING SATELLITES, IN SITU PIGMENTS AND MICROSCOPE CELL COUNTS OFF THE IBERIAN WESTERN COAST**

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The increase in Harmful Algal Bloom (HABs) episodes in the last decades is a major challenge for marine scientists and coastal managers, due to its strong negative socio-economic consequences.

The use of ocean colour sensors to estimate chlorophyll-a, the biomass proxy for phytoplankton, allows a synoptic and quasi-permanent following of this pigment concentration in surface waters. Hence, it has received a growing investment in the scientific community to detect HABs over the world.

However, remote sensing (RS) data alone does not provide the knowledge of the species involved, and it is generally accepted that RS should be complemented with in situ observations, once the bloom has been detected by satellite imagery.

HABs episodes occur frequently in the Portuguese coast, during late summer, generally under relaxation conditions after upwelling periods, *Dinophysis acuta* and *D. acuminata*, and *Gymnodinium catenatum* are recurrent species.

This work presents results obtained from two cruises off Aveiro (NW Portuguese coast), an area with particular incidence of blooms, in September 2010 and 2011. Water samples were collected for determination of chlorophyll a (Chla), accessory photosynthetic pigments and species abundance, in surface and DCM (deep chlorophyll maximum). Chla was also measured by an in situ fluorometer, coupled to a CTD. Data on light penetration was also recorded. Contemporaneous satellite imagery of SST (Sea Surface Temperature) and Chla were processed.
The proportion of the three phytoplankton size classes, pico-, nano- and microplankton were estimated from biomarker pigments concentrations. The composition of taxonomic groups was estimated by Chemtax (a program that applies matrix factorization to pigments data in order to estimate the contribution of phytoplankton groups to total chlorophyll a). Microscope cell counts were performed. Synoptic Chla L3 and L4 products from MODIS and MERIS, were used to characterize the Chla distributions contemporary to the surveys.

Significant correlations were obtained between RS Chla, Chla determined by in situ fluorimetry and by HPLC. Significant correlations were also obtained between Chla concentration and microplankton percentage within the community.

Significant correlations between taxonomic groups obtained by Chemtax and by microscopy were found. Communities were found to be different in the two cruises, which highlights the relevance of understanding phytoplankton community structure.

In summary, the results obtained show the advantages and constraints of using ocean colour images to monitor the occurrence of algal blooms (including HABs), and highlight the need for further work with in situ data on pigment concentration and microscopy observations to refine RS detection of HABs in Iberian waters.

**QUANTIFICATION OF THE TOXIC DINOFLAGELLATE Ostreopsis spp. BY qPCR ASSAY IN MARINE AEROSOL**

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Marine aerosols are airborne particles of biological origin containing algal cells, bacteria, spores, and viruses, which are carried out by bubbles to the sea surface microlayer and to the atmosphere. Since the summer of 2005, in the Mediterranean Sea, growing concerns regarding exposure to harmful marine aerosols associated with toxic benthic dinoflagellate *Ostreopsis* spp. blooms have been reported, as they represent major health and economic risks to human populations.

Toxic events in humans after inhalation or cutaneous contact have been reported during *O. cf. ovata* blooms and were attributed to palytoxin (PLTX)-like compounds produced by this microalga. In this context, we developed a qPCR assay for the estimation of the toxic benthic dinoflagellate *Ostreopsis* cf. *ovata* in the complex matrix of marine aerosol at Sant Andreu de Llavaneres (northwestern Mediterranean Sea) during a bloom together with a determination of PLTX-like compounds using hemolytic assay and liquid chromatography.

Marine aerosol samples collected at two stations were analyzed by qPCR. The sensitivity was set at two rDNA copy number and $8 \times 10^{-4}$ cell per reaction. Results showed that *O. cf. ovata* abundance in marine aerosol during the bloom varied in the range of 1–102 cells per filter. No PLTX was detected in the aerosol filters by analytical determinations, while the estimation of PLTX like-compound concentrations in microepiphytic assemblages varied between 0.1 and 1.2 pg/cell.

In conclusion, the developed qPCR assay is a highly sensitive and specific quantification method for toxic *O. cf. ovata* in a complex matrix, such as marine aerosol.
PHENOMER: BETTER KNOWLEDGE OF HAB WITH THE HELP OF CITIZEN OBSERVATIONS

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In 2013, Ifremer and its French scientific and NGO partners are launching a citizen monitoring program on HAB along the French coast: PHENOMER (an acronym for ‘visible phenomena at sea’ in French). Citizens are invited to report and/or sample HAB events they may observe. The twofold objective is to help scientists gain a better knowledge of red tide occurrences, and to increase communication on HAB to the general public.

In the same context a partnership with the schools of the “îles du Ponant” has been initiated. Schoolchildren have been asked to follow a phytoplankton sampling protocol in the same location every week in order to create a new high frequency database on micro-phytoplankton diversity and HAB risks among islands from Atlantic to English Channel. All results will be available on www.phenomer.org

OCEANOGRAPHIC SETTINGS ASSOCIATED WITH INTERANNUAL VARIABILITY IN THE INITIATION OF DINOPHYYSIS BLOOMS

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In a conceptual model proposed before, the onset of the upwelling season and availability of Mesodinium prey are essential conditions for the initiation of Dinophysis acuminata blooms in the Galician Rías Baixas (NW Spain). Here we examine the climate variability through teleconnection patterns as the North Atlantic Oscillation (NAO), the dominant mode of atmospheric variability in the North Atlantic, and winter conditions—minimum seawater temperature, persistence or absence of scattered individuals in the winter months within the rías and adjacent shelf, and time of initiation of the upwelling season and its intensity—from observations in the last 20 years to explain the exceptional (early initiation and intensity) D. acuminata bloom in 2012, in what appeared to be a mesoscale event affecting other regions in Western Europe. In the Galician Rías, the initiation of the D. acuminata growth season appeared tightly coupled to the upwelling season. Our results suggest that anomalous winter upwelling patterns (predominance of upwelling in winter) caused in response to changes in the surface forcing, combined with the presence of scattered overwintering cells of Dinophysis (January-February) that would act as the inoculum population are the key factors explaining early initiation of the blooms. These scattered cells would act essentially as “pelagic seed bank”. Our ongoing activities include parameterization of these key factors to describe the “optimal environmental window” for D. acuminata blooms.
Harmful Algal Blooms, in particular recurrent blooms of *Alexandrium catenella*, associated to the Paralytic Shellfish Poisoning (PSP), pose a serious socio-economical problem in Southern Chile. During the last decade there has been a northwards progression of the impacted area, reaching the inner sea of Chiloé during the last most intense PSP events. Record levels of PSP toxins in shellfish have been recorded in the Aysén region with a historic maximum of $10^7 \times 10^4$ µg STXeq kg$^{-1}$ in Chilean mussels (*Mytilus chilensis*) during 1996. This situation has led the health authorities to enforce shellfish harvesting closures through extensive geographic areas (up to 450 km) for very long periods (up to years). PSP events in the region have shown a seasonal pattern, with the initiation by the end of spring (December) and decay in early autumn (April). Considerable interannual variability has also been observed, with weaker or no events at all in some years. Here we analyze trends in the occurrence and intensity of PSP events in the last 15 years and its relationship to climate anomalies. Our results suggest that climate descriptors, such as negative anomalies in rainfall and positive anomalies in sea surface temperature during the spring-summer transition play a key role in the development of exceptionally toxic events in Southern Chile. This variability appears determined by large-scale climatic processes, such as the Antarctic Oscillation (AAO) and modulated by small-scale local processes. Positive phases of AAO during spring appear as the optimal conditions for the development of *A. catenella* blooms.

**ETUDE D’UNE EFFLORESCENCE A CYANOBACTERIE DANS LE BARRAGE HAMMAM-DEBAGH (GUELMA-ALGERIE)**

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La prolifération d’algues en eau douce et en particulier les efflorescences ou bloom des cyanobactéries, généralement toxiques, a un impact majeur sur la perturbation du fonctionnement et de la biodiversité d’un écosystème aquatique ainsi que sur la santé humaine et animale lors de la consommation de l’eau.

Dans le cadre d’une étude du bloom observé dans le barrage de la willaya de Guelma, un échantillonnage a été réalisé au niveau de 6 stations de prélèvement (4 au niveau du barrage et 2 au niveau de la station de traitement) ; ceci dans le but de la détermination de la zone euphotique, de la mesure des paramètres physico-chimiques et de la mesure de la phycocyanine à l’aide d’une sonde TRIOS à phycocyanine. Ceci s’accompagne d’une identification et d’un comptage des cyanobactéries recensées, d’un dosage des éléments nutritifs et d’un dosage des microcystines à l’aide d’une chaîne ELISA (Enzyme-linked Immunosorbent Assay) utilisant un kit Microcystins-ADDA ELISA (microtiter plate) « ABRAXIS » product N° 520011.

L’observation des caractères morpho-anatomiques nous a permis d’identifier le genre *Planktothrix* présentant comme pigment majoritaire la phycéerythrine qui est à l’origine de la coloration rouge brun observée dans la retenue. Quant au comptage de *Planktothrix*, nous avons noté une diminution nette au cours des différents prélèvements effectués ; notant que la teneur en phycocyanine suit la même évolution...
que le dénombrement. Cette diminution est expliquée par la phase de sénescence des cyanobactéries. La présence de toxine a été observée uniquement lors de la phase de sénescence avec des concentrations n’excédant pas 1 µg/l, valeur guide recommandée par l’OMS.

Les mesures de la température, de l’oxygène dissous et de la conductivité ont montré une augmentation d’un prélèvement à l’autre. L’élévation de la température suit le caractère de saisonnalité méditerranéenne et la forte production de biomasse pourrait être la cause des fortes teneurs en pH et oxygène dissous. Les concentrations en nitrites, nitrates, phosphate et ammonium n’excèdent pas les valeurs seuils; ce qui serait dû à la consommation massive de ces nutriments par les cyanobactéries colonisant le plan d’eau.

L’apparition de ce phénomène dans nos plans d’eau destinée à l’approvisionnement en eau potable tire la sonnette d’alarme et impose un suivi rigoureux suivant les recommandations de l’OMS.

*Mots-clés* : cyanobactéries ; *Planktothrix sp.* ; toxicité ; microcystines ; barrage Bouhamdane.

**MODELLING LIFE CYCLE DYNAMICS OF TWO IMPORTANT HAB-TAXA: CYANOBACTERIA AND DINOFLAGELLATES**

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Observations indicate that the life cycle of harmful algae plays an important role in their bloom dynamics. Both cyanobacteria and dinoflagellates produce resting stages that lead to the formation of seed banks. Sudden outbreaks are often the consequence of synchronized germination of resting cells and subsequent growth. Examples of life cycle modelling for two important HAB taxa (cyanobacteria and dinoflagellates) are presented; both distinguish between growing and resting stages, each with specific nutrient requirements and motility behaviour. The results show that the overall bloom characteristics, i.e. timing and duration of these two species in the Baltic Sea are very well reproduced. Since it is expected that both phytoplankton groups benefit from global warming, climate projections have been performed. Cyanobacteria show a significant increase in the maximum abundance of vegetative and resting stages while such a trend is not visible for dinoflagellates. Additional sensitivity experiments indicate that the response of cyanobacteria and dinoflagellates to changes in the atmospheric forcing is highly nonlinear and a result of life cycle related feedback mechanisms.

**MARINE PHYTOPLANKTON TEMPERATURE VERSUS GROWTH RESPONSES FROM POLAR TO TROPICAL WATERS – OUTCOME OF A SCIENTIFIC COMMUNITY-WIDE STUDY**

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Both the Evolution and Climate Change in Oceanography (ECCO) program and the GEOHAB program recently completed a workshop to evaluate how, and whether, there is credible evidence linking global climate change to phytoplankton, and more specifically to harmful algal blooms. The rapidity and complexity of climate change and its potential effects on ocean biota are challenging how ocean scientists conduct research. One way to tackle these challenges is to conduct community-wide scientific studies. While physiological experiments are not new, our experiments were conducted in many laboratories using agreed upon protocols and 25 strains of eukaryotic and prokaryotic phytoplankton isolated across a wide range of marine environments. This community-wide approach provides both comprehensive and internally consistent datasets produced over considerably shorter time scales than conventional individual and often uncoordinated lab efforts. A comparison with prior published data suggests that the optimal temperatures of individual species and, to a lesser degree, thermal niches were similar across studies. However, a comparison of the maximum growth rate across studies revealed significant departures between this and previously collected datasets. Thus, not all phytoplankton thermal traits from the prior literature can be applied to modelling projections of the future ocean. Using our community-wide approach we can reduce such protocol-driven variability in culture studies, and can begin to address more complex issues such as the effect of multiple environmental drivers on ocean biota. This approach is ideally suited to the development of international, community-wide studies supported by GEOHAB and similar programs.

**HABs IN THE STRATIFIED GULF OF FINLAND (BALTIC SEA)**

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Blooms of cyanobacteria are recurrent phenomena in the stratified Gulf of Finland. The spatial extension, duration, intensity and species composition of these blooms varies widely between years. Nutrient, especially phosphorus, and weather conditions affect the outcome of the blooms. The surplus phosphorus related to the pre-bloom upwelling events in the Gulf considerably determines the bloom intensity as the surplus phosphorus left after the spring bloom is consumed, e.g. by vertically migrating mixotrophic ciliate *Mesodinium rubrum*, far before cyanobacterial biomass increases.

Several other, functionally different phytoplankton groups (dinoflagellates, prymnesiophytes), may co-dominate in summer community in the upper layer of the Gulf. Also the sub-surface and deep maxima of migrating phytoplankton and photosynthetic ciliates are regular occurrences. It results in bimodal vertical distribution of phytoplankton characterized by a thick maximum in the upper 10 m layer and a thin maximum in the deeper part of the thermocline. The dynamics and vertical distribution patterns of chlorophyll and motile species in relation to the vertical stratification and its spatial and temporal variations were analyzed on the basis of high resolution observational data. Bimodal distribution with the highest sub-surface biomass of the dinoflagellate *Heterocapsa triquetra* in the areas of locally weaker stratification at the mesoscale and concurrent increase of its biomass in the surface layer were observed in the stratified Gulf of Finland in July 2010.

Information on species forming surface, sub-surface or deep biomass maxima in stratified water bodies and their survival strategies is particularly important because among them are species forming harmful blooms.

**SHIPS PUMPING BALLAST WATER IN A POTENTIALLY HARMFUL ALGAL BLOOM : RISKS INVOLVED**

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Bulk carrier ships transporting cargo along the gulf of Gascony coasts deballast water before (or during) loading cargo. This ballast water generally pumped in the last port, is released in the arrival port itself or the waiting area close by. For the first time in France, in samples of ballast water taken aboard ships in the French port of La Rochelle and coming from Spanish coast, we observed a huge number of potentially harmful dinoflagellates, still alive. A simulation by a computerised 2D model of this release, from the waiting area or the port itself, led us to this conclusion: the released waters spread southward to the main oyster farming area in Europe, or northward to mussel poles and longline areas, in five to six days.

**MOLECULAR CHARACTERIZATION AND CYST-CELL SIZE RELATIONSHIPS IN THE GLOBALLY DISTRIBUTED YESSOTOXIN PRODUCING DINOFLAGELLATE *PROTOCERATIUM RETICULATUM***


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Preliminary results of morphological and molecular analysis of the yessotoxin producing dinoflagellate *Protoceratium reticulatum* (Claparède et Lachmann 1858) Bütschli 1885 are presented. Body size was measured for up to 50 specimens encountered in 34 globally distributed plankton samples. When possible, these measurements were compared to the body diameter of 50 cysts of *P. reticulatum* extracted from surface sediment at the same locations. The average body length of theca and average body diameter of cyst were found to be significantly correlated ($R^2 = 0.83$). A global distribution map of cyst body diameters from 609 surface sediment samples shows that the largest cysts are to be found in South Africa, Chile, British Columbia (Canada), Laptev Sea and southern Greenland. Some of these locations with large cysts coincide with locations where high cell concentrations of *P. reticulatum* have been recorded, in particular South Africa, Chile and British Columbia. It is therefore possible that strains forming these large cysts and cells might be responsible for toxic outbreaks of this species. We also sequenced some
cysts or thecate cells germinated from cysts (LSU, SSU and ITS rDNA). This molecular data reveals that although the LSU and SSU sequences are identical for the sequenced individuals, there are significant differences in the ITS sequences of this species and currently we are reinvestigating cultures to link these molecular differences to morphological variations and toxin production. Samples from Florida and Yucatan contained Protoceratium cf. globosum and no Protoceratium reticulatum.

**SATELLITE DISCRIMINATION OF KARENIA MIKIMOTOI AND PHAEOCYSTIS HARMFUL ALGAL BLOOMS IN EUROPEAN COASTAL WATERS: CLASSIFICATION OF OCEAN COLOUR DATA**

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Dense harmful algal blooms (HABs) are typically detected by satellite remote sensing through analysis of chlorophyll-a as a proxy, though this cannot indicate the harmfulness of bloom or dominant species. An automated data-driven approach has been developed to identify HAB characteristics of ocean colour data, and to classify pixels into ‘harmful’, ‘non-harmful’ and ‘no bloom’ categories using Linear Discriminant Analysis (LDA). The false alarm rate is reduced by labelling data that cannot be reliably classified as ‘unknown’, and discrimination power is increased using spectral slopes of water leaving radiances, absorption and backscattering. This method has been thoroughly validated by the EC AquaMar project for two high biomass HAB species: Karenia mikimotoi off the English and Scottish coasts and Phaeocystis globosa in the southern North Sea, by comparison with in situ measurements of cell concentrations. Accurate results were achieved using both MODIS and MERIS satellite data, correctly identifying 89% of Phaeocystis and 88% of Karenia blooms in these regions. The LDA output can also be transformed into an estimate of HAB cell counts, which is particularly useful for an early warning system.

This generic approach is now being trained to discriminate further high biomass HAB species in other regions, for instance the North African coast of the Mediterranean, and is being considered for addition to existing HAB monitoring efforts for the Scottish aquaculture industry and in the southern North Sea.

**CIGUAHAB: A REGIONAL STUDY OF CIGUATERA IN THE GREATER CARIBBEAN**

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Ciguahab is a five-year project funded by NOAA’s Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) Program. The focus of this study is to investigate the environmental conditions leading to ciguatera fish poisoning (CFP) in the Greater Caribbean Region (GCR), and to develop numerical models that may predict outbreaks. The GCR was chosen due to a long history of CFP in some
areas such as St. Thomas, the Florida Keys, and Bahamas, coupled with the more recent CFP outbreaks in emerging areas of concern (e.g., Flower Garden Banks National Marine Sanctuary).

CiguaHAB will take advantage of new tools and approaches to investigate genetic connections between local and regionally dispersed populations of *Gambierdiscus*, trophic transfer of ciguatoxin precursors and toxins, and linkages between coral reef health, the environment, and *Gambierdiscus* abundance. Development of a model of bloom dynamics and toxin production is central to this effort, and will provide information that will facilitate fisheries management and public health protection. This model will lead towards a predictive capability that may assist in elucidating the effects of climate or environmental perturbations on this important public health issue. In addition to the substantial scientific knowledge generated by this research, these products represent a major advance in the development of management tools to prevent CFP.

**DIVERSITY, DETECTION AND QUANTIFICATION OF HAB PHYTOPLANKTON BY INNOVATIVE MOLECULAR TECHNOLOGIES**

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Harmful Algal Blooms, mainly caused by dinoflagellates, have become increasingly common in coastal waters throughout the world, causing important negative impact on ecosystem quality, human health, and economic activities related to the exploitation of coastal areas. Moreover in temperate Seas, such as the Mediterranean Sea, these phenomena are in expansion due to the occurrences of new microalgal species already known to be typical of inter-tropical areas.

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Currently, rapid, sensitive and specific identification and quantification methods of target harmful microalgae in marine environments are required for both exploring their community dynamics and life cycle stages. For these purposes, in the last few years, we have developed several molecular methods including PCR, qPCR and Microarray-based assays. Focusing on ribosomal gene, STR sequences, and mitochondrial and plastidial sequences, which resulted highly informative to infer population genetic, phylogeography, phylogeny relationships at inter and intra taxa level and design species-specific molecular probes. The study of known genomic target regions and the application of different molecular techniques let us to estimate the diversity of protists in marine ecosystems. In particular, the study of *Alexandrium minutum* population dynamics as well as phylogeographic or phylogenetic relationships among benthic dinoflagellate *Ostreopsis* spp. and diatom *Pseudo-nitzschia* species has been carried out. The identification and quantification of different Dinophyta and Haptophyta species on cultured and field samples by quantitative real-time PCR, and DNA microarray technology was accomplished.

These innovative molecular systems proved to be effective tools for rapid, specific and sensitive detection and enumeration of potentially harmful microalgae.

**IDENTIFICATION OF RESTING CYSTS OF COCHLODINIUM POLYKRIKOIDES**

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Palynological identification of resting cysts produced by HAB's causing ichthyotoxic *Cocchlidinium polykrikoides* has been addressed in several publications. Matsuoka and Fukuyo (2000) illustrated cysts as being ovoidal with brownish fin-like projections. Subsequently, Kim et al. (2007) made a dedicated study of *C. polykrikoides* life cycle in the Korean coastal waters, and identified another morphotype, as a haline round cyst with folding on one side. This was first done in the lab, but similar cysts were also found in sediments. Given the importance of *C. polykrikoides*, it is essential to investigate the spatial distribution of these two cyst morphotypes in the Korean coastal waters. In this work (Pospelova and Kim, 2010, *Marine Micropaleontology*), we performed a comprehensive study of the dinoflagellate cyst assemblages along with the geochemistry data from surface sediment samples collected at multiple locations separated by small spatial scales in the coastal area of Tongyeong and Gosung, South Korea.

Using cyst assemblages as a signal of nutrient enrichment, we determined the most eutrophic sites in the studied estuarine systems of Southern Korea. The distribution of dinoflagellate cysts on small spatial scales correlates with available environmental and sedimentary data. We identified the correct morphotype of cysts of *C. polykrikoides*. Cysts of *C. polykrikoides* were not found in Buk Bay, and were otherwise recorded in most of the studied sites in low proportions, except in Gosung Bay where they contribute up to 41% of the cyst assemblage. This is in agreement with previously observed blooms of *C. polykrikoides* in Gosung Bay.

**APPLIED SIMULATIONS AND INTEGRATED MODELLING FOR THE UNDERSTANDING OF TOXIC AND HARMFUL ALGAL BLOOMS IN THE NW IBERIAN REGION**

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The north-western Iberian coast (Galician rias and shelf) is frequently affected by HABs associated to dinoflagellates, especially from *Dynophysis* spp. associated with DSP toxins. In this contribution, we will present numerical simulations with a 3d realistic hydrodynamic model coupled to a biochemical model during different periods. Simulations have been performed in the framework of the project ASIMUTH (http://www.asimuth.eu) aimed to develop forecasting capabilities to warn of impending harmful algal blooms (HABs). The poster will illustrate we can generate oceanographic variables that can be used to provide insight on the oceanographic conditions affecting HABs in the W and NW Iberian coast. Additionally, the biogeochemical model in the area can be run routinely and give hindcast and forecasts of phytoplankton and nutrients concentrations. Although a simple biochemical model is a strong simplification of the complexity of the ecosystem, we will show that we can extract useful information from the model results that can be used for experts to issue a forecast and which can be displayed in different formats and viewers. A demonstration HAB forecasting products web page has been launched (http://www.indicedefloramiento.es). Forecasts of temperature, salinity, currents and chlorophyll can be shown in the model domain including shellfish harvesting areas in the Galician shelf and rias as will be illustrated in this poster for different hindcast periods.

**LA PROBLEMATIQUE DES CYANOBACTERIES AU NORD EST ALGERIEN (CAS DU BARRAGE MEXA) RISQUES POUR LA SANTE PUBLIQUE ET L’ENVIRONNEMENT**

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Suite au phénomène d’eutrophisation, la prolifération des cyanobactéries potentiellement toxiques est devenue un énorme problème menaçant l’équilibre des écosystèmes aquatiques ainsi que la santé humaine et animal.

Ce travail porte sur la caractérisation des populations cyanobactériennes du plan d’eau Mexa (El-Tarf Algérie) desservant en eau potable les villes d’Annaba, El-Tarf et El-Kala au nord est algérien. Analyser les éléments nutritifs pouvant favoriser le développement des cyanobactéries et déterminer leur potentiel toxique.

Les résultats de l'observation des caractères morpho anatomiques des cyanobactéries récoltées dans notre site d’étude ont permis d'identifier 9 genres: Microcystis, Chroococcus, Merismopedia, Planktothrix, Lyngbya, Spirulina, Oscillatoria, Limnothrix, Pseudoanabaena. Cinq d'entre eux sont reconnus comme toxiques: Microcystis, Planktothri, Lyngbya, Pseudanabaena, Oscillatoria.

La densité moyenne des cyanobactéries recensées fait apparaître la prédominance nette du genre Microcystis. Nous notons, par ailleurs, que les plus fortes proportions en cyanobactéries sont relevées en automne et en été dans l’ensemble des 6 stations d’échantillonnage.

Le pic de concentrations de toxines (168,41 µg/l) relevé en janvier concorde avec les pics de concentrations de chlorophylle a et de densités cellulaires des cyanobactéries au niveau de la station 1. En revanche nous notons l’absence de la microcystine à la sortie de la station de traitement des eaux Mexa(eau potable) correspondante a la station 9.

La présence de cyanobactéries toxiques dans notre site d’étude combinée à l’éventuelle présence, dans les eaux brutes, de microcystines soulignent l’importance de la mise en place du programme de surveillance de ces eaux afin de lutter efficacement contre ce problème de santé publique.

Mots clés : cyanobactéries, toxine, santé publique, eaux potable, barrage Mexa

DINOFLAGELLATE SUCCESSIONS, INFECTIOUS DISEASES, AND HABS EVENTS

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Phytoplankton species succession (including HABs), control of invasive species (exp: Alexandrium) and ecosystem resilience appeared strongly driven by infectious diseases. New methodological approaches have been recently applied in semi-confined estuaries or bays, and results well-illustrated the importance of parasites in HABs terminations. Calibrated on host/pathogen dynamics observed (Penzé estuary, France), this study presents a complementary modeling approach. In this area, bloom initiation is mainly driven by dilution rates (tide and river outflow), seasonal cycle and maximal growth rate of host populations. In absence of pathogens, the model confirms that the diversity of blooming populations is driven by the species fitness through an exclusive competition within individuals. The model also shows how the presence of pathogens and their specificity can modulate the genetic diversity of bloom. If diversity of specialists is increasing, then the host diversity is increasing too, whilst presence of generalists is decreasing it. Indeed, generalists should favor the emergence of few species/individuals particularly well-adapted to the ecosystem constraints, whilst specialists will favor the coexistence of host species/genotypes having a wider range of fitness.
Some theoretical models from terrestrial ecology also provide important bases for the interpretation of host/pathogen dynamic in the context of HABs events. However, due to the specificity of marine/aquatic environments (fluid dynamic, sampling difficulties, etc …), it seems important to see how such concepts and tools can be applied on HABs. This research area could thus be federating for marine and terrestrial ecologists and could constitute a strong axe for further international project like GEOHAB.

DATA PUBLICATION: APPLICATIONS TO RESEARCH ON HARMFUL ALGAL BLOOMS

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Harmful algal blooms (HABs) are a global phenomenon with significant economic, social, and environmental impacts. The Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) program was designed to help scientists from around the world to cooperate in studies of HABs in comparable ecosystems. An important aspect of global cooperation is sharing of data.

GEOHAB provides a mechanism to coordinate among national research programs. We describe data resulting from regional studies of the toxic dinoflagellate *Alexandrium fundyense* in the Gulf of Maine and on Georges Bank, and how these data have been assigned a digital object identifier (DOI) to make them more accessible for re-use and to give the data originators credit for the data.

The Scientific Committee on Oceanic Research (SCOR), Marine Biological Laboratory/Woods Hole Oceanographic Institution (MBLWHOI) Library, and International Oceanographic Data and Information Exchange (IODE) of the Intergovernmental Oceanographic Commission have assembled a team of librarians, data managers, and scientists who are collaborating to identify best practices for tracking data provenance and clearly attributing credit to data collectors/providers.

A key element in the data publication process is the assignment of persistent identifiers (e.g., a DOI) to enable access to data sets and accurate data citation. The DOI is ideally assigned before submission of the article in which the data are used, so the DOI can be included in the published paper and readers can link directly to the dataset. However, DOIs can also be assigned to datasets that support papers that have already been published, as described in this poster.

EMERGING BENTHIC HABs IN THE MEDITERRANEAN: EXPLORING THE CONNECTION BETWEEN *Ostreopsis* BLOOMS AND HUMAN RESPIRATORY DISORDERS

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Ostreopsis blooms have intensively been studied in Sant Andreu de Llavaneres beach (NW Mediterranean Sea) since 2007. These dinoflagellates were present from late spring to autumn, with the highest abundances usually during the summer months. Molecular identification revealed that the bloom was clearly dominated by the Atlantic/Mediterranean O. cf. ovata genotype, although O. cf. siamensis was occasionally present. Epiphytic O. cf. ovata concentrations above 10^7 cells/g FW were continuously recorded during the hot season, forming brown mucilage that coated the benthic macrophyte community. In the water column, numbers above 10^5 cells/L were sporadically recorded.

Repeatedly, in the summer period, people spending long time (several hours) nearby the beach were affected by respiratory symptoms. In 2009 and 2010, the EBITOX project tested the eventual link between health problems and Ostreopsis outbreaks. High-volume air pump samplers were installed in the beach to characterize the marine aerosol. SEM observations revealed the presence of some marine microalgae (mainly diatoms), although Ostreopsis was not clearly visualized in the aerosol. However, a new validated qPCR assay revealed up to 102 cells of O. cf. ovata per filter during an outbreak in 2010. Palytoxin-like compounds (PLTX) concentrations in the aerosol filters were below the detection limit. In contrast, PLTX ranged between 0.1 and 1.2 pg/cell in the microepiphytic assemblages. The potential implication of bacterial assemblages on the observed toxic outbreaks is also under study. High bacterial abundances and activity coincided with Ostreopsis blooms. Several bacterial strains (e.g. Vibrio) detected by DGGE might contribute to the toxicity of the bloom.

**VARIATION IN CYLINDROSPERMOPSIS RACIBORSKII ECOTYPES IN RESPONSE TO NITROGEN AND PHOSPHORUS**

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Cylindrospermopsis sp. is a global cyanobacterium that negatively impacts drinking water quality by the production and release of toxin during blooms. C. raciborskii is a common species in Australian tropical and subtropical reservoirs. It produces the cytotoxin cylindrospermopsin (CYN), which is harmful to both humans and animals. Reservoirs in the region have an increased frequency of harmful algal blooms, such as C. raciborskii, caused by anthropogenic nutrients loads.

Management and prediction of blooms in water supply reservoirs is based upon the cell enumeration of C. raciborskii, however this is complicated by the co-existence of multiple morphologically similar ecotypes that can differ in their toxin content. Understanding the interplay between dominance of different ecotypes and available nitrogen and phosphorus is an important question that needs to be addressed to improve management strategies.

This study examined the growth response of four Australian ecotypes of C. raciborskii, two toxic and two non-toxic, to high and low concentrations and ratios of nitrogen (N) and phosphorus (P). Cell growth rate increased with increasing N addition while P alone affected the duration of growth, rather than the growth rate. Each ecotype had differences in response to available N and P. Importantly, this study showed that although there were growth differences with available N and P, toxin cell quota remained constant.

This study illustrates the importance of understanding the variations between multiple ecotypes of a single species and suggest that population dynamics within an ecosystems can greatly affect bloom toxicity.
THE RESULTS OF THE MONITORING POTENTIALLY TOXIC AND HARMFUL PHYTOPLANKTON SPECIES NORTH-EASTERN PART OF THE BLACK SEA

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Monitoring studies of the phytoplankton in water areas of the Black Sea northeastern shelf have been conducted by the Southern Scientific Centre of Russian Academy of Sciences (SSC, RAS) specialists using space technologies. One of the goals of the joint project is timely detection and diagnostics of water blooms, caused by potentially toxic algae, as well as the most harmful, delivered via vessels ballast water.
QUANTIFYING HAB RESTING STAGE EMERGENCE AND DEPOSITION FLUXES: A COMPARATIVE WORKSHOP AND TRAINING PROGRAM

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Many harmful algal bloom (HAB) species produce dormant cysts or resting spores during their life histories. Some also produce temporary or “pellicle” cysts that are less resistant, but which still provide a refuge during difficult conditions. Hereafter, for convenience, these will all be included under the umbrella term “resting stage.” The resulting alternation between a dormant, resting stage and a vegetative existence in the plankton is critically important in many aspects of bloom dynamics. Resting stage germination provides the inoculum for blooms, and the transformation back to the resting state can remove substantial numbers of vegetative cells from the population and act as a major factor in bloom decline, while also providing the inoculum for future blooms.

As critical as these life history transformations are for many HAB species, quantitative data on many aspects of resting stage formation, deposition, and germination are lacking. Direct measurements of resting stage emergence and deposition fluxes are limited, as measurement methods are difficult, prone to artifacts, and for emergence fluxes, limited to shallow waters, leaving major deposition or accumulation zones in deeper waters unstudied in this regard. Several emergence trap designs have been proposed and used in field studies of some HAB species, but no concurrent measurements have been made to ascertain the similarity and differences between approaches. The measurements are indeed challenging, as it is necessary to isolate a portion of bottom sediments without altering the chemistry or physical environment, capture small numbers of newly germinated cells before they divide, all while avoiding contamination from potentially abundant vegetative cells of the same species in the surrounding water. Likewise, sediment traps with designs ranging from simple to sophisticated have been used but never evaluated or compared in terms of efficiency and accuracy in the context of HAB resting cell dynamics. Again, these devices are susceptible to artifacts depending on current speed, resuspension events and the swimming behavior of the cells of interest. As a result of these limitations in methodologies, progress towards one of GEOHAB’s major goals has been limited – namely the development of comprehensive models of the dynamics of cyst- or spore-forming HAB species.

Here we propose a series of community workshops that will compare and evaluate methods for direct measurements of the rates of major life history transitions in HAB resting stages. These include in situ measurements of germination rates and emergence fluxes, as well as encystment rates and resting stage depositional fluxes to bottom sediments. A related workshop activity would involve examination of the manner in which these rate measurements can be incorporated into HAB numerical models.

Two and perhaps three separate workshops are envisioned for this program. The first would convene interested workers at a site and a time where HAB resting cysts and spores are present in bottom sediments and are germinating, with relatively easy access in terms of water depth and research vessel.
availability, and with appropriate laboratory and field facilities for instrument preparation and deployment, and for analysis of samples. With concurrent deployment of devices of different designs and careful experimental planning with appropriate controls, comparative studies can be conducted and each of multiple approaches evaluated for a range of HAB species. Presentations and discussions will also be held on "best practices" for laboratory experiments that quantify germination using cultures and sediment samples. Some characteristics of resting stage formation and germination will only be possible to resolve in the laboratory.

The second workshop would focus on quantifying the formation and deposition of resting stages in field populations. The site for the workshop would again be a location where blooms of the target species are recurrent, predictable, and accessible. Multiple designs of sediment traps and collection methods can be evaluated, concurrent with methods for assessing levels of sexual induction and resting stage formation in the plankton. The latter would include traditional cytological methods, as well as novel optical and molecular approaches.

The third workshop in this series would involve modelers as well as biologists in an effort to refine methods to incorporate resting stage dynamics into HAB population dynamics models. In addition to defining the critical processes that need to be parameterized, the meeting would help to identify common approaches and computer code that can be shared among species and applications.

Potential funding sources for this project could include international agencies such as IOC-UNESCO, SCOR and national funding agencies such as the U.S. National Science Foundation (NSF) and the U.S. National Oceanic and Atmospheric Administration (NOAA).

Note also that this proposed workshop series covers an important but relatively narrow area of HAB population dynamics, and thus could be combined with other GEOHAB concept proposals related to life history transformations.

### HARMFUL ALGAL BLOOMS IN STRATIFIED SYSTEMS: THE NEXT DECADE OF DISCOVERY

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Since the establishment of the Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB, SCOR and IOC/UNESCO) program in 1999, the scientific community has devoted important efforts to improve the comprehension of HABS in stratified systems. In August 2012, a workshop organized by the GEOHAB Core Research Program “HABs in Stratified Systems” and entitled “ADVANCES AND CHALLENGES FOR UNDERSTANDING PHYSICAL-BIOLOGICAL INTERACTIONS IN HABS IN STRATIFIED ENVIRONMENTS” was conducted at the Monterey Bay Aquarium Research Institute to review our current understanding of the processes governing the structure and dynamics of HABs in those systems - related in particular to “Thin Layers”. Engineers, physicists, biologists and modelers from all over the globe, working on the various aspects of phytoplankton dynamics in stratified systems, attended the meeting to provide an interdisciplinary understanding of this phenomenon.

The main advances attained in the recent decade, were identified from the presentations and the discussions during the workshop. In addition, participants highlighted gaps in knowledge and methodology and formulated open questions in order to orient future research for the improved modeling and prediction of HABs in these systems. These open questions and gaps were arranged into six overarching themes:
Theme 1) Physical structure
* Can organisms modify the physical microstructure in ways that influence Thin Layer ecology?

Theme 2) Biological structure: Rates and Interactions
* How are toxic phytoplankton and zooplankton distributed at fine spatial scales within the Thin Layer?
* How do these fine-scale spatial relationships influence trophic transfer of toxins?

Theme 3) Organism Behavior
* How do organisms behaviorally locate Thin Layers of HABs in stratified systems?
* How do organisms behave once they are within and in the vicinity of the Thin Layer?
* How does the fact that the environment is stratified favor the particular HAB organisms?

Theme 4) Nutrients
* How are the suites of nutrients distributed in space and with time within the layer over time?
* How do variations in nutrient gradients within the layer contribute to the development and persistence of the layer, as well as to the potential toxicity of the layer?

Theme 5) Temporal evolution of HABs in stratified systems and Thin Layers
* How does the physiological and viability status of the phytoplankton cells change over time with the Thin Layers?
* How do net growth and grazing rates in situ evolve within the Thin Layer?

Theme 6) Predictive modeling
* How can the latest advances in modeling help predict HABs in stratified systems?
* How will HAB distribution change with a changing climate?

The workshop revealed that some of the most recently developed instrumentation and modeling approaches can now provide responses to some of the ‘roadmap questions’ to address in the next 10 years of discovery, after the synthesis meeting of GEOHAB (Paris, April 2013). International collaboration and multidisciplinary field experiments will certainly favor to overcome challenges.

Proposed Activity

We propose to organize a 3-day International Proposal Writing Workshop at the University of Hawaii at Manoa. During this 3-day workshop, we propose to

1) Identify sources of funding for an international effort to answer these outstanding questions,
2) Outline one or two proposals which aim to answer these questions
3) Prepare a draft of one or two proposals
4) Develop a timeline, within which the proposals will be completed and submitted.

COMPARATIVE STUDIES OF CYANOBACTERIAL HABS (CHABS)
TO IMPROVE PREDICTION, MANAGEMENT, AND MITIGATION

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GEOHAB aims to foster and promote the global study HABs. A key focus to date has been on marine and estuarine HABs. However, freshwater HABs are also a significant issue around the world. The main group responsible for these issues is cyanobacteria (CHABs). CHABs are an increasing phenomenon worldwide, with a suite of cyanotoxins being responsible for deaths and hospitalisation of many people
(Falconer 1999). In countries such as China, large-scale toxic cyanobacterial blooms in lakes have affected the drinking water supplies of millions of people (Guo 2007; Qin et al. 2007). In Australia, hundreds of kilometres of the Murray River had major cyanobacterial blooms in 2009 (Al-Tebrineh et al. 2012) and 2010 (http://www.theage.com.au/environment/murrays-algae-red-alert-fails-to-sway-swimmers-20100221-oo1p.html), affecting drinking, agricultural and recreational use of the water. Water authorities spend millions of dollars annually testing water supplies for the presence of CHABs. CHABs also affect the recreational use of waterways, impact on commercial and recreational fishing, and reduce property values near affected water bodies. The estimated cost of this in the USA in 2009 was approximately US$2.2 billion p.a. (Dodds et al. 2009). Globally these costs are predicted to increase over time due to a warming climate increasing CHAB incidences (Wagner and Adrian 2009, Carey et al. 2012).

Within the GEOHAB framework, the issue of CHABs fits within the following Core Research Projects:

- HABs and Eutrophication
- HABs and Stratification
- HABs and Modelling

CHABs typically develop in systems with longer residence times, such as lakes, reservoirs, weirs and rivers with low or no flow. These systems may be thermally stratified for some or most of the year depending on the climatic conditions. Therefore species, such as CHABs, which are able to regulate their buoyancy gain a competitive advantage over other species (O’Neil et al 2012). Global warming will increase stratification in the future and is predicted to further promote CHABs (Paerl & Huisman 2008). Therefore, an understanding of climate change responses of CHABs is critical to effectively modelling and predicting future HABs.

Eutrophication is a major driver of HABs in many coastal areas where human impacts are large. This is also true in freshwater systems where nutrient inputs from degraded catchments stimulate CHABs. CHAB species capable of producing toxins may dominate, include *Microcystis aeruginosa, Cylindrospermopsis raciborskii* and *Anabaena circinalis*. The major *M. aeruginosa* bloom in Lake Taihu, China, for example, has been linked to excessive nutrient loads from sewage discharge, agricultural runoff and other human activities (Qin et al. 2007). Toxin production by these species is not predictable based on cell counts, and recent studies have shown highly variable responses of different strains (or ecotypes) to nutrients and other physico-chemical drivers (e.g. Vezie et al. 2002, Davis et al. 2009). Therefore, there is a need to understand the range of responses within a species reflecting the variability in ecotype response. This links with the HABs and Modelling component of GEOHAB since a new approach to modelling is needed to capture this variability in response and how this translates to whole system responses (Franks 2009).
Within this context, there are some key activities which could be conducted within GEOHAB to foster international collaboration on CHABs:

- Workshops to integrate our current understanding of drivers of CHABs, how this knowledge is linking with modelling (linking or partnering with Global Lakes Ecological Observatory Network (GLEON)), and prediction of how climate change will preferentially promote CHABs
- These workshops would be the basis for potential collaborative research projects which focus on knowledge gaps
- Examination of the efficacy of mitigation strategies, and information sharing with developing countries to aid in bloom identification, management and mitigation

References

**VISCOSITY AND RHEOLOGY IN RELATION TO EPS, HAB’S, BACTERIA AND THIN LAYERS**

Ian R. Jenkinson1,2 and Laurent Seuront3,4

**Overview.** GEOHAB [3] posed the question, “How can we quantify modifications in turbulence by phytoplankton through changes in the viscosity of its physical environment?” At that time the state-of-the-art was that viscosity $\eta$ of seawater and freshwaters was composed of an aquatic component $\eta_W$ due to water (and salts) plus an excess organic component due mainly to EPS, $\eta_E$

**Total viscosity,**

$$\eta = \eta_W + \eta_E \quad \text{[Pa s]} \quad (1)$$

Broadly, $\eta_E$ shows a negative relationship power-law relationship with shear rate $\dot{\gamma}$, so that

$$\eta_E = k \dot{\gamma}^P \quad \text{[Pa s]} \quad (2)$$

where $k$ is a coefficient related to EPS concentration and type. $P$ can vary from 0 to $\sim$1.4 (shear thinning), and has exceptionally been found positive (shear thickening). $\eta_E$ also varies with phytoplankton concentration. Using chlorophyll $a$ concentration $\text{chl}$ as a proxy for phytoplankton,
\[ \eta_E = k \text{chl}^Q \gamma^P \]  

[Pa s]  

(3)

where \( Q \) is the phytoplankton concentration exponent, found to about 1.3 generally. Further research, however, has shown the \( Q \) can vary locally with the growth phase of the bloom, and even become negative (negative correlation between viscosity and chl locally in a \textit{Phaeocystis} bloom) [11]. EPS also imparts elasticity to the water. Swimming trajectories of copepods over scales of mm to cm are also greatly changed by viscosity from \textit{Phaeocystis} EPS [10].

EPS thickening, moreover, is generally lumpy, this produces length-scale dependent viscosity, which can be modelled using a lumpiness exponent.

Eq. 3 can now be "corrected" for length scale by a third exponent:

\[ \eta_E = k \text{chl}^Q \gamma^P (L/M)^d \]  

[Pa s]  

(4)

where \( L \) is the length-scale of interest, \( M \) is the length scale of measurement, and \( d \) is the length-scale exponent. A model of whether lumpy EPS could thickening the water enough to stabilize a pycnocline found [8] found that the value of \( d \) in Eq. 4 was very critical. To investigate \( d, \eta \) of phytoplankton and bacteria (PB) cultures was measured in capillaries of different radii. While \( \eta \) was increased in some combinations of shear rate, capillary radius, 0.35 to 1.5 mm, and PB species, presumably by EPS, \( \eta \) was surprisingly decreased in other combinations. This may be associated with superhydrophobic conditions, sometimes called the \textit{Lotus Leaf Effect}, at the surfaces of PB and EPS. (scales nm to possibly 100s \( \mu \)m).

Also associated with surfaces, MDalton protein-polysaccharide complexes produced by the Raphidophycean, \textit{Heterosigma akashiwo}, control community structure allelopathically, through species-specific recognition and binding to other phytoplankton at cell concentrations characteristic of natural, dense blooms. This mechanism is reminiscent of those acting in cell-specific recognition and binding associated with control of development and apoptosis in both mammals and flowering plants. [12]. The length scale of adhesion/recognition is \( \sim \)10-100 nm.

Blossom et al [1] report that a dinoflagellate produced toxic mucus zones that poison and immobilise passing flagellates, that the dinoflagellates, staying nearby, then feed on them. These toxic traps are of size \( \sim \)30-300 \( \mu \)m. Presumably they will also tend to increase the viscosity of the water at larger scales [4].

**Some effects** of increased viscosity (with suggested primary length scales) include:

1. Damping of turbulence and of sub-Kolmogorov-scale water movement: 1 nm – 1 m
2. Due to elasticity and lumpiness, complex changes to patterns of water movement, and de-coupling of shear rate from dispersion: 1 nm – 1 m;
3. Partial and/or total clogging of the gills of fish, molluscs, tunicates, sponges, polychaetes, etc.: 1 nm – 1 mm;
4. Due to rising organic matter and adsorption to the air-sea surface, reduction of air-sea gas exchange [3], wave and ripple damping: 10 \( \mu \)m – 10 m;
5. Complex situations, illustrated by \textit{Phaeocystis}, which produces closely associated stiff mucus holding cells together in colonies (~50-2000 \( \mu \)m), while also producing looser diffuse mucus that increases viscosity at larger scales [11]: 50 \( \mu \)m – 1 m;
6. Flocculation into mucous aggregates, thus increasing sinking or rising speed and hence vertical organic flux [2]: 100 \( \mu \)m -
7. Possible reinforcing of pycnoclines by PB EPS [8]: 10 cm – 10 m;
8. Trapping of toxins close to metabolically active surfaces, such as cell membranes and gills [6]: 10 nm – 1 mm;

**Investigation techniques** of seawater and lakewater thickening include:

1. Rheometry: a) concentric cylinder; b) sliding piston; c) capillary flow; d) ichthyoviscometry;
2. Studies of fluid movement at small scale: a) 3D particle image velocimetry (PIV); b) 3D particle tracking velocimetry (PTV);
3. Studies of small forces at small scale: Atomic Force Microscopy (AFM)
4. Scanning electrochemistry of organic matter film dynamics: Hanging mercury drop
5. Studies of attraction-repulsion fields, electrical double layers (EDLs)
6. Immunological type radicle-radicle recognition and adhesion
7. Combination of electrochemical techniques with rheometry, microscopy and PIV/PTV;

**Linking to other international and other oceanographic programmes:**
Air-sea exchange, ripple and wave dynamics, air-sea gas exchange (SOLAS, WOCE...), and turbulence programmes, GOTM, GETM, FABM, IMBER.
Others...

Sediment erosion-deposition dynamics, dredging, coastal erosion-accretion; fluid mud projects;
Plankton encounter dynamics, trophic dynamics, mating and social dynamics.

**Training**
Already for many years there has been an unfulfilled need for training of ocean and plankton researchers in rheological techniques, of rheologists in ocean and plankton science, and for creation of mixed research teams [7]. We would envisage training if MSc to postdoc level ocean scientists in regular rheology training course. These are organized regularly in many countries, often by national rheology societies (Society of Rheology (USA), British Society of Rheology, Groupe français de Rheologie,...) and also by manufacturers of research rheometers (Malvern, Anton Paar, Haake, Cambridge Instruments, etc.). However, we should also envisage courses aimed at techniques specific for ocean problems (low-shear, low-force, multi-scale) but also using cheap “home-made” or “problem-targeted” rheometers, for which no manufacturer exists (e.g. pressure-recording capillary rheometers or ichthyoviscometers). Techniques would involve: Concentric cylinder; sliding piston, capillary and ichthyoviscometry for fish-gill related problems.

**SCOR Endorsement**
We think this subject is important to develop as part of oceanography, and we should like to seek SCOR endorsement of this project, Thalassorheology, perhaps within GEOHAB.

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**HABS IN BENTHIC SYSTEMS: TRAINING AND CAPACITY BUILDING**

Wayne Litaker, Mireille Chinain, Gires Usup and Pat Tester with endorsements from collaborators*

**Background - GEOHAB** The Global Ecology and Oceanography of Harmful Algal Blooms Science Plan (2001) envisioned an international community “seeking to improve prediction of HABs by determining the ecological and oceanographic mechanisms underlying their population dynamics, integrating biological, chemical and physical studies supported by enhanced observation and modeling systems.” After the first decade, we are ready to push modeling forward to monitoring and mitigation by building regional capacities.

**BHABS** The Harmful Algal Blooms in Benthic Systems (BHAB) Open Science Meeting (OSM) in 2010 resulted in a broader recognition of the risks of benthic HABs to human health, environmental quality and regional economies. Current information was presented on (1) Gambierdiscus and ciguatera fish poisoning, (2) the taxonomy and harmful effects of Ostreopsis blooms and (3) the taxonomy and toxicity of Prorocentrum, Coolia and other benthic dinoflagellate species. This meeting triggered a resurgence of interest in the effects and consequences of BHABs and the publication of the GEOHAB Core Research
Project: HABs in Benthic Systems (BHAB, 2012). This report detailed the current state of knowledge concerning BHABs and recommended productive avenues for future research and collaborations. A successful taxonomy workshop attended by 22 international participants was another outcome of the BHAB OSM. This workshop, with double the number of expected applicants, demonstrated the critical need for taxonomic training and methods development and inspired the 2012 International Training Workshop on the Ecology and Taxonomy of Benthic Marine Dinoflagellates.

**Training and Capacity Building** The International BHAB workshop was sponsored by IOC-SCOR and funded by the YEOSU project, a component of the Expo 2012 Yeosu Korea which seeks to bridge the divide between the developed and the developing world and to build capacity for meeting the challenges of climate change and its impact on the marine environment. During the first week, 18 participants from six Southeast Asian countries worked on Pulau Sibu, off the southeast coast of Malaysia. They learned BHAB sampling, processing and counting methods, generic level identifications and data analysis techniques. A follow on session at The Universiti Kebangsaan was attended by the original participants and eight others. This training involved a detailed taxonomic overview of various BHAB species and lectures on molecular identification.

The YEOSU participants were given the opportunity to submit modest funding proposals, which, if approved, would allow them to implement and evaluate the improved sampling methods in their local environments. Following completion of the funded projects, a follow-up meeting will be convened to discuss the challenges encountered, assess the implementation of the methods and to evaluate the success of their efforts. A joint publication describing the combined results will be one of the end products of this project. Convening the participants a second time fosters continued communication and collaboration and supports implementation of standard methods and protocols. It also provides the stage for developing monitoring strategies that are specific to regional needs.

**Example Topics - Detection and Monitoring of BHAB Species and Toxins** Based on the success of the YEOSU Project, we request GEOHAB's endorsement and IOC and SCOR's facilitation and sponsorship of a series of Regional Training and Capacity Building workshops for the Caribbean/Gulf of Mexico, Mediterranean / North Africa and Pacific / Indian Oceans. The goal will be to build regional capacity to detect and monitor BHAB species and toxins. The target species and techniques to be covered in the workshops will vary depending on the needs of each region and the type of infrastructural support available. The YEOSU model, suggests that one potential set of workshops could include taxonomic assessments within a local region or island archipelago (Biodiversity). Techniques covered could include sampling methods, such as the use of artificial substrates, as well as identification of species morphologically and/or by PCR assays depending on the needs and capacity of the group. Participants could additionally bring material from their region for identification (Biogeography). Regionally specific taxonomic guides would be one of the first products. A follow up meeting after 12 to 18 months is recommended to assemble regional data sets and confirm species identifications, if required. The compilation of regional distribution and abundance maps serve as a baseline. This information and ecological observations will help inform predictive efforts (Forecasting, Modeling) and strengthen monitoring capabilities (Capacity Building). Projects would include development of websites, wikis and blogs as useful communication aids. Additional training workshops under the YEOSU format could be provided at six month intervals if project funding is augmented.

**Other Capacity Building Activities**
- New BHAB species are being found with surprising frequency. Currently there are qPCR assays for some genera and more will follow. A workshop to demonstrate qPCR assays for *Gambierdiscus* could be a standalone effort providing species identification capabilities to assist with management and research efforts including how BHABs respond to changing environmental conditions. A workshop is tentatively planned in November before/after ICHA 2014 in Wellington NZ or other Pacific location.
Hands-on training workshop in Malaysia (2012) aimed to learn the lastest techniques for monitoring BHABs. (Image: P. Tester).

- Toxin detection and methods comparison workshops would be particularly beneficial to many participants as they develop regional management strategies for mitigating risks associated with BHABs. A newly developed receptor binding assay, using a fluorescence signal rather than an isotopic one, for detecting ciguatoxins is in development. The fluorescent RBA could be taught as an alternative technique for laboratories that do not have a license to work with isotopes. Workshops are proposed in the Caribbean in association with IAEA RBA workshops efforts there and in the Pacific. Workshop funding assistance will be requested from IAEA.

Capacity building leads the way to the design and implementation of regional monitoring programs to assess BHAB abundances and identify increased risk of toxic events. In the coming decade, we seek to
build on the achievements of GEOHAB to mitigate effects of HABs on human health, marine resources and local economies with these collaborators:

*Masao Adachi, Katerina Aligizaki, Don Anderson, Dan Baden, Elisa Berdalet Andrés, Nicolas Chomarat, Errol Dakin, Fathy Elzeat, Santiago Fraga, Simon Hales, Gustaaf Hallegraeff, Francisco Rodriguez Hernández, Mona Hoppenrath, Amany Ismael, Mitsunori Iwataki, Hae Jin Jeong, Gurjeet Kohli, Chui Pin Leaw, Lyndon Llewellyn, Lincoln Mackenzie, Ulysses Montojo, Shauna Murray, Silvia Nascimento, Normawaty Binti Mohammad Noor, Lam Nguyen-Ngoc Leonel Carrillo Ovalle, Mike Parsons, Antonella Penna, Beatriz Reguera, Lesley Rhodes, Mindy Richlen, Maria Saburova, Damian Shea, Chi Thoï Nguyên, Giang Nguyen Tuong, Thamrin Thamrin, Ho Van The, Maribelle Vargas, Noime Walican, Being Yeeting, Hua Zhang, and Adriana Zingone. Others are welcome to join this effort.

### HARMFUL ALGAE BLOOMS IN A CHANGING WORLD

Mark Wells, Bengt Karlson, and Raphael Kudela (on behalf of the ICES/PICES/IOC-GEOHAB WORKSHOP ON HARMFUL ALGÆ BLOOMS IN A CHANGING WORLD, WKHABCW)

#### Background/Introduction

In 2013, representatives from ICES, PICES, and GEOHAB met to discuss what we know about HABs and climate change. There were three main topics:

1) Assessment of the state of understanding of HAB’s and climate change, focusing on the research topics of greatest need and likelihood of achieving over the next decade;

2) Description of two types of sentinel sites for observing change based on existing long-term monitoring stations. The first would be "observer" or "sentinel" sites, where a minimal set of parameters are added to those measured at most long-term oceanographic monitoring sites. A second, shortened list of most key parameters were identified that could be measured in places where there now is no monitoring being done, or where instrumentation or expertise is limited. The goal at these sites would be to detect change in HABs, by either capturing shifts in existing HAB frequency and intensities or the expansion of HABs into new areas. The second set of sites, referred to as "super" sites, would be fewer in number and include a list of more sophisticated sampling sites. Beyond simply detecting change in HABs, these “super” sites would enable study of the ecological processes contributing to this change;

3) Detailed discussion on preliminary plans for an Open Science Symposium to focus the HAB research community on: a) the bar needed to establish with high confidence that observed changes are due to climate change, b) to highlight the priority directions for HAB research on climate change related issues, and c) to attract new, non-traditional HAB researchers with novel tools and expertise. The latter goal deals with the realistic outlook that in many cases funding for HAB research is not going to increase, but that there are other fields of climate change research where the addition of HAB considerations would both strengthen their goals while simultaneously advancing HAB research.

#### Relationship to GEOHAB past and future activities

The GEOHAB program identifies long-term records, including those related to climate change, in multiple documents. For example, climate responses are specifically identified in Program Element 1 of the Science Plan: “Comparative studies of the geographical distribution of HAB species in relation to the environment should provide a probabilistic model of the likelihood of spreading or invading another ecosystem”. Climate change is also inextricably linked to Program Element 2 (nutrients and eutrophication), and is called out in Program Element 4: “Quantify the response of HAB species to environmental factors in natural ecosystems”. And finally, any assessment of climate change must rely on models (Program Element 5) to predict likely scenarios for the future.

62
Despite this strong linkage to climate change in the Science Plan, and mention of climate change as key questions in the Upwelling, Eutrophication, Fjords & Coastal Embayments, and Benthic HAB CRPs, this topic has not been directly addressed to any extent as part of past GEOHAB activities, generally because of the difficulty of tackling such a complex issue. The WKHABCW was formed specifically to address these difficulties and identify key objectives that GEOHAB (and partners) could accomplish in the next few years.

WKHABCW conceptual diagram showing linkages between climate change and HABs, the Key Variables identified by the working group, and various partner groups that could participate in a coordinated effort to implement recommended activities.

**WKHABCW Recommendations**

1) Convene an open scientific symposium on *Climate Change Impacts on Harmful Algal Blooms* (or Harmful Algal Blooms and Climate Change) in 2014-2015 to:
   a. identify and promote research on critical topic aspects of the broader field of HAB research to advance our knowledge of the impacts of climate change on the global scale
   b. attract and retain new expertise from other scientific disciplines
   c. provide guidance to scientists and agencies and to identify the need for best practice recommendations for research and monitoring
d. promote the use of observing system technologies for the collection on long term data on an appropriate parameters
e. To develop the HAB component of global climate observing systems

Given the impetus from the WKHABCW Expert Group a steering committee has been organized for this Open Science Symposium. The committee will be composed by Mark Wells (Chair), D. M. Anderson, Bengt Karlson, Raphe Kudela (Chair GEOHAB SSC), Charles Trick, Vera Trainer, Angela Wulff, Gustaaf Hallegraeff, Akira Ishikawa, Stewart Bernard, Martin Visbeck, Ted Smayda, William Cochlan, and other experts to be added upon consultation with the IPHAB Chair and the IOC Secretariat.

2) To instruct the IPHAB Task Team on HAB Observation and Forecasting Systems to review the current technologies for HAB sensors and observing systems and recommend a globally distributed network HAB observing assets in coordination with 1) e. and working within the existing plans for global observing systems.

3) IPHAB Nations are requested to establish long-term sampling sites capable of detecting the emerging presence of new HABs or changing characteristics in existing HABs. These sites could include a recommended minimum set of parameters or a more comprehensive set that allows investigation of the selective processes leading to HAB development.

4) To invite the SCOR Working group 137 and PICES Working Group 27 on North Pacific Climate Variability and Change, the ICES/PICES Strategic Initiation on Climate Change Impacts on

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**SEA-CAGE FISH FARMING AND HABS: EVIDENCE FOR CAUSALITY IN TEMPERATE COASTAL ECOSYSTEMS?**

Lincoln MacKenzie, Cawthron Institute, Nelson, New Zealand
Presented by Dr Raphael Kudela, Ocean Sciences Dept., University Of Southern California, USA

**Introduction**

The rearing of finfish in sea-cages has many benefits including the creation of valuable high-protein food, reducing the pressure on wild fisheries and supporting economic development and employment. In some countries it is a significant contributor to the national economy. Nevertheless for a variety of reasons (environmental sustainability, disease and parasites, food and water quality, use of therapeutics, effects on the benthos, effect on wild fisheries, occupation of public space, landscape values etc.) the operation of sea-cages in temperate coastal waters is controversial. The effect of sea-cages on the benthic environment is well studied but the effect on the water column is less well understood. A frequently cited concern is the potential to cause eutrophication leading to the generation of HABs, as a result of the large quantities of combined nitrogen that are introduced into the water column in the fish feed. On the face of it this concern is justified, but when existing published evidence is examined, it is not at all clear that there really is a close association. Because of the rapid assimilation, dilution and dispersion of dissolved and particulate nutrients, in many situations it appears to be difficult to directly attribute a response by the phytoplankton to sea-cage effluents. Justified of not, the perception that sea-cage fish farming leads to increased problems with HABs invariably becomes an important environmental planning question on which it is difficult to confidently provide an expert opinion.

**A brief review of the literature**

Several studies have demonstrated that coastal eutrophication is associated with the increased incidence of HABs (Anderson et al. 2002, 2008; Heisler et al. 2008), but in none of these studies were sea-cages identified as a significant cause. Searching the international literature does not reveal a strong relationship between HABs and sea-cage fish farming, except in the most confined, poorly flushed and grossly polluted situations where the nutrient loads from the farms clearly far exceed the assimilative capacity of the water body (e.g. Romdhane et al., 1998). There is little published evidence that. phytoplankton
biomass is enhanced by nutrient inputs from fish farm cages (Beveridge et al., 1994; Pitta et al., 1999; Wu et al., 1994), even when these farms are in enclosed inland locations with restricted water exchange (e.g. Navarro et al., 2008). In the few countries (e.g. Scotland) where systematic evaluations have been made (e.g. Rydberg et al., 2002; Scottish Executive Central Research Unit, 2002; Gubbins et al. 2005; Smayda 2006,) no connection between the occurrence of HABs and fish farm wastes has been identified. In a large study of the nutrient impacts of farmed Atlantic Salmon on the pelagic ecosystem in Chile, Buschmann et al. (2006, 2007) stated that “there is little scientific evidence that nutrient loading from salmon farms is sufficient to initiate and sustain harmful algal blooms…”, though they acknowledged that “… nearly all the rigorous pelagic ecosystem science related to HABs has occurred outside the areas directly influenced by salmon farms” In Korea and other regions where *Cochlodinium polykrikoides* blooms have caused serious problems, blooms originate offshore as the result of large scale oceanographic processes and there is no strong evidence that implicates coastal eutrophication in their origin and development (Kudela et al., 2008, Kim et al. 2010). *Heterosigma akashiwo* is notorious for its effect on salmon farms in the USA and Canadian Pacific North-West regions though Rensel (2007) stated that “It is evident that fish farms do not cause *H. akashiwo* blooms in marine waters of Western Washington and the data suggest that it is unlikely they exacerbate blooms.” Nutrient inputs from fish farms may have contributed to the well-known case of the eutrophication of the Seto Inland Sea, Japan in the mid-20th century (Okaichi, 1997; Imai et al. 2006) but the more influential factors were massive effluent inputs from urban and industrial sources.

Norway is the largest producer of farmed salmon in the world and although toxic and noxious algal blooms are a common problem in the coastal waters of Scandinavia there is no suggestion in the literature that sea cages cause or exacerbate this. The extensive problems with *Pseudochattonella* and *Chrysochromulina* in the 1990s have been attributed to oceanographic processes (Graneli et al., 1993). A recent risk assessment of the environmental impacts of Norwegian aquaculture (Taranger et al., 2011) reached the conclusion that the risk of regional eutrophication in all areas associated with sea-cage salmon farming was low. New Zealand and Australia both have rather small sea-cage salmon farming industries in sheltered fjord-like locations though in both countries these are about to undergo significant expansion. Toxic and noxious HABs are relatively common (e.g. MacKenzie et al. 2011) in salmon farming regions in New Zealand but there has been little if any convincing evidence of causality over the 30 year history of the industry.

**The proposal**

As the brief discussion above shows there is little convincing proof of a cause and effect relationship between sea-cage fish farming and HABs. This is contrary to the views of some in the HAB science community (e.g. Fukuyo 2012: “Development of fish aquaculture almost always accelerates eutrophication of culture area and consequent occurrence of HABs.”). In fact given that these sea-cages can be responsible for high rates of nutrient loading to enclosed waters, it is puzzling that that their effects are not more obvious and well documented. There may be a considerable amount of information on this topic in the ‘grey literature’ such as locally commissioned environmental assessment reports that would shed more light on it. The proposal is to develop a project under the GEOHAB umbrella that would be aimed at drawing out this information so that a consensus can be reached on where HAB related problems associated with sea-cages occur and what can be done to mitigate them. The proposal does not aim to address issues surrounding intensive pond culture nor sea-cages in tropical systems where data would not be directly comparable with temperate coastal ecosystems.

This proposal encompasses aspects of at least three of the programme elements from the GEOHAB Science Plan, including: Nutrients and Eutrophication, Comparative Ecosystems and Observation Modelling and Prediction

The specific objectives may include:

- A comprehensive review of published and unpublished data and the knowledge and opinion of local experts in all countries (e.g. Norway, Scotland, Ireland, USA/Canada, Japan, Korea, China, Australia, New Zealand etc.) with significant temperate sea-cage fish farming industries. This
review may ultimately comprise series of papers focussed on specific regions published as a special journal issue or stand-alone volume.

- Foster the development of novel technologies to track effluent plumes from sea-cages to enable direct observations of their effects on the water column (e.g. drone-mounted remote sensing).
- Provide guidelines for effective monitoring of water quality and HABs associated with sea-cages, encourage research on in situ autonomous instrumentation to achieve this.
- Development of biophysical simulation models to more accurately predict the impact of fish farm effluents on the phytoplankton in general and HABs in particular.
- Identify means by which the environmental effects of fish farms effluents and their potential for stimulation of HABs might be minimised.
- Provide guidelines for the attributes necessary for the optimum location and nutrient loading rates of sea-cages to minimise the risk of HABs. Generic guidelines could be published under the GEOHAB banner.
- Encourage multidisciplinary research to accurately quantify nutrient assimilation, remineralisation and loss rates in waters and sediments of fish farming regions to parameterize biophysical models.

References


IMPROVING MODELING AND MONITORING CAPABILITIES FOR BENTHIC HAB TAXA, TOXINS, AND HUMAN HEALTH IMPACTS

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Harmful algal blooms caused by benthic microalgae, or BHABs, encompass a diversity of taxa and ecosystems worldwide. In terms of public health, the most prominent BHAB syndrome is ciguatera fish poisoning (CFP); however, toxin exposure from *Ostreopsis* spp. blooms and other benthic taxa (e.g., *Prorocentrum* spp.) may also contribute to human toxic effects in some regions. The sporadic nature of BHAB poisonings, coupled with uncertainty regarding the environmental and physiological factors that contribute to outbreaks, present many challenges to scientists seeking to develop predictive models and management programs. Compared to poisoning syndromes associated with planktonic HABs, the study of BHAB phenomena is nascent, and still lacks standardized methods and approaches for their observation and prediction. The goal of this concept paper is to outline a strategy to advance modeling and monitoring capabilities for BHAB taxa and toxins, and associated illnesses. These activities relate directly to the BHAB Core Research Project (CRP) objectives described for GEOHAB Program Elements (4) Comparative ecosystems and (5) Observation, modeling and prediction; however, activities under this project will also help meet objectives under elements (1) Biodiversity and biogeography and (3) Adaptive strategies.

The proposed strategy includes a tiered approach, which will comprise several levels of modeling and monitoring complexity based on location, funding, and capacity. Within this framework, participants will explore alternative modeling systems and approaches, define modeling parameters, and standardize methods. Previous modeling work carried out in Hawaii, as well as work currently underway in the Caribbean can help inform the proposed effort. These activities will benefit future comparative studies as well as monitoring and management programs. The major deliverables will include a joint workshop, a website, and significant technology transfer among scientists in the BHAB community. The following objectives and associated tasks will serve as a framework for coordinating activities under this effort:

1) **Objective 1:** Host a joint workshop during which participants share models and datasets, and establish approaches, methods and technologies. During the workshop, participants will define a tiered approach to modeling and monitoring based on the parameters and methods deemed most appropriate and useful to the participants’ program and/or location. This approach and the collaborative network established during this workshop will also inform activities under Objectives 2 and 3. The objectives and outputs from this workshop comprise four subtasks:

   a) **Subtask 1.1:** Participants will identify different model formulations that might be useful for BHAB species and toxins. This will include existing population dynamics models, as well as empirical models that link environmental parameters (e.g., temperature, climactic/environmental perturbations) to outbreaks of human illness.

   b) **Subtask 1.2:** Participants will identify areas for integration into predictive models (e.g., small scale/coastal oceanography) and identify knowledge gaps, such as different BHAB food-web dynamics and the influence of epidemiological factors.

   c) **Subtask 1.3:** Participants will identify methods to be standardized for cross comparison of different models. This effort will benefit substantially from the identification of standardized sampling and identification protocols, as called for in the BHAB CRP.

   d) **Subtask 1.4:** The joint workshop will help to establish a network of cooperating investigators working on numerical models for benthic systems, and those interested in developing predictive capabilities.

2) **Objective 2:** Develop a website to serve as a clearinghouse of information and products resulting from the workshop, and to facilitate communication and networking among managers and scientific teams. To the extent possible, existing websites and databases developed by the BHAB community will be leveraged to maximize existing resources and avoid duplication of effort.

3) **Objective 3:** Foster comparative approaches among taxa and geographic regions. The networking opportunities afforded by this initiative will bring together scientific teams from around the world, and thus will facilitate collaborative research related to the BHAB CRP program elements 1 (*Biodiversity and biogeography*) and 4 (*Comparative ecosystems*). These activities will benefit
substantially from the identification of standardized methods during the joint workshop, which will ensure a consistent approach to these comparisons.

We anticipate to secure funding during 2013-2014, and to convene the joint workshop in 2014 (as early as possible). Website development will commence immediately following the workshop, and maintenance will continue through the duration of the project, guided by input and direction from the participants. Similarly, the workshop is intended to help initiate the collaborative work described in Objective 3, which will continue through the project duration (and beyond). Potential funding sources for this project could include international agencies such as IOC-UNESCO, SCOR, WHO, FAO and national funding agencies such as the U.S. National Science Foundation (NSF) and the U.S. National Oceanic and Atmospheric Administration (NOAA). Existing websites and databases will be leveraged to maximize resources, and thus will be funded to the extent possible through existing sources.

The joint workshop proposed and follow-up activities will provide a unique forum for scientists interested in modeling to share different approaches and methods, thus advancing methods standardization as well as the development of predictive tools and capabilities. BHAB research teams are scattered around the world, and there are very few international programs outside of GEOHAB that can serve to facilitate this level of networking and collaboration. Without the kind of focused coordination and technology sharing provided by initiatives such as the one outlined here, modeling of BHABs will proceed very slowly and without the diversity of perspectives provided by the international BHAB scientific community.

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**LIFE-STAGE DEPENDENT SWIMMING BEHAVIOR AS THE UNDERLYING CAUSE FOR DINOFLAGELLATE BLOOMS AS WE RECOGNIZE THEM**

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Life-stage-dependent swimming behaviors seem to be the underlying cause of the accumulation of dinoflagellate populations known as “blooms.” It is important to incorporate this recognition in the plans for future research on dinoflagellate blooms. The same principles might apply for both cyst-producing and non-cyst-producing dinoflagellates – that what we see as “blooms” is a consequence of the assembly of sexually-reproducing cells. Chemical attraction between gametes is the cause, and collective swimming behavior interacts with hydrodynamic factors at a larger scale causing bioconvection and hydrodynamic trapping, followed by further concentration in a yet larger scale by currents, fronts, and water-mass stratification.

In two recent publications that include video recordings as supplemental material, we describe the swimming behavior of different life stages of *Alexandrium fundyense*. Different life stages have different swimming behavior; vegetative cells are phototactic; they are known to perform daily, vertical migration between surface and deeper waters. When observed in culture, vegetative cells swim straight (although rotating around the apical axis) until they hit something and then swim straight in a different direction. Gametes, on the other hand, are not phototactic in culture and can accumulate in thin layers in the pycnocline in nature. Gamete swimming behavior is optimized for achieving cell contact and fusion within dense accumulations of cells; gametes change swimming direction often (‘swarm’ or ‘dance’) and contact other cells frequently. A gamete will contact and attach to a compatible gamete with the transversal flagella before fusing. The angle of attachment of gametes is perpendicular to each other and results in a non-directional tumbling motion, unlike dividing vegetative cells that are oriented parallel to each other with no disruption in motion. Gamete formation is induced in vegetative-cell cultures by transfer into encystment medium (also during turbulent situations) even if no compatible strain is available. Behavior of gametes is affected significantly by the presence of a compatible strain, suggesting
the presence of a pheromone working at short distances within the assemblage of cells. These results are consistent with population accumulation caused by seasonal signals such as nutrient composition and water mass stratification at the end of the growth season. Zygotes swim slowly when newly formed and later become nearly immobile; they continue to contact other cells and also surfaces until they attach to “marine snow” (floculant) and sink as part of larger aggregates while forming resting cysts.

The differences in swimming behavior between dinoflagellate life-history stages result in different responses to water movement. Early stationary-phase cells in culture (gametes or pre-gametes) assemble in bioconvection patterns along the water surface and as stripes in the water; whereas, cells in exponential growth (vegetative cells) do not. We have studied the swimming behavior of early stationary-phase *A. fundyense* cells both on the individual level and on the population level. In shallow petri dishes, cells assembled in bioconvection accumulations that appeared as “spots” when viewed from above. Individual cells swam faster the denser the cell accumulations were. The closer the cells were to the center of spots, the faster they swam and the more often they changed direction. On a population level, the behavior of spots of assembled cells was studied using time-lapse photography. The spots entrained more and more cells as they grew, and spots fused with each other; the closer the spots came to each other, the faster they moved until they fused to form larger and larger bioconvection units. Large spots attracted smaller spots that moved toward them and united.

We suggest that chemical attraction between gametes causes the observed behavior. As undisturbed blooms of *A. fundyense* are known to end with cyst formation, and cyst formation by necessity has to be preceded by gamete formation, a large proportion of the cells in a bloom are likely to be gametes. The microscopic movements of individual cells in the field during a dinoflagellate bloom are unknown, but likely fundamental to bloom dynamics. When cells are in salinity-stratified conditions similar to those that occur during a bloom, they are known to accumulate in the halocline. Models for hydrodynamic trapping of microorganisms in layers require motility of the cells. It is well known that upwelling, currents, and fronts are important for dinoflagellate bloom formation and transport. The interaction between life-stage-dependent swimming behavior, water movements and stratification is probably of great importance for the understanding of the formation and development of dinoflagellate blooms in general. Gamete assembly on the micro-scale can be the underlying cause for large-scale phenomena seen as dense accumulations of dinoflagellates in thin layers and widespread surface blooms. Populations can grow diffused in the water (or for some species perhaps near-bottom) as vegetative cells, but when mating-season cues induce gamete formation, swimming behavior changes. As soon as conditions permit (calm weather, especially after rain with land run-off that creates a strong stratification) gametes subsequently must accumulate to mate. Chemical attraction between gametes may initiate cell accumulations that, in turn, cause bioconvection patterns at a scale larger than the cells can influence. These accumulations with high cell density then can be magnified on an even greater scale and transported by water movement and hydrodynamic trapping. When bloom–forming dinoflagellates are toxic, and gametes release toxins to the water, the accumulation of cells (bloom) is avoided by predators. Allelopathic growth inhibition of competing microalgae or reduced grazing pressure associated with toxicity is well known for many toxic dinoflagellates.

Future research plans on bloom dynamics must be based on a more thorough understanding of underlying processes. It is well known that dinoflagellates grow relatively slowly, and it is often suggested that they do not grow in the bloom, but are accumulated and transported by hydrodynamic factors. With better understanding of life-stage-dependent swimming behavior, models for prediction and management can improve based upon incorporation of previously-unrecognized mechanisms. Bloom initiation and bloom termination processes are today poorly understood but are crucial for the prediction and management of bloom impacts.

I would like to give a presentation of our results and include video recordings from our experiments, and also examples from other dinoflagellate species as a base for further discussions about the importance of life-stage-dependent swimming behavior in dinoflagellate bloom dynamics.
• **Suggested projects**: identification of life stages in natural blooms, laboratory studies of hydrodynamic trapping of different life stages followed by theoretical modeling.

• **Potential participants**: dinoflagellate researchers.

• **Timeline**: 2014-2018.

• **End product**: better understanding of bloom initiation and bloom termination processes.

• **Relevance to GEOHAB**: leads to better prediction and management of bloom impacts.

• **Potential funding sources**: national and international funding agencies and organizations

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**LINKAGES BETWEEN HARMFUL ALGAL BLOOMS AND ANOXIA**

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**Participants**
The following participants are committed and funded to undertake this project within the southern Benguela upwelling system:

- Durand, Pierre M., Department of Molecular Medicine, University of Witwatersrand and National Health Laboratory Service, Johannesburg, SA
- Pitcher, Grant C., Fisheries Research and Development, Cape Town, SA
- Probyn, Trevor A., Fisheries Research and Development, Cape Town, SA
- Schroeder, Declan C., Marine Biological Association, Citadel Hill, Plymouth, UK
- Sym, Stuart, School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg, SA

Other participants will be identified following establishment of other systems to be included in the project for the purposes of comparison.

**Summary**
Oxygen deficiencies in coastal environments have increased during recent decades and eutrophication is considered a causal factor. Here high biomass dinoflagellate blooms (red tides) are often deemed the cause of anoxia. However the transient character of these events has contributed to a poor understanding of the causes and timing of bloom mortality leading to anoxia. This study will seek to establish the nature of phytoplankton mortality within blooms and the role of microbial activity in carbon transformation and oxygen consumption. Quantitative estimates of these processes will contribute to the prediction of anoxia linked to HABs. St Helena Bay in the southern Benguela upwelling system offers a unique environment to further study and quantify these links and for the purpose of comparison it is intended that parallel studies are undertaken in other systems.

**Project outline**
Oxygen deficit in the oceans is a critical determinant of biological and ecological processes and the expansion of hypoxia and anoxia represent major perturbations to the diversity, structure and functioning of coastal marine ecosystems. Dissolved oxygen is now recognized as a property of the ocean that has changed dramatically, with oxygen deficiencies having increased in frequency, duration, and severity during recent decades. Rates of oxygen decline are considered to be greatest in coastal regions and evidence for eutrophication as an important causal factor is increasing. Temperature also interacts through a multitude of processes to control the extent of oxygen depletion, and projected warming associated with climate change shows an increase in susceptibility of coastal marine ecosystems to hypoxia and/or anoxia.

Anoxia is regularly listed as a major consequence of harmful algal blooms (HABs), but the linkage of blooms to anoxia and consequent mortalities within ecosystems is poorly established. Four categories of anoxia have been defined: permanent, seasonal, episodic and diel. Events of anoxia linked to HABs are typically confined to the episodic and diel categories and their local and transient character has
contributed to our poor understanding of these events. Specifically the causes and timing of bloom mortality leading to anoxia are unknown. In contrast to the efforts to establish the conditions, mechanisms and strategies that control phytoplankton cell growth and bloom development, considerably less effort has focused explicitly on phytoplankton mortality and as a consequence the mechanisms that control abrupt bloom termination in natural systems are not well understood. Until recently phytoplankton were considered somewhat immortal unless eaten by predators, but it is now known that spontaneous death may result, particularly under adverse environmental conditions, as a consequence of infection by viruses or as a result of programmed cell death, with significant ecological impact. To date our studies have focused on the role of nutrient input and limitation in bloom development and demise rather than the role of microbial activity in carbon transformation and oxygen consumption.

This study will seek to establish the nature of mass, episodic phytoplankton mortality within HABs leading to the transfer of organic matter to the heterotrophic microbial community. Quantitative estimates of these processes will contribute to the prediction of anoxia linked to HABs. Our approach will be to track bloom development and demise through moored instrumentation at sites known to be susceptible to anoxia. In addition to monitoring dissolved oxygen concentration, measurements will also be made to quantify micro-zooplankton grazing, virus-mediated cell lysis and programmed cell death, as plankton mortality processes. These measurements will be made before, during and after the onset of anoxia.

Upwelling systems are subject to the risk of hypoxia and anoxia, and of the world’s four major eastern boundary current systems, water column shelf anoxia is best known in the Humboldt and Benguela Currents. Here episodic events of anoxia have been linked to red tides in areas such as Paracas Bay and St Helena Bay, respectively. In St Helena Bay recent observations have shown that these events are confined to relatively shallow waters during periods of downwelling, when subthermocline nutrients are inaccessible leading to bloom stress. St Helena Bay therefore offers a unique environment to further study and quantify the links between HABs and anoxia. For the purpose of comparison it is intended that parallel studies are undertaken in other systems, including other upwelling systems (e.g., Paracas Bay) and other systems subject to regular anoxia linked to HABs.

**Timeline and deliverables**

2013: Initiate project in the southern Benguela upwelling system. Identify collaborators in other systems prone to anoxia associated with HABs. Secure additional funding.

2014-15: Undertake field and experimental work.

2016: Conclude project through comparative assessment of findings and publication of results.

**Relevance to GEOHAB**

The project seeks to further our knowledge of the ecology and oceanography of HABs leading to events of anoxia in upwelling and other systems. Although bloom development will be tracked, the project will focus on the processes associated with bloom mortality and associated anoxia. Quantitative estimates of these processes will contribute to prediction of anoxia triggered by HAB events.

**Funding sources**

Funding to initiate the project in the southern Benguela upwelling system is secured. Funding to extend the project to additional systems will be accessed following identification of these systems. Extension of the project may be achieved by funding of co-supervised post-doctoral students through bi-national or bi-lateral agreements.
The negative impacts to human populations of benthic dinoflagellate toxins in tropical coastal fisheries products are well known, these impacts and increasing frequency are most felt in indigenous coastal populations that rely on fish for subsistence and export. At the most recent CFP workshop in Noumea 2008, led by SPC, most of the delegates of the island countries represented declared their CFP problem to be serious and needed help with monitoring, taxonomy and ecotoxicology etc, and that there was no funding to deal with the problem. Resolution and/or prevention of such impacts have been hampered by the complexity of toxin(s) chemistry, inadequate detection capabilities, and ambiguity related to the taxonomy and toxin production among dinoflagellate species/genera.

There is now a basic record on the biogeography of Gambierdiscus from past sampling.

In a number of PICTs throughout the Pacific, using basic identification skills with the light microscope to start with, (then later up to date taxonomy tools/information) and with a coordinated approach, among various collaborating island nations, where sampling efforts and monitoring can be established, with the provision of postgraduate researchers or government staff (using a research through training approach) to undertake such monitoring and collections, a record of the organisms biogeography can be achieved.

The first step is a workshop with funding assistance from FAO and SPC to send PICTs delegates to the Pacific Science Intercongress in USP, in Fiji in July. This is where the training in sampling/preservation, enumeration and identification of benthic HABs will take place, and then delegates with assistance, perform the taxonomic assessments to describe the relative abundances and distribution of these species in their home PICT. Toxin extraction, preservation and analysis will also be covered.

A second target of the work will be to collect dinoflagellate materials from some selected sites to isolate/culture and/or extract toxins and measure the MW of toxin material produced. Given that this effort will require substantial control over the collections, it is anticipated that the participant nations employ postgraduate research students for this collection and continuing monitoring efforts, and where possible be coordinated with coral reef monitoring projects (such as Ocean’s Foundation or NOAA’s coral reef monitoring program). We envisage correlating microalgal biogeography and ecotoxicology with coral cover, where coral monitoring coincides with microalgal collection.

The third target of this research will focus on the examination of food web effects: of the extracted toxin material produced. Implementation of this facet will require considerable amounts of extracted toxic material and to anticipate using the growth rate of juvenile fish and/or shrimp as dependent ecosystem variables; we believe we may also have means to assess responses by corals to the introduction of benthic dinoflagellate toxins. Measuring the amount of other benthic fauna and flora at the first trophic level amongst selected PICT monitoring sites with some of the students will also take place, to judge some of the impacts on biodiversity, where scholarships may be provided for those students. At the top of the coral reef ecosystem, using collections of opportunity an assessment of toxin load in megafauna will also be undertaken.

To enable assessment of the role of ballast water in the bioinvasiveness of these genera, special efforts will be made to identify areas representing a wide range of ship access, and shipping intensity; for example, within the Hawaiian Archipelago we anticipate the coordination of sampling with both the Main Hawaiian Islands, and the uninhabited Northwest Hawaiian Islands. Results of this work is also expected to dovetail and leverage future planned work on toxic benthic dinoflagellates (within GEOHAB?), to be
coordinated by this collaboration; and to involve scientists from beyond the Pacific: the Caribbean, Indian Ocean, Mediterranean Sea and SE Asia.

It is anticipated that the project co-ordinator and his team, once funded, will also be available to not only assist the PICTs selection of their future ongoing monitoring sites, supervisor the project and its components but also be available to assist where ciguatera outbreaks occur, be it seafood poisonings, marine fauna kills or aerosols to determine the responsible HABs and advise on management. The author has recently assisted with a marine turtle die off on the GBR and a marine fauna kill in the Solomon Islands.

To enable assessment of the role of ballast water in the bioinvasiveness of these genera, special efforts will be made to identify areas representing a wide range of ship access, and shipping intensity; for example, within the Hawaiian Archipelago we anticipate the coordination of sampling with both the Main Hawaiian Islands, and the uninhabited Northwest Hawaiian Islands. Results of this work is also expected to dovetail and leverage future planned work on toxic benthic dinoflagellates (within GEOHAB?), to be coordinated by this collaboration; and to involve scientists from beyond the Pacific: the Caribbean, Indian Ocean, Mediterranean Sea and SE Asia.

It is hoped that international agencies will assist this project with appropriate funding for the project team, scholarships for students, the food web impacts component and assistance to the PICTs monitoring and rapid response team for ciguatera outbreaks.

**UNDERSTANDING BENTHIC AND PLANKTON OUTBREAKS WITH IMPACTS ON HUMAN HEALTH RELATED TO AEROSOLIZED TOXINS: A COMPARATIVE ANALYSIS**

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**Background.** Results from the Spanish EBITOX funded project: “Biology and toxinology of benthic dinoflagellates involved on outbreaks affecting human health risks (CTQ2008-06754-C04-04)”. IP: J.M. Franco.

*Ostreopsis* blooms have been intensively studied since 2007 in Sant Andreu de Llavaneres beach (NW Mediterranean Sea). The abundances of the organism (mainly *O. cf. ovata*) follow a clear seasonal pattern: it is present from late spring to autumn, with the highest numbers usually reached during the summer months (July-August). Repeatedly, people spending long time (several hours) nearby the beach studied are affected by respiratory problems. It has been hypothesized that such health incidences could be related to the presence of aerosolized compounds originated from the benthic community during the bloom period.

This hypothesis was tested by the EBITOX project installing high-volume air pump samplers in the beach to characterize the marine aerosol during the bloom period. Furthermore, the presence of *Ostreopsis* in the aerosol filters was investigated using both Scanning Electron Microscopy (SEM) and molecular tools (qPCR); the potential presence of palytoxin-like compounds (PLTX) was tested by LC-FLD and haemolytic assay.

In the aerosols, SEM observations revealed the presence of some marine microalgae (mainly diatoms) but *O. cf. ovata* was not clearly visualized. In contrast, qPCR assays estimated up to 100 cells per filter
during an outbreak in summer 2010 (Casabianca et al., 2013). In the filters, PLTX concentrations were below the detection limit of the quantification method. In contrast, PLTX ranged between 0.1 and 1.2 pg-cell$^{-1}$ in the microepiphytic assemblages (Riobó et al., in prep.).

The eventual relationship between Ostreopsis concentrations, health alteration symptoms and meteorology is currently being analysed (Vila et al., in prep.). Furthermore, systematic epidemiologic studies and laboratory experiments exposing natural epiphytic assemblages to different physical and chemical forcings are planned for the near future. The aim is to determine whether the Ostreopsis abundances (both planktonic and benthic) and PLTX content are related to certain weather conditions that could trigger those harmful outbreaks. The ultimate goal would be to provide management tools to minimize the inconvenience suffered by beach users. The respiratory problems observed in the study site concurrently to the Ostreopsis blooms, have also been reported in other Mediterranean beaches (e.g. Mangialajo et al., 2011) with similar uncertainties related to the implication of aerosolized toxins.

In another completely different environment, the Gulf of Mexico, Karenia brevis causes toxic outbreaks, which may result in extensive fish kills, marine mammal mortalities, neurotoxic shellfish poisoning, and respiratory irritation due to the aerosolized brevetoxin (Steidinger et al. 1997). Blooms of K. brevis initiate off the west coast of Florida (Steidinger 1975) and may develop quite rapidly—populations of approximately 5000 cells L$^{-1}$ may reach up to $10^6$ cells L$^{-1}$ within 2–4 weeks. Nowadays, the performed studies have provided a good understanding of the environmental factors (shoreline wind speed and direction, ultraviolet light exposition, impact of wave activity on cellular integrity) favoring the production and dispersion of toxic aerosols. Furthermore, respiratory effects from exposure to either aerosolized K. brevis red tides or pure brevetoxins have been reported in experimental animals. Suitable medication to prevent and/or treat the effects of exposure to the red tide aerosols (e.g. asthma medications, anti-histamines) is already identified and a highly sensitive quantification method of the K. brevis toxins is available.

Future steps. Proposed activities.

Besides the main biological differences between the planktonic Karenia brevis and the benthic Ostreopsis spp., some commonalities exist concerning the impacts of their outbreaks on both the environment and the human health. However, while consistent and useful information already exist to protect citizens against the toxic K. brevis outbreaks, this understanding is still lacking in the case of the Ostreopsis spp. outbreaks.

We propose to conduct a workshop to compare the ecology and biology of Karenia brevis and Ostreopsis spp. in order to improve our comprehension of their outbreaks dynamics and their impacts on human health and the environment.

Given that the studies on K. brevis blooms started about 30 years ago, scientists working in the Ostreopsis outbreaks in the Mediterranean could learn from the experience on both, the ecology and epidemiology, in the Gulf of Mexico. Thus, future steps would consist on applying in the Mediterranean analogous and most effective approaches used for the K. brevis. In turn, the possibilities of applying the recently developed molecular tools to quantify Ostreopsis in any field or matrix, will also be considered for the K. brevis research. Specifically, the workshop would address comparison on the aerosol sampling and analysis techniques, methods to assessing potential human exposure to marine biotoxins, ecological and epidemiological studies, and diffusion to the society in the two areas, the Mediterranean and the Gulf of Mexico. Depending on the response to the workshop, in a future step, a working group could be established.

International cooperation among the groups studying the impacts of K. brevis in the Gulf of Mexico and the ones in the Mediterranean dealing with the Ostreopsis outbreaks will foster the advance towards the understanding on the dynamics of such blooms and their impacts on human health. The workshop will contribute to implement the road map of the “HABs in Benthic Systems” CRP, in general and in particular in the frame of the “Comparative ecosystems” Element of the GEOHAB Science Plan.
A CONVERSATION ON EVALUATION AND FUTURE OF GEOHAB

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Following cited is part of my answer to the Questions to Evaluate GEOHAB which circulated by GEOHAB SSC in 2011. I think that the questions were well designed to cover many areas on the evaluation of GEOHAB and more importantly, the future of GEOHAB. Therefore, I am happy to share my answer and to discuss the future of GEOHAB/GEOHAB like program with colleagues in the HAB study community.

1. Do you think that GEOHAB has had a positive influence on international HAB activities related to this mission?
   Yes, of course! GEOHAB has a very clear positive influence. Some of the main contributions could be listed such as:
   - First global scientific program for HABs specifically, which links most of the researches who are working on HABs in different areas of the world.
   - First effort to understand the blooming mechanisms of HABs through multi-disciplinary approaches in different marine systems in the world.
   - Important role in promoting regional and national HAB projects or programs.

2. What critical science/management questions can best be addressed by a GEOHAB-type organization?
   - Can HABs be predicted/broadcasted similar to that for bad weather? How?.
   - What is the consequences of HABs to the marine ecosystem?
   - Should/could HABs be linked to other abnormal ecological phenomena such as jellyfish blooming and hypoxia…?.
   - Have we really understood HABs in teams of their relationship with human activities and global change?

3. Are there cross-cutting activities (e.g. climate change, modeling) that GEOHAB should focus on rather than the existing Core Research Project structure that focuses (primarily) on ecosystems?
   Yes, there are strong needs for GEOHAB to expand its focus to include not only climate change but also nutrients loading dynamics/LOICZ and other abnormal ecosystem phenomena in its structure, make priority of modeling in its projects’ plan and try its best to provide total/integrated/one set scheme for HAB monitoring/management.

4. If GEOHAB (or a similar organization) were to continue beyond 2013 what emphasis should be placed on international management issues?
   Any future HABs-related program or organization needs to be linked to other abnormal ecological phenomena such as jellyfish blooming and hypoxia…and needs to be linked to land-based nutrient overloading issues/LOICZ. In another word, there would be no bright future if HABs-related research/program is continuing to focused on HABs only or too much. Schemes on HABs-related project/program must be connected with the influence of human activities from the land at one end and with the consequences to marine ecosystem at another end. In the scheme, all aspects which are important to public and decision makers should be put priority such as human health, economic impacts, ecosystem disruption, HABs-based management to eutrophication and mitigation, prediction and precaution of abnormal ecosystem phenomena including HABs….

5. How do you see future international HAB research being most effective: through joint IOC-SCOR (the current model), just IOC, just SCOR, as a working group, etc.?
After the sunset of GEOHAB, maybe IOC could play an essential role to continue the activities of an international core group on HABs before a new international HABs program/project could be set up by initiating and supporting meetings necessary for discussion and design.

6. If an international HAB program were to continue beyond 2013, funding would be required through some agency or agencies. In your opinion, what level of funding (or activity) would be appropriate, and what agencies or countries do you think would be willing to contribute?
   I think we need to think of two kinds of funding. The first funding is to support the activities beyond 2013 and before the set up of a new GEOHAB like program. The second is for the new program. For the first, I suggest IOC to initiate the first meeting and seek funding from different level of sources for hosting following meetings. For the second, I think that series of meetings with well-designed step by step built-up process are needed to draw decision makers/managers/funding providers from different countries to attend the meetings and join the discussion and design of the new program (not only “pure” HABs).

7. If you have other comments or suggestions for GEOHAB...
   I do think that the most important thing to locate possible funding for the potential new international program/project is to have an excellent design of the program/project from the very beginning and that funding should be possible if the program/project could meet the need of public and decision makers apart from their scientific value, particularly from some of the fast-developing countries.
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<tr>
<th>Acronym</th>
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<tr>
<td>AAO</td>
<td>Antarctic Oscillation</td>
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<tr>
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IIM-CSIC  Instituto de Investigaciones Marinas (Spain)
ILM  Institute Louis Malardé
IMAS  Institute for Marine and Antarctic Studies (University of Tasmania)
IMBER  Integrated Marine Biogeochemistry and Ecosystem Research project (SCOR and IGBP)
IOC  Intergovernmental Oceanographic Commission of UNESCO
IOCCG  International Ocean Colour Coordinating Group
IODE  International Oceanographic Data and Information Exchange (IOC)
IPCC  Intergovernmental Panel on Climate Change
IPHAB  Intergovernmental Panel on Harmful Algal Blooms (IOC)
ipma  Instituto Português do Mar e da Atmosfera
ISSHA  International Society for the Study of Harmful Algae

LC-FLD  Liquid Chromatography with Postcolumn Fluorescence Derivatization
LDA  Linear Discriminant Analysis

N  nitrogen
NAO  North Atlantic Oscillation
NERC  Natural Environment Research Council (U.K.)
NOAA  National Oceanic and Atmospheric Administration (U.S.)
NSF  National Science Foundation (U.S.)

OSM  open science meeting

P  phosphorus
PICES  North Pacific Marine Sciences Organization
PIV  particle image velocimetry
PLTX  palytoxin
PSP  Paralytic Shellfish Poisoning
PTV  particle tracking velocimetry

qPCR  quantitative polymerase chain reaction

RBA  receptor binding assay
RS  remote sensing

SCOR  Scientific Committee on Oceanic Research
SEM  Scanning Electron Microscopy
SOLAS  Surface Ocean – Lower Atmosphere Study (SCOR, IGBP, WCRP, iCAGCP)
SPM  suspended particulate matter
SSC, RAS  Southern Scientific Centre of Russian Academy of Sciences
SST  sea-surface temperature
STX  spirolides

TTX  tetrodotoxin
TWG  Technical Working group
WHO  World Health Organisation
WKHABCW  Working Group on HABs in a Changing World
WOCE  World Ocean Circulation Experiment
www.geohab.info