Proposal for SCOR Working Group on

Land-based Nutrient Pollution and the Relationship to Harmful Algal Blooms in Coastal Marine Systems

Abstract

Nutrient over-enrichment (*eutrophication*) from land-based sources has degraded estuarine and coastal marine waters worldwide. Eutrophication has been linked to the increased prevalence of harmful algal blooms (HABs) that cause serious ecological, economic, and human health impacts. Yet, the linkage between nutrient loading and HABs currently lacks a firm, quantitative foundation. This working group will assess and compare *spatial* relationships between changing global nutrient exports and loads and the proliferation of major HAB species around the world. However, nutrient loads alone are likely not sufficient to predict where certain HABs may occur. Therefore, the patterns in nutrient loads and HABS will be further evaluated in the context of physical characteristics of the receiving waters (the typology) as well as the type of HAB (functional group) and their physiological characteristics. We will use a range of global databases and models in these analyses, including spatially explicit watershed nutrient export models, ecosystem and physiological models, and statistical approaches. This project will advance predictive capability of the extent of blooms, the dominant harmful taxa involved, and our ability to manage these HABs by an improved understanding of the impacts of nutrients on HABs. Products will be an atlas of maps of global HABs and nutrient export, as well as future predicted scenarios, which will be published in newsletters, peer-reviewed articles and graphic-rich reports which will be produced and made available in print and on the web.

Rationale

Nutrient over-enrichment (*eutrophication*) is one of the most serious aquatic pollution problems throughout the world (National Research Council 2000, Smil 2001, Cloern 2001, Howarth et al. 2002, Seitzinger et al. 2002, 2005, Wassmann 2005). Nutrient pollution arises from human activities such as use of synthetic fertilizers, energy production, and expansion of industrialized agriculture and aquaculture operations. An important adverse consequence of eutrophication is the increased prevalence of harmful algal blooms (HABs) that can cause oxygen depletion and fish kills, seafood poisoning, and undesirable shifts in food webs (Smayda 1990, Hallegraeff 1993, Anderson et al. 2002, Glibert et al. 2005a,b). Although eutrophication is generally known to stimulate many harmful estuarine and marine algal species (Anderson et al. 2002), the relationship is complex (Glibert et al. 2005a,b, Glibert and Burkholder 2006). *Through improved global, spatially explicit models of nutrient loading from watersheds to coastal systems, and the development of new spatially referenced global databases of HAB occurrences, we are now in the position to begin to link patterns of eutrophication with HAB occurrence around the world in a more rigorous and quantitative way.*

A SCOR working group is the ideal mechanism to address this issue. The questions are international in scope, build on existing SCOR and Intergovernmental Oceanographic Commission (IOC) activities, and will provide the kind of global synthesis that is only

possible when individuals who have developed these databases and models come together to integrate their knowledge. Knowledge of these relationships is also important for developing countries, as these areas are experiencing rapid changes in nutrient export and HABs as the use of fertilizers and large-scale aquaculture grows in those regions.

The activities of this working group are relevant to several SCOR and IOC international research programs. They are directly relevant to the Global Ecology and Oceanography of Harmful Algal Blooms Programme (GEOHAB 2006; http://www.geohab.info) which has specifically identified the following questions as priorities in the Core Research Project on HABs and Eutrophication, chaired by P. Glibert, "What HAB species or species clusters are indicators for nutrient over-enrichment at global and regional levels?" and "How are long-term trends in nutrient loading changing HAB bloom patterns and dynamics?" (GEOHAB 2006). The working group can address these questions in a fundamentally different way from the activities of GEOHAB, however, since GEOHAB is focused on ecology, physiological adaptive strategies of species, and oceanography (GEOHAB 2001), but does not have expertise on watershed nutrient loading or the development of coastal typology databases. However, the Global Nutrient Export from Watersheds Program (Global NEWS), chaired by S. Seitzinger, has developed and applied spatially explicit models that predict nutrient (nitrogen, phosphorus, carbon) loading from watersheds to coastal systems globally. Global NEWS has been an ad hoc workgroup of IOC (http://www.marine.rutgers.edu/globalnews/).

Questions of nutrient export and its effects in the coastal zone are relevant to many global change programs. Nutrient fluxes and their key impacts are relevant to the mission of LOICZ, IMBER, and the International Nitrogen Initiative (INI), which is cosponsored by IGBP and SCOPE. Global NEWS has received endorsement from LOICZ, and we will seek endorsement from LOICZ, GEOHAB and IMBER for this SCOR working group. Co-sponsorship for this working group by IOC is also under consideration at this time. The working group will build on existing data sets and models, synthesize relationships and lay the groundwork for new research which can, and likely will, be proposed under the auspices of these global programmes. Our working group will be composed of biologists, chemists, hydrologists and modelers, as well as those who have experience in large-scale data and GIS analysis.

Scientific Background

The questions related to understanding the linkages between HABs and eutrophication are many. Our goal is to determine if there are patterns in the relationships between nutrient loading and HABs, by building on existing global nutrient loading models and HAB databases.

There are literally hundreds, if not thousands, of reports of HAB occurrences around the world. Historically, the data on HAB occurrence were scattered in government reports, websites, and scientific journals, and often data on nutrients and coastal typology were not included in those reports. Therefore, to date, our attempts to relate the occurrence of particular HAB species with nutrient loading have largely been based on using a limited

amount of data from the literature on HAB occurrences where nutrient loading and other parameters could also be found. However, a major effort has been underway by the IOC-HAB program to develop a global database that documents the occurrence of species, along with many site characteristics (http://ioc.unesco.org/hab/data.htm). Maps based on frequency of occurrence are also available for ICES nations for the past ten years (http://www.ices.dk/marineworld/hab.asp). There are also a number of excellent databases for particular regions that have not yet been submitted to the IOC-HAB program and thus are not yet included in the database.

The IOC-HAB database is a critical component of any attempt to relate the global patterns of HAB occurrence with coastal eutrophication. However, most of the studies in that database do not contain specific information on nutrient loading rates, and in many cases details of the coastal typology. The Global NEWS efforts make available those needed data and expertise. The Global NEWS group maintains a global database of measured and modeled river nutrient loads and watershed nutrient sources (including IOC-UNESCO, LOICZ, U.S. Geological Survey and others (http://www.marine.rutgers.edu/globalnews/).

Estimating nutrient export to the coastal zone has been a challenge, but enormous advances have been made with respect to global models over the past several years. The first global model of nitrogen loading to coastal systems was published less than 10 years ago (Seitzinger and Kroeze 1998). Our initial efforts combining literature data on HAB species occurrences with the outputs of global nitrogen loading models suggested a high degree of correspondence for one group of HABs, as represented by the dinoflagellate *Prorocentrum minimum*, but a lesser correspondence for the species that tend to form paralytic shellfish poisoning (Fig. 1; Glibert and Burkholder 2006). While these results are interesting, these initial efforts represent only a small portion of HAB species groups and the data were not geo-referenced (they were derived from literature reviews). Also, the data in Fig. 1 are only for nitrogen export models and comparable relationships for other nutrients or nutrient forms are not yet available. Through the work of the Global NEWS workgroup, global models of nitrogen, phosphorus and carbon exports, by form, have been developed based on watershed characteristics such as river discharge, land use, human population, fertilizer nitrogen and phosphorus use, manure from animal production, atmospheric nitrogen deposition and biological N_2 fixation (e.g., Beusen et al. 2005; Bouwman et al. 2005a,b; Dumont et. al. 2005; Harrison et al. 2005a,b; Seitzinger et al. 2005) and are available for use. These models demonstrate that the ***amount*** of nutrient discharge is unevenly distributed, the ***nutrient forms and their ratios*** vary with land use, and the ***composition*** of the nutrient discharge is changing due to land-use patterns. These new models need to be compared to HAB distributions.

Development of these models also allows us to now ask questions about whether different nutrient elements, forms and ratios are related to different functional groups of HABs. A gradient of habitats has been characterized which tend to foster distinct types of dinoflagellate HABs (Reynolds and Smayda 1998; Smayda and Reynolds 2001). Some types of HABs, such as the high-biomass bloom former *Prorocentrum minimum*, seems to mirror the global export of nitrogen as shown in Figure 1, with hot spots along the U.S.

east coast, European and Asian coasts, and appears to be increasing, along with its deleterious effects (Heil et al. 2005). However, other species groups, such as *Karenia mikimotoi*, on the other hand, are dinoflagellate species that bloom in open coastal waters, aggregate in fronts and are transported by coastal currents (Dahl and Tangen 1993; Vargo et al. in press). They proliferate in oligotrophic waters (Heil et al. 2001), but appear to be maintained in nearshore waters. We aim to compare the global nutrient export models with the available global data of these HAB types. There are several classification schemes of estuarine and coastal typology that are now available that have been related to algal composition, but not necessarily HABs (e.g., Ferreira et al. 2005). We aim to build on these efforts and to use that information to develop relationships that predict the probability of occurrence of different HAB groups. We aim to focus on the dinoflagellates, as most data are available for this class of HABs, but may explore relationships for other HAB groups, including raphidophytes or cyanobacteria, if sufficient data are available.

Note: best viewed in color

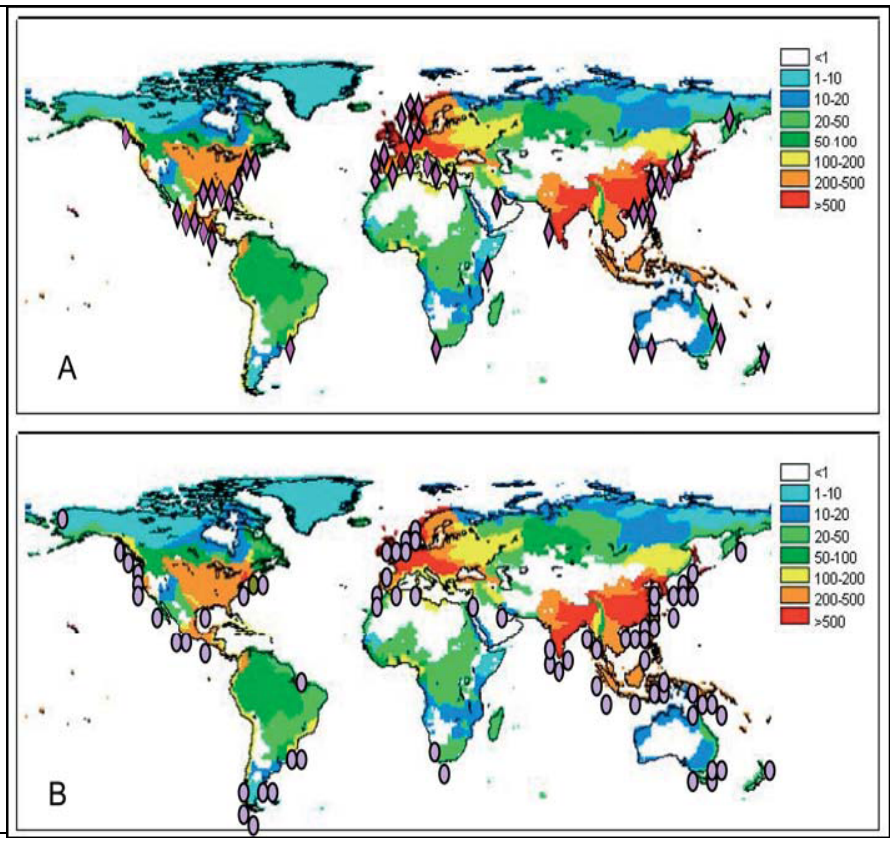

Figure 1. Global distribution of recorded incidences of major toxic HAB species super-imposed on a global map of modeled nitrogen export (base map from Seitzinger and Kroeze 1998). Nitrogen export is calculated as kg N · km^{-2} watershed · $year^{-1}$.
A) Documented occurrences of dinoflagellates *Prorocentrum minimum*, based on the review by Heil et al. (2005).
B) Documented occurrences of a species cluster that causes paralytic shellfish poisoning (dinoflagellates *Alexandrium tamarense, A. minutum, Gymnodinium catenatum, Pyrodinium bahamense* var. *compressum*), modified from GEOHAB (2001).

The results of this analysis will also be used to link the future predicted magnitude of sources to the anticipated future occurrences of HABs. Previous modeling explored the effect of a number of global change scenarios on nitrogen export, including changes in population, and food and energy production (Kroeze and Seitzinger 1998; Kroeze et al. 2001; Seitzinger et al. 2002a; Bouwman et al. 2005b). Model forecasts predict that large

increases in dissolved inorganic nitrogen export to coastal ecosystems will occur by 2050 for many world regions, due to predicted large increases in the global population and in associated food and energy production. The Global NEWS workgroup is currently developing input databases for their nutrient export models that are consistent with the four scenarios for the year 2030 outlined in the Millennium Assessment (http://www.maweb.org/documents/document.332.aspx.pdf). The Global NEWS models will be run with these input databases to explore the changes in nutrient loading to coastal systems around the world under these four development scenarios. In this proposed SCOR working group we will use these Global NEWS model predictions in concert with the relationships we develop between nutrient loading and HAB occurrence to explore future scenarios of HAB occurrence. *Thus, this effort also will begin to link human dimensions with coastal ecosystem effects.*

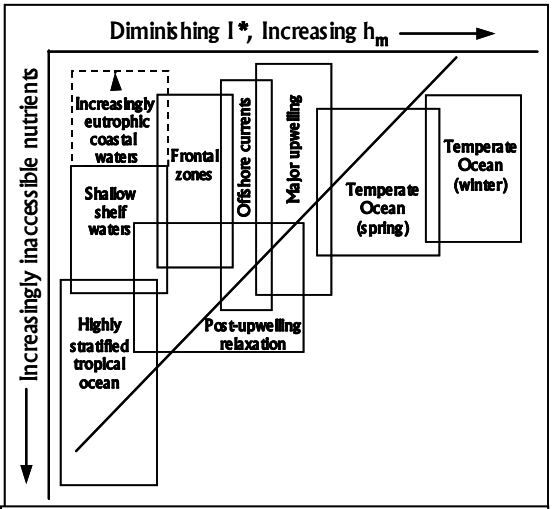

Figure 2. Habitats in marine coastal waters as a function of light and nutrient regimes (Smayda and Reynolds 2001). These habitats select for certain HAB species, species clusters, or species functional groups. The model incorporates parameters describing the abilities of the species to grow in these hydrographic regimes as physical/chemical factors or behavior alter vertical distributions and growth potential.

Neither GEOHAB nor Global NEWs has the mandate or the resources to conduct the kind of analysis that is proposed for this working group.

Terms of Reference

The working group will integrate existing data on HABs and eutrophication by conducting the tasks listed below:

1. Integrate the existing IOC-HAB database and nutrient loading databases into a compatible GIS format.
2. Advance the development of a GIS coastal typology database.
3. Interrogate the above databases for relationships between HAB species, nutrient loading/forms/ratios, and coastal typology.
4. Explore possible changes in HAB occurrences in the future (year 2030), using the relationships developed above (3.) and global nutrient export patterns under the Millennium Assessment scenarios for 2030.
5. Publish the results of these analyses in peer-reviewed scientific journals and develop newsletters/outreach reports for managers and the public summarizing the findings.

Approach and Products

The groundwork for the working group effort will be laid by accomplishing the first term of reference. This will be done through volunteer efforts by several of the working group members in advance of the first group meeting by examining each data record in the HAB database and formatting it for GIS application using the same grid format employed for the NEWS model. GIS expertise is represented on the working group. We will also work to develop a detailed global coastal typology using high resolution GIS coastal delineations to define open coastal environments, enclosed estuaries, shallow lagoons, and fjords, including their size, freshwater flow, retention time, and depth.

Through the working group process, we will then combine and develop/explore the databases for relationships between HAB species, nutrient loading/forms/ratios, and coastal typology. The first product will be series of maps in which various HAB groups are compared to the global maps of nutrient by form (e.g. nitrogen as nitrate, organic nitrogen, phosphorus by phosphate and organic phosphate), by ratio (e.g. N:P, N:Si, C:N), by season, or by physical factors such as flow or retention time. Regional maps will be made by working group members for the regions in which they have expertise. Estimates of forecasts of nitrogen and phosphorus export (by form) under future scenarios will be developed by using the land use changes as predicted in the Millennium Assessment under their four global change scenarios. These forecasts will then be related to future estimated HAB occurrences based on the relationships established for existing data (by nutrient form, ratio, etc.). The synthesis products expected include a series of maps which then will be interpreted in interdisciplinary, concept-driven, peer-reviewed papers. The expertise of the working group will guide the emphasis on particular regions and HAB types. Progress reports, maps and conceptual syntheses will be made broadly available through the global publication *Harmful Algal News*, similar regional/national publications, websites (such as http://www.geohab.info (GEOHAB), http://www.whoi.edu/redtide, http://www.marine.rutgers.edu/globalnews/, and the institutional and laboratory websites of the working group members. We will also publish several outreach newsletters and reports on the web and in print, through GEOHAB, LOICZ and other outlets.

Proposed Activities/Timeline

A series of 3- to 5-day workshops will be conducted over 3 years:

1. Spring 2008 in the Netherlands— The first meeting will be to advance the database as much as possible, to introduce the Global NEWS models to the HAB community and the complexities of HABs to the Global NEWS members. A list of the desired relationships and maps will be developed, and explored at the meeting and in post-meeting efforts.
2. Spring 2009 in Hong Kong or Japan— The second meeting will be to critique and interpret the maps and relationships developed, and to outline the projections of future scenarios required; and

3. Fall 2010, in conjunction with the 14th International HAB meeting in Greece—The third and final workshop will be to assess the scenarios developed from applying the Millenium Assessment projections; to critique, interpret and discuss all the findings of the working group; and to prepare the final manuscripts and report.

A newsletter will be prepared at the end of each workshop and made available through GEOHAB, *Harmful Algal News* or other outlets.

Participants –The working group will be chaired by the current chair of the GEOHAB Core Research Project on HABs and Eutrophication (**Glibert**) and Co-Chair of the IOC ad hoc working group on Global NEWS (**Bouwman**). These chairs bring together knowledge and experience on HABs and global nutrient use and land-use changes.

The following individuals have the expertise required for the working group, and to date, 8 of the 10 have agreed to participate in this working group (awaiting responses on the other 2), if approved by SCOR:

Name	***Country***	***Expertise***
Patricia Glibert* CO-CHAIR	USA	HABs and Eutrophication, GEOHAB Core Research Project Chair
Lex Bouwman CO-CHAIR	Netherlands	Land Use and Nutrient Export, Global database development; GIS modeling, Global NEWS Co-chair
Sybil Seitzinger	USA	Global nutrient export, biogeochemistry, GIS modeling, Global NEWS Chair
Paul Harrison	Hong Kong	Nutrient Export, Biogeochemistry, HABs
J. Icarus Allen	United Kingdom	Numerical modeling of marine systems, coupling of ecosystem and physical models, ecosystem forecast
Edna Graneli	Sweden	HABs and Eutrophication
Adnan Al-Azri	Oman	Time series of HABs; HABs in Arabian Gulf and Arabian Sea
Sandor Mulsow	Chile	Nutrient input to the coastal zone; Global NEWS; GIS modeling, effects of land-use change and aquaculture on coastal ecosystems
Paul Wassmann	Norway	Nutrient export to the coastal zone; impacts and effects including HABs
Ichiro Imai	Japan	Ecology of HABs in North Pacific; HAB database for North Pacific

* cv available at: http://www.hpl.umces.edu/faculty/glibert.html

We anticipate that there will be associate members of this working group who will participate in some or all the workshops. We will work with SCOR to identify additional associate members from developing countries. The preliminary list of associates will include the following people:

Name	***Country***	***Expertise***
Charlie Vörosmarty	USA and Italy	Hydrology
K. Padmakumar	India	HABs in India
Jorge A. Herrera-Silveira	Mexico	Nutrient export, HABs, Global NEWS, GIS modeling
Hak-Gyoon Kim	Korea	Asian HABs; eutrophication
Gustaf Hallegraeff	Australia	Australia and New Zealand HABs; eutrophication
Vera Trainer	USA	North Pacific HABs; time series databases
Grant Pitcher	South Africa	African HABs, nutrient relationships, GEOHAB Core Research Project chair
David Dickey	USA	Statistics, time series analysis, nutrient trends with time

Anticipated Results and Beneficiaries

Impacts of HABs on human health, ecological health and coastal economies are increasing worldwide (e.g., Glibert and Pitcher 2001, Ramsdell et al. 2005), and many of these blooms have been linked to eutrophication (Smayda 1990, National Research Council 2000, Anderson et al. 2002, Glibert et al. 2005a,b). At present, however, scientists, public health officials, federal and global agencies concerned with managing and protecting marine resources lack a firm, quantitative foundation on which to manage and mitigate this global epidemic. In this workshop series, we will assess the importance of eutrophication in stimulating various HAB species by applying quantitative and comparative analysis to global nutrient export/HAB data. Through this analysis an increased understanding of the potential to manage these threats by nutrient reductions will also be attained.

The work of this group will contribute to GEOHAB Core Research Project on HABs and Eutrophication by providing an in-depth analysis of the relationship of HAB occurrences to land-based factors, which GEOHAB is not addressing. The results should also contribute to LOICZ and IMBER. The work of the group will add value to, and leverage, the results of Global NEWS.

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