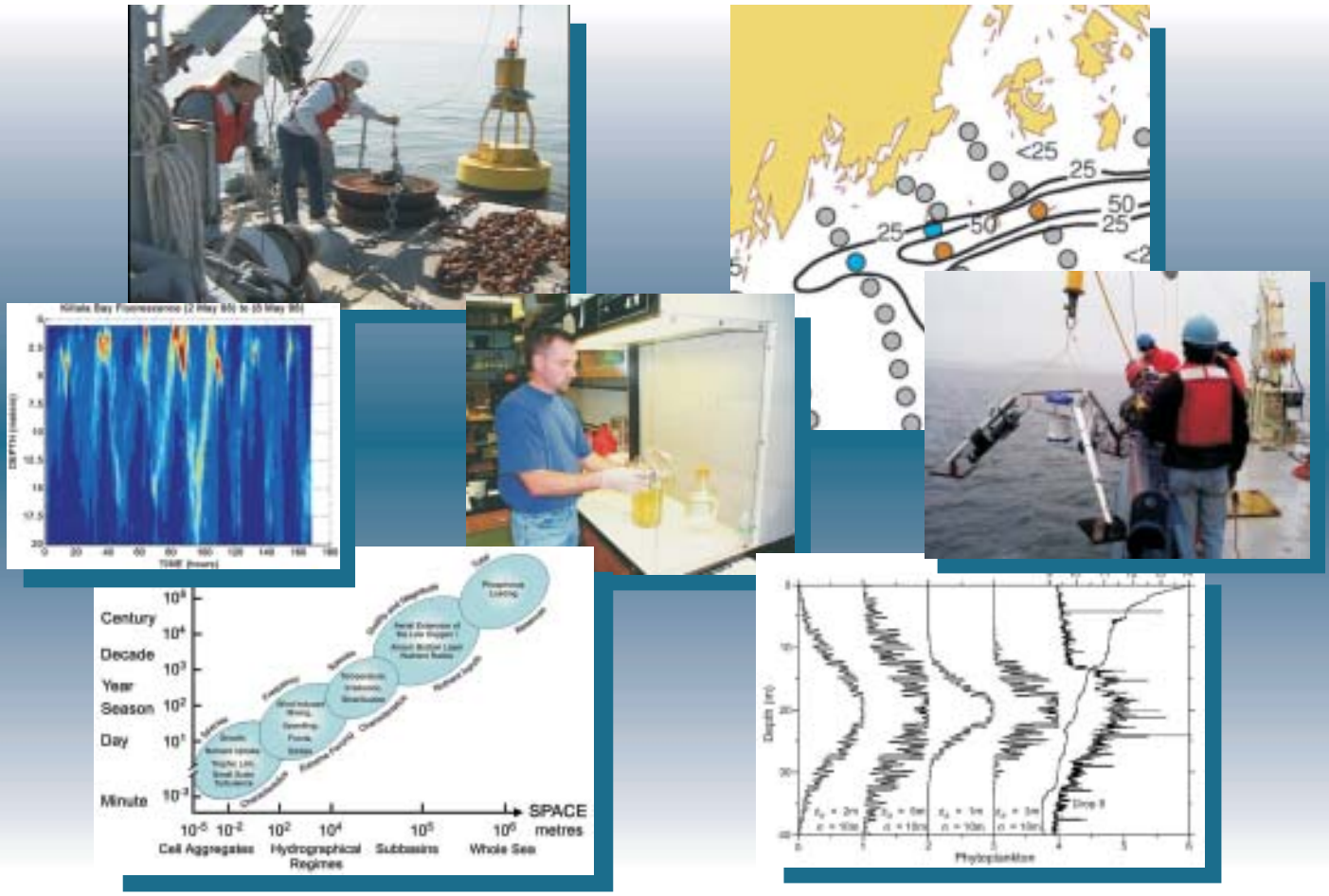
GEOHAB

Global Ecology and Oceanography of Harmful Algal Blooms



Implementation Plan

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GEOHAB

Global Ecology and Oceanography of Harmful Algal Blooms

Implementation Plan

An International Programme Sponsored by the
Scientific Committee on Oceanic Research (SCOR) and the
Intergovernmental Oceanographic Commission (IOC) of UNESCO

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Implementation Plan

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PREFACE

The Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) Programme is an international activity aimed at fostering and promoting co-operative research directed toward improving the prediction of harmful algal bloom events. Such events have been associated with fish and shellfish kills, human health impacts, and ecosystem damage throughout the world. The GEOHAB Programme has been endorsed by the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO and is intended to be of at least 10 years duration.

This plan for implementation of the programme serves as an invitation to the broad scientific community to participate. Scientists working in physical, chemical and/or biological disciplines, or other fields related to harmful algal research, including the development of relevant instrumentation and models, are encouraged to contribute to this programme. Active participation by the widest international representation of the research community will be essential to ensure the success of GEOHAB.

This *Implementation Plan* builds on the *Science Plan* previously published, which provides greater information about the justification for GEOHAB science and the specific types of science that are of greatest importance to GEOHAB. The *GEOHAB Science Plan* is available at http://www.jhu.edu/scor/GEOHAB_2001.pdf. This *Implementation Plan* begins with an overview and introduction to the GEOHAB Programme, then describes the Implementation Actions for implementation. Finally, a formal invitation to participate is provided, accompanied by a description of the procedure for application and associated obligations and benefits.

The GEOHAB Scientific Steering Committee (SSC) thanks the sponsors of GEOHAB, including the Institut Français de Recherche pour l'Exploitation de la Mer, Intergovernmental Oceanographic Commission, Tor and Maj Nessling Foundation, U.S. National Oceanic and Atmospheric Administration, and U.S. National Science Foundation for their financial support during the SSC's work on the *Implementation Plan*. Finally, the SSC thanks the reviewers of this plan for their valuable comments.

LIST OF ACRONYMS

CACGP :	Commission on Atmospheric Chemistry and Global Pollution
CLIVAR :	Climate Variability and Predictability programme
GOOS :	Global Ocean Observing System
GEOHAB :	Global Ecology and Oceanography of Harmful Algal Blooms programme
GLOBEC :	Global Ocean Ecosystem Dynamics project
HABs :	Harmful Algal Blooms
ICSU :	International Council for Science
IGBP :	International Geosphere-Biosphere Programme
IMBER:	Integrated Marine Biogeochemical and Ecosystem Research
IOC :	Intergovernmental Oceanographic Commission
IPO :	International Programme Office
JGOFS :	Joint Global Ocean Flux Study
LOICZ :	Land-Ocean Interaction in the Coastal Zone project
SCOR :	Scientific Committee of Oceanic Research
SOLAS :	Surface Ocean - Lower Atmosphere Study
UNESCO :	United Nations Educational, Scientific, and Cultural Organisation
WCRP :	World Climate Research Programme
WMO :	World Meteorological Organisation

INTRODUCTION AND OVERVIEW

Harmful algal blooms (HABs) are proliferations of algae that can cause massive fish kills, contamination of seafood with toxins, and/or ecological damage through the development of anoxia or habitat alteration. Such blooms cause world-wide problems with significant economic, social, and human health consequences. There is now considerable evidence that certain HABs, or at least their associated impacts, may be increasing globally. As with all phytoplankton dynamics, those of harmful algal species result from a combination of physical, chemical, and biological processes, many of which remain poorly understood. Some HABs have been linked to changes in nutrient inputs to coastal ecosystems, particularly as a consequence of human activities, but many harmful events occur in areas where anthropogenic input of nutrients or other pollutants are not considered to be contributing factors. The effects of global or local climate change on HAB populations are even less well understood.

In spite of considerable research on HABs over the past few decades, particularly on their distribution, environmental impacts, and effects on human health, the ability to describe factors controlling the dynamics of individual species, or species groups, has been limited by critical gaps in knowledge of the physiological, behavioural, and genetic characteristics of these taxa. In particular, there is an incomplete understanding of the interactions between physical and other environmental conditions that promote the selection of one group of species over another. Most previous research on HABs has been supported at the local or national level, with few attempts to consider such events from the ecosystem perspective at the appropriate regional scale. Furthermore, there has never been a programme designed to study such phenomena with a view to integrating global data from comparable ecosystems. An international, multidisciplinary, comparative approach is needed to advance our understanding of the mechanisms underlying population dynamics of HABs in differing physical and oceanographic regimes.

Development of the GEOHAB Programme

The Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) Programme was initiated under the auspices of the Scientific Committee on Oceanic Research (SCOR) of the International Council for Science (ICSU) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

A Scientific Steering Committee (SSC) for GEOHAB was formed in 1999, with specific tasks of determining the scope of the research, developing a *Science Plan*, and assisting with the co-ordination and implementation of the programme. The SSC activities and the GEOHAB Programme will be co-ordinated by an International Programme Office (IPO), which is currently being established.

The *GEOHAB Science Plan*

The overall scientific goal of GEOHAB is 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 modelling techniques.***

The *GEOHAB Science Plan* (GEOHAB Report #1, 2001; http://www.jhu.edu/scor/GEOHAB_2001.pdf) defines five Programme Elements that serve as a guide to establish research priorities. Although HABs also pose critical problems in freshwater ecosystems, the focus of GEOHAB will be on the manifestation of these blooms in marine and brackish waters to create a project of manageable scope.

The elements of GEOHAB and their overarching questions are:

- ***Biodiversity and Biogeography.*** *What are the factors that determine the changing distribution of HAB species, their genetic variability, and the biodiversity of associated communities?*
- ***Nutrients and Eutrophication.*** *To what extent does increased eutrophication influence the occurrence of HABs and their harmful effects?*
- ***Adaptive Strategies.*** *What are the unique adaptations of HAB species and how do they help to explain their proliferation or harmful effects?*
- ***Comparative Ecosystems.*** *To what extent do HAB species, their population dynamics, and community interactions respond similarly under comparable ecosystem types?*

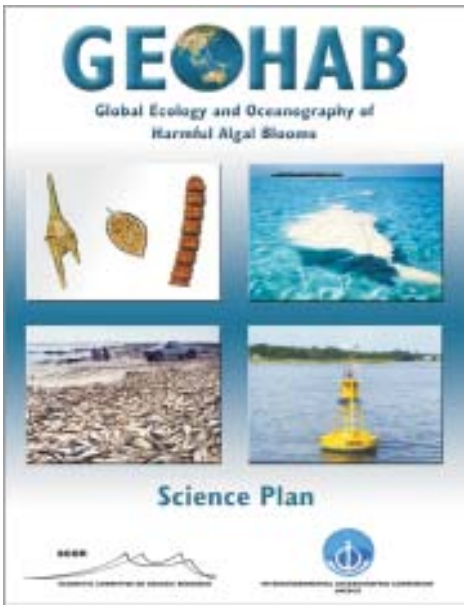


Figure 1. The *GEOHAB Science Plan* was published in 2001.

- ***Observation, Modelling, and Prediction.*** *How can we improve the detection and prediction of HABs by developing capabilities in observation and modelling?*

A summary of the specific objectives to be addressed under each Programme Element is provided in Table 1. The rationale for each of these objectives and the anticipated outcomes are fully described in the *GEOHAB Science Plan*.

Table 1. Summary of specific objectives for the Programme Elements (from the *GEOHAB Science Plan*).

Programme Element 1: Biodiversity and Biogeography

Specific Objectives:

- Assess the genetic variability of HAB species in relation to their toxicity, population dynamics, and biogeography
- Determine the changes in the biogeographical range of HAB species caused by natural mechanisms or human activities
- Determine changes in microalgal species composition and diversity in response to environmental change

Programme Element 2: Nutrients and Eutrophication

Specific Objectives:

- Determine the composition and relative importance to HABs of different nutrient inputs associated with human activities and natural processes
- Determine the physiological responses of HAB and non-HAB species to specific nutrient input
- Determine the effects of varying nutrient inputs on the harmful properties of HABs
- Determine the role of nutrient cycling processes in HAB development

Programme Element 3: Adaptive Strategies

Specific Objectives:

- Define the characteristics of HAB species that determine their intrinsic potential for growth and persistence
- Define and quantify biological-physical interactions at the scale of individual cells
- Describe and quantify chemical and biological processes affecting species interactions
- Identify the functional role of cell properties

Programme Element 4: Comparative Ecosystems

Specific Objectives:

- Quantify the response of HAB species to environmental factors in natural ecosystems
- Identify and quantify the effects of physical processes on accumulation and transport of harmful algae
- Identify and quantify the community interactions influencing HAB dynamics
- Define functional groups in communities containing HAB species

Programme Element 5: Observation Modelling, and Prediction

Specific Objectives:

- Develop capabilities to observe HAB organisms *in situ*, their properties, and the processes that influence them
- Develop models to describe and quantify the biological, chemical, and physical processes related to HABs
- Develop and evaluate systems for long-term monitoring of HAB species
- Develop capabilities for describing and predicting HABs with empirical models
- Develop capabilities in real-time observation and prediction of HABs

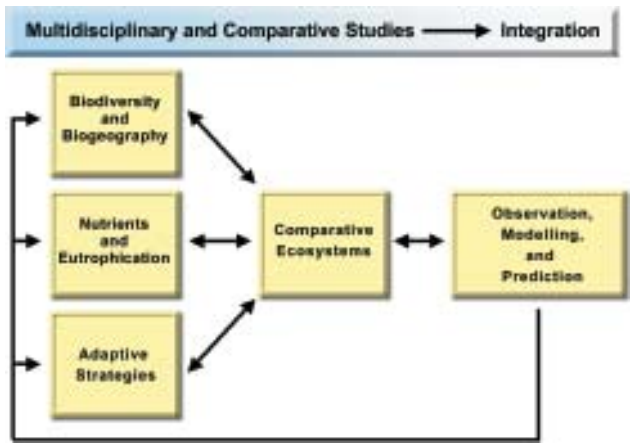


Figure 2. The integration of findings from the individual Programme Elements described in the *GEOHAB Science Plan* is required to achieve not only an understanding of HAB organisms and associated events, but also to develop predictive capabilities.

To understand and ultimately predict HABs, the broad range of objectives and tasks outlined under the individual Programme Elements must be addressed. This will require co-ordination and integration among Programme Elements, as indicated in Figure 2.

The findings of *Biodiversity and Biogeography* (Programme Element 1), *Nutrients and Eutrophication* (Programme Element 2), and *Adaptive Strategies* (Programme Element 3) are integrated in *Comparative Ecosystems* (Programme Element 4), through field studies in different hydrographic and ecological systems. Under the latter Programme Element, the physical, chemical, and biological characteristics of the environment are compared for different sites. Through *Observation, Modelling, and Prediction* (Programme Element 5) information on HAB biomass, species composition, and population dynamics are integrated. Parameterisation of processes, such as growth, mortality, and turbulent dispersion as well as model verification, will require information from each of the Programme Elements.

Strategy and Mission of GEOHAB

The list of GEOHAB objectives in Table 1 represents a significant challenge for programme implementation. The GEOHAB strategy is to address these issues through several categories of research that differ in their scales of international and disciplinary co-operation. Details of these Core, Targeted, and Regional/National studies are given below. Framework Activities, which are not specifically research, will also be developed to achieve the mission of GEOHAB.

The central feature of GEOHAB programme implementation will be the Core Research in comparable ecosystems, which will promote the synthesis and integration of research conducted in many different countries and regions and on many different HAB species, as well as the identification of common features and processes. Accordingly, the mission of GEOHAB is to:

Foster international co-operative research on HABs in ecosystem types sharing common features, comparing the key species involved and the oceanographic processes that influence their population dynamics.

GEOHAB is an international programme that co-ordinates and builds on related national, regional and international efforts in HAB research within an ecological and oceanographic context. GEOHAB will encourage combined experimental, observational, and modelling approaches, using current and innovative technologies in a multidisciplinary approach that is consistent with the multiple scales and oceanographic complexity of HAB phenomena. Through such efforts, the emergence of a truly global synthesis of scientific results should be attained.

GEOHAB is not a funding programme; rather, its research and related activities will be sponsored by national, regional, or international funding agencies that must respond to diverse scientific priorities, while permitting access to national facilities, resources, and expertise. GEOHAB will provide a framework for the integration of resources of many countries and the expertise of many individual scientists in the study of HAB population dynamics.

The achievement of GEOHAB's mission will be of significant value to governmental agencies worldwide because the outcomes will aid in improvement of management of marine resources and coastal ecosystems by advancing the ability to predict HABs and potentially enabling more effective prevention and mitigation measures.

Categories of Research

For the purposes of implementation, the GEOHAB SSC has adopted a three-category system for defining and endorsing GEOHAB research:

Core Research is comparative, interdisciplinary, international, and directly addresses the overall goals of GEOHAB as outlined in the *Science Plan*. Core research will directly address Programme Element 4 on Comparative Ecosystems and thus will cross-cut the other Programme Elements. Core research involves scientific co-ordination by the SSC. Core research comprises:

> **Oceanographic field studies conducted in, and application of models to, comparable ecosystems, supported by identification of relevant organisms, and measurements of the physical, chemical, and biological processes that control their population dynamics.**

Development of a GEOHAB Core Research Project is based upon the premise that a comprehensive understanding of the population dynamics of HABs requires the integration of oceanographic studies with the application of models to comparable ecosystem types. Such comparisons will assist in:

- *Definition of common characteristics, including the grouping of harmful species from similar habitat types and identification of functional groups;*
- *Identification of the key life-history transitions;*
- *Determination of the primary physiological, genetic, and behavioural processes that regulate cellular growth and toxicity;*
- *Identification of important physical and chemical influences over appropriate temporal and spatial scales;*
- *Development and validation of technologies for detailed and extensive monitoring; establishment of real-time observation platforms; and*
- *Establishment of systems and protocols for co-ordinated data management.*

A major objective of Core Research is the integration achieved by the application of coupled biological/chemical/physical models to HAB dynamics in geographically distinct ecosystems sharing common features. Modelling activities within Core Research Projects may include the application

of specified models to different ecosystems, testing, and validation of different models within given ecosystems, and modification of existing models to fit current, emerging, or hypothetical data sets. The extent to which HAB species respond in a similar way in ecosystems with similar characteristics will assist in defining the oceanographic processes that influence their population dynamics and community interactions. Interpreted via models, this comparative approach is ultimately expected to lead to an enhanced capability for HAB prediction.

Targeted Research addresses specific objectives outlined in the *GEOHAB Science Plan*. Targeted Research may be solicited by the SSC as the need arises from Core Research Projects. Targeted Research includes, but is not limited to:

- *Development and comparison of specific models and observational systems*
- *Studies on autecological, physiological, and genetic processes related to harmful algae*
- *Studies on sub-grid formulations of physical, chemical, and biological interactions affecting harmful algal blooms*

Targeted research differs from Core Research in scope and scale. Whereas Core Research must be comparative, integrative, and multi-faceted, Targeted Research activities may be more tightly focussed and directed to a research issue or element. It is expected that such studies will facilitate the wider and larger-scale studies. For example, investigations on specific methods for model comparisons and intercalibration are targeted activities, valuable in their own right, yet are also essential to conduct comprehensive field studies and modelling in Core Research Projects.

Regional/National Projects are those research and monitoring activities relevant to the objectives of the *Science Plan*, but which may have other overall objectives. Regional/National research is co-ordinated at a regional or national level rather than by the SSC.

To be endorsed by GEOHAB, Regional/National Projects must share objectives with GEOHAB in furthering the understanding of the ecological and oceanographic mechanisms underlying HAB population dynamics. As an example, toxin production will be studied if toxin production directly influences population dynamics, as in the case of grazing inhibition. Thus, phytoplankton and toxin monitoring *per se*, or research on toxicity, human health, and environmental impacts, are not endorsable as GEOHAB activities, but research projects aimed at understanding factors leading to HABs may be. Although HAB monitoring will not be endorsed by GEOHAB, the programme will seek to use data from national and international monitoring programmes in conjunction with Core Research Projects, modelling, and other activities. While the GEOHAB SSC is not directly responsible for the co-ordination or implementation of Regional/National Projects' research activities, it can provide advice on aspects of such activities that can advance GEOHAB's goals. The SSC will assist in linking relevant aspects of national plans with GEOHAB-related research in other regions of the world.

Framework Activities

Framework Activities are activities that are not research, but will facilitate the implementation of GEOHAB. They serve to enhance the value of research by ensuring consistency, collaboration, and communication among researchers.

Several types of Framework Activities will be co-ordinated by the SSC and the IPO, including:

- ***Scientific Networking and the Co-ordination of Resources***
  Scientific networking will support GEOHAB research in order to provide the communication necessary for a co-ordinated programme and to ensure comparability of approaches, methods, and procedures. Modelling within Core and Targeted Research projects will be co-ordinated by the GEOHAB Modelling Task Team to encourage model development and to ensure the general availability of models. GEOHAB will identify and draw the attention of responsible bodies to opportunities for co-ordination of resources that will add value to ongoing or planned research.

- ***Data Management***
  Data management and quality assurance are essential in the implementation of GEOHAB research projects. The data management activities of GEOHAB will be aimed at developing and recommending procedures for the management of data from GEOHAB projects. These activities will facilitate access to data by a broad community of scientists, and will enable regional and global synthesis and communication of results.

- ***Specification of Protocols and Quality Control***
  Specification of protocols within GEOHAB projects will ensure that data generated are reliable and compatible, thereby facilitating synthesis and modelling. In some cases, well-defined, internationally agreed descriptions of methods exist and, where appropriate, these will be adopted. In other cases, the GEOHAB SSC will initiate Framework Activities that lead to the development of appropriate protocols to ensure data collection in a uniform manner for comparative studies.

- ***Capacity Building***
  Capacity building will ensure that a new generation of scientists are trained in the study of HABs. GEOHAB can meet its objectives only if well-trained scientists from a wide range of countries are involved. Within its endorsed projects, GEOHAB will encourage a "training through research" approach that offers opportunities for student participation in cruises and instruction in marine research disciplines relevant to HABs.

- ***Interaction with Other Programmes and Projects***
  Interaction with other international programmes is essential for GEOHAB to meet its objectives. To accomplish this, the GEOHAB SSC will co-ordinate activities through cross-representation on project scientific steering committees or by forming joint working groups with other projects and programmes to assist research. The SSC may delegate Framework Activities to Task Teams, as mentioned later in the report.

- ***Resources and Funding***
  The GEOHAB SSC is presently funded by national and international funding agencies and organisations for international planning and co-ordination. The SSC will seek increased funds to conduct the Framework Activities described later in this plan.

Task Teams will be comprised of members from the SSC and from the broader HAB research and management community.

High biomass blooms of *Prorocentrum micans* (left) and *Prorocentrum minimum* (right) often follow heavy rains and can lead to severe ecosystem impacts, including oxygen depletion and loss of habitat. These blooms were from Bigelow Harbor, Maine (left) and the Chesapeake Bay (right). The comparative approach of GEOHAB will lead to better understanding of the physical, chemical, and biological factors that regulate these and other types of blooms. Photos by M. Keller of Bigelow Lab and P. Glibert.

IMPLEMENTATION ACTIONS

GEOHAB is, and will continue to be, an evolving network of scientific activities, with programme growth dependent on national and international research priorities, investigator interest, methodological capabilities, availability of funding, and other resources for the successful accomplishment of GEOHAB's goals. The implementation strategy of GEOHAB provides enough structure for programme coherence among diverse investigators and projects, but is not intended to be prescriptive or subject to unreasonable restriction on participation. Rather, the *Implementation Plan* is designed to be sufficiently flexible to allow for the development and introduction of new Core Research Projects, Targeted Studies, Regional/National Projects, and Framework Activities throughout the decadal life-span of the programme. To provide guidance to the research community, the GEOHAB SSC has proposed a number of Core Research Projects to which it will devote special attention during the critical initial stages of programme development. Other activities will be phased in, with the help of the GEOHAB IPO and subject to the establishment of proposals submitted by the research community. Proposals and innovative ideas for all aspects of GEOHAB participation will be welcome throughout the duration of the programme.

Core Research Projects

Proposals for Core Research Projects will be reviewed on a regular schedule to co-ordinate with GEOHAB SSC meetings. The GEOHAB SSC will actively co-ordinate the Core Research Projects, which emphasise field investigations in comparable systems from different regions, and promote the exchange of technology, models, and data. Comparable ecosystems can be defined by their bathymetry, hydrography, nutrient status, productivity, and/or trophic structure. Several Core Research Projects have been identified and are in the process of being planned. Framework Activities to launch these projects are underway. The four Core Research Projects described in this plan can be supplemented by new Core Research Projects during the life of GEOHAB, depending on the interests of the global scientific community.

Scientific Approaches

Core Research Projects share similar scientific challenges. The development of common research methodology will be critical to their success. The types of scientific approaches that should be considered for incorporation into any GEOHAB Core Research Project involve:

Comparison — The comparative approach is essential for major field studies proposed in Core Research Projects, to allow comparisons of how HAB species assemblages and population dynamics are similar or different in similar ecosystems in different areas of the world. The extent to which HAB species respond in a similar way in systems that share similar characteristics will assist in defining the oceanographic processes that influence their population dynamics and community interactions. Understanding the response of harmful algae to environmental perturbations will assist in prediction, and identification of divergences from predicted responses will also be informative. Sharing of expertise and resources, the formulation of common research objectives, and the implementation of similar research activities and field investigations based on common methods at each of the designated Core Research Project sites within a given ecosystem type will facilitate these comparisons.

Causative Organisms — Identification of the causative organisms of HAB events is necessary for investigations of comparative ecosystems within which such events occur. Yet identification of species is often a difficult task in routine analysis. Many harmful species resemble benign or closely related harmful taxa and distinctive morphological characters are not always evident. The problem of uncertain and time-consuming identification of HAB species in field studies can be addressed by cross-disciplinary investigations that utilise a spectrum of existing and new techniques to characterise taxa, and to distinguish among species, strains of single species, and toxic and non-toxic forms. A variety of identification approaches may be applied, and application of new probe technologies is encouraged. These new methods should be actively pursued, but traditional systematic or morphological investigations using standard microscopy or biochemistry also should be supported in the identification of harmful species in the field.

Parameterisation — Parameterisation of population rate processes can be facilitated by molecular and biochemical techniques developed to assess growth rate and a suite of physiological processes within cells, such as nutrient uptake, nitrogen fixation or nutrient limitation, and photosynthetic activity. In the context of HABs, the objective of these studies would be to develop analytical methods and diagnostic indicators that can be applied to specific species in the field. Full-cycle life history transformations and behavioural characteristics should also be followed in field studies to elucidate the factors that regulate these transitions and adaptations. Although recent technological advances are encouraging, there is a clear need for an early development and calibration of methods to be used in GEOHAB's comparative studies. The ultimate goal is to apply these techniques in comparative ecological studies, ideally with simple and rapid measurements that are specific for the processes and organisms of interest. The GEOHAB SSC will form a Subcommittee on Parameters and Methods to develop an overall GEOHAB policy on core parameters and standard methods.

Validation — The key is to obtain data at appropriate time and space scales for the blooms under study. Data records should be comparable between sites, and interpretable in an ecological context. Presently, few data sets include information on water motion at the spatial and temporal scales necessary to carry out a detailed analysis of the potential physical-biological interactions. Therefore, collaborative efforts among physical, chemical, and biological oceanographers that apply advanced technology will be emphasised and encouraged.

Physical Processes — Determination of the influence of physical processes on the development of HABs requires advances in the physical oceanography of HAB-prone areas and new linkages between physical oceanographers working in near-shore, coastal, and deep regions. Among the most important aspects to be studied are those of advection and dispersion, and the distribution and intensity of small-scale turbulence. Information on the distribution of physical and biological variables should preferably be synoptic in space and highly resolved in time, covering the phases before, during, and after successive bloom periods.

Observation — Minimum requirements for field measurements include basic physical and chemical measurements and methodologically consistent phytoplankton counts, including HAB species and community assemblages (including species of phytoplankton, bacteria, and zooplankton). Shipboard observations, dock-side sampling programmes, remote sensing, and moored instrument arrays can all provide important data on water chemistry and plankton composition. Shipboard observations and other large-scale field sampling will assist in resolving spatial differences, particularly for regimes that are not amenable to remote optical sensing. Shipboard research on the principal physical components, for example, obtained by means of acoustic Doppler current profilers and towed

undulating sampling systems, in addition to standard discrete measurements, are also essential to elucidation of the role of physical processes in HAB dynamics. There are strong reasons for using remote sensing as a research tool to develop empirical and conceptual models of bloom development and transport. Applications of satellite images of ocean colour concurrent with field measurements of bloom distribution or toxicity and/or scum formation under a variety of meteorological conditions are encouraged. With sufficient background information of this type, development of conceptual models will be possible, allowing observations from a variety of sources, including remote-sensing images, to be used for actual forecasts of impending outbreaks along specific sections of coast. Progress in this area should be rapid in the immediate future due to the launch of several satellites with sensors designed to collect ocean colour data.

Innovation — The GEOHAB Programme will encourage the adaptation of new observational technologies to HAB observations. Research on new sensors and approaches directly applicable to monitoring is also consistent with GEOHAB objectives. There is considerable potential for the use of moored sensors and remote-sensing techniques to obtain simultaneous time-series observations of both physical and biological parameters. Moored instrumentation packages, including nutrient, plankton, and optical sensors, are needed to resolve the fine scale of spatial and temporal relationships between forcings and shifts in plankton composition. This approach will require adapting spectral optical and video sensors for deployment on vertical profilers, or towed systems to detect HAB distributions in real-time, designing "smart" sampling systems to collect discrete samples, developing techniques for measuring *in situ* buoyancy control and swimming behaviour of motile HAB taxa and affected species, and improving methods for rapid quantification of HAB toxin concentrations. Other useful new technologies include species-specific molecular probes for HAB species identification, methods for *in situ* detection and quantification of HAB taxa, diagnostic indicators of the physiological status of HAB species and grazers, methods for assessing grazer food quality, video techniques for measuring *in situ* grazing and avoidance behaviour, and high-resolution sampling of fine-scale HAB and grazer distributions.

Data Mining, Integration, and Enhancements — For the foreseeable future, much of the detailed information on environmental variability in coastal regions of the world will come from conventional sampling programmes whereby data are collected on species composition of phytoplankton, along with measurements of chemical and physical properties of the water from discrete samples or vertical profiles. Substantial amounts of data already have been compiled, though not necessarily analysed in a systematic way. These monitoring data represent an extremely important resource for characterising the temporal and spatial variability of HABs, particularly in the context of anthropogenic influences versus climate change.

An analysis of retrospective and current databases on HAB events and distributions of harmful species and associated organisms is required to distinguish the effects of physical-chemical forcing from local to larger scales, and thus to resolve the relative contributions of human influences versus natural climate variability on algal population dynamics. For the known HAB species that form resistant resting stages capable of persisting in sediments, stratigraphic evaluation of sediment cores offers potential as indicators of historic conditions. Measurements of pigments and other biomarkers in the sediment also yield useful information on phytoplankton communities. Multivariate analyses of such distributional data might foster the development of empirical models based upon long-term climatic variation.

Time-series analyses of existing databases for phytoplankton communities and environmental variables such as macro- or micro-nutrients are required. Retrospective analyses of historical data and information may provide important insights. In some cases, the sediments may hold important historical information. Land-use data, available from maps and geographic information systems, may yield trends in nutrient inputs to the landscape. Where such data are lacking, long-term consistent monitoring programs must be initiated in key regions where anthropogenic influences are either known or anticipated to increase. Long-term data sets in areas removed from human impact are probably just as important for identifying effects of meteorology, altered stratification intensity/ depths, and shifts in ocean currents and global climate.

Expanded databases should include environmental information, remote-sensing data, and information on anthropogenic factors such as population increase, input of nutrients and other pollutants from sewage, agricultural and industrial sources, ballast transport, and major coastal engineering activities. In addition to monitoring of nutrient composition, specific approaches are required to differentiate the sources of nutrient delivery. Tracer studies, such as natural isotopic composition measurements, provide one approach for differentiating nutrient sources.

The proposed assimilation of data and archiving serve to bridge observations and modelling of HABs. As for other predictive models, empirical models of HABs must be tested by a comparison of predictions with observations. GEOHAB's support of data management will strengthen the close connection between monitoring, modelling, and fundamental research, and will contribute to the development of GOOS.

Initial Projects

In the *GEOHAB Science Plan*, comparative ecosystems were defined on the basis of several key parameters. Examples of comparative ecosystem types are given in Table 2. The GEOHAB SSC has agreed to the implementation of Core Research Projects in several of these ecosystem types. The current four Core Research Projects address HABs in (1) Upwelling Regions, (2) Semi-confined Eutrophic Zones and Estuaries, (3) Fjords and Coastal Embayments, and (4) Stratified Regions. These developing projects are described in the Example Boxes that follow.

Implementation through GEOHAB

The initial Core Research Projects will be developed with full and open involvement from the scientific community. Preliminary planning steps have been taken so that the structure of each of the Core Research Projects can be developed and fully formulated through Open Science Meetings. The purpose of these meetings is to review the state of knowledge and to draft research plans that specify and justify site selection and methodologies to attain consistent results. The research implementation plans will be posted on the GEOHAB web site.

To establish priorities for additional Core Research Projects, the following criteria have been proposed for site selection and field activities:

- *Reasonable likelihood of recurrent HABs based upon past plankton records;*
- *Willingness of investigators to participate in a multi-disciplinary study at the specified locations;*

- *High probability of resources to be allocated to the study;*
- *Accessibility of the study sites;*
- *Willingness of the participants to accept the responsibilities of participation in GEOHAB as described in the Invitation to Participate; and*
- *Development of, or progress toward development of, a model of the physical oceanography of the proposed study site.*

Table 2. Example ecosystem types, as defined by their bathymetry, hydrography, nutrient status, productivity, and trophic structure. (From *GEOHAB Science Plan*, p. 48.)

- Upwelling systems, such as those off the coast of Portugal and Spain, Peru, Mazatlan in Mexico, the west coast of the United States, Australia, Japan, West Africa, and Southern Africa.
- Estuaries, fjords, and coastal embayment systems, as in the United States, Canada, Australia, southeast Asia, Philippines, Mexico, Scandinavia, and Chile.
- Thin-layer producing stratified systems occur along most coasts, including the Atlantic coast of France, Sweden, California, and in East Sound, Washington.
- Coastal lagoon systems such as in the United States, Mexico, Brazil, and France.
- Shelf systems affected by basin-wide oceanic gyres and coastal alongshore currents such as off the northwestern European coast, the Gulf of Mexico and Gulf of Maine in the United States, and off the coast of southeastern India.
- Systems strongly influenced by eutrophication, such as in Hong Kong, Black Sea, Baltic Sea, Adriatic Sea, Seto Inland Sea of Japan, and the mid-Atlantic regions of the United States.
- Brackish or hypersaline water systems such as the Baltic Sea, St. Lawrence, Dead Sea, and Salton Sea.
- Benthic systems associated with ciguatera in the tropics or DSP in temperate waters.

The above list is not intended to be comprehensive or exclusive, and these systems are offered only as examples of the types of ecosystems that could be studied and compared within GEOHAB.

Example Core Project 1: HABs in Upwelling Systems

HAB events, sometimes manifested as "red tides", are often features of upwelling and subsequent relaxation, and certain HAB species (e.g., *Alexandrium catenella*, *Gymnodinium catenatum*) are frequently associated with these zones around the world. Upwelling zones have been selected as a priority for Core Research within GEOHAB, since they represent systems within which the dominance of physical forcing functions (wind-driven circulation, nutrient upwelling) can be studied with respect to biological processes, such as species succession and niche differentiation. Upwelling systems can be classified according to their physical, chemical, and biological characteristics. Coastal upwelling systems present high variability at diverse temporal and spatial scales, and occur in geographically dispersed locations along the western coasts of North and South America, Western Europe, and Northern and Southern Africa. Nevertheless, they share common features in their basic physical structure and biological components.

Overall Objective: To understand the critical processes underlying HAB population and community dynamics in upwelling systems.

Programme Duration: 2003-2008

Presently Designated Study Sites:

Californian coast
Iberian coast
Benguela Current

Selected Scientific Objectives:

- *Characterise the HAB species using morphology, molecular genetics, biochemical composition, and other cellular properties*
- *Determine groups of co-occurring taxa or assemblages within upwelling systems, define functional groups in which HAB species are found, and determine their temporal succession within upwelling systems*
- *Identify the physical, chemical, and biological processes that define or characterise upwelling systems and quantify the response of HAB species to these processes*
- *Establish the intrinsic potential for growth of HAB species*
- *Characterise environmental influences on life history events, including encystment and excystment*
- *Establish the importance of microbial pathogens in the growth and toxic properties of harmful species*
- *Determine the role of grazing control in HAB dynamics*
- *Establish sites of HAB initiation, and identify and quantify the physical processes responsible for the accumulation, transport, and dispersion of HABs*
- *Incorporate the role of coastal morphology and remote forcing in creating physical aggregating mechanisms and in controlling cross-shelf and alongshore transport of blooms*
- *Establish the role of nutrient cycling processes (including macro-, micro-, inorganic, and organic nutrients) and varying nutrient ratios in the development of HABs in upwelling systems*
- *Develop models of HABs in upwelling systems to support fundamental research and predictive capabilities*
- *Determine the applicability of regional prediction systems for other upwelling systems*

Example Core Project 2: HABs in Semi-confined Eutrophic Zones and Estuaries

Concurrent with escalating influences of human activities on coastal ecosystems, the environmental and economic impacts of HABs and consequent challenges for coastal zone management have increased in recent years. The relationship between HABs and the increasing nutrient enrichment of many of the world's coastal and estuarine environments is of particular concern. Increasing nutrient loading to coastal and enclosed or estuarine environments is a result of agricultural, aquacultural, industrial, and sewage effluents. The relationship between nutrient loading and alteration in nutrient supply ratios and many HABs is now recognized, but much remains to be understood in terms of the relationship between nutrient loading and other factors. The overarching question to be addressed is: to what extent has increased eutrophication influenced, and continues to influence, the occurrence of HABs and their harmful effects?

Overall Objective: To determine the significance of eutrophication and nutrient transformation pathways to HAB population dynamics.

Program Duration: 2004-2009

Presently Designated Study Sites:
The Core Research Project on eutrophic zones will include a suite of comparative systems that range in eutrophication state, in types and sources of nutrient inputs, in nutrient composition, and in abundance and distribution of HAB species and toxicity status.

The study sites will be developed and justified in the context of:

- *eutrophication gradients*
- *quantity and quality of nutrient loading*
- *species differences*
- *physical factors that impact HABs*
- *existing or developing databases, models, and/or monitoring programs*
- *other factors, including programme management*

Specific Scientific Objectives:

- *Identify the HAB species in systems of differing eutrophic status*
- *Identify the major pathways of nutrient input and their relationship to HAB occurrences*
- *Determine the relative importance of nutrient loading from human activities and natural processes to HAB events*
- *Assess and quantify the importance of differing nutritional strategies (nutrient uptake and growth kinetics) among HAB species and in comparison to non-HAB species*
- *Determine the conditions under which a HAB species may adopt alternate nutritional strategies*
- *Determine the nutrient-dependent factors that regulate toxin synthesis*
- *Determine nutrient transformation and regeneration pathways in relation to HABs*
- *Determine the functional relationships among HAB species, co-occurring non-HAB species, and rates of nutrient transformation and fluxes*
- *Incorporate knowledge about HAB population dynamics and factors controlling HABs in eutrophic systems into existing physical and ecosystem models*

Example Core Project 3: HABs in Fjords and Coastal Embayments

Fjords and coastal embayments are combined in this GEOHAB Core Research Project because they share features such as the importance of geographical constraints on water exchange and bloom retention, and the dominance of meso-scale structures. Classic fjords, usually characterised by a high ratio of length to width, a deep wedge-shaped basin, freshwater input, and a sill located toward the mouth, create retention and/or initiation zones that favour the proliferation of a particular suite of HAB species. Many groups of key species (e.g., *Alexandrium* spp., *Pseudo-nitzschia* spp., and various raphidophytes) are virtually identical in fjords in the Northern and Southern hemispheres at similar latitudes. Such ecosystems are often only marginally affected by human activities because of low population densities, thus they are usually not subject to eutrophication. Coastal embayments are a broader category of an ecosystem type; generally, such systems comprise relatively shallow nearshore marine environments, partially surrounded by land, and often affected by terrigenous run-off, but on a smaller spatial scale than open coastal or upwelling systems. As with fjords, the hydrodynamic processes may be complex, with an accentuated role of tidal flux, storm surges, wind-driven mixing, and salinity and thermal stratification. The physical processes associated with HABs in these systems are most often related to "density adjustment" problems, that is, buoyancy and frontal dynamics, geostrophic adjustment, establishment of a pycnocline after a storm, and perhaps topographic frontal motion. The effects of benthic-pelagic coupling are likely to be crucial in understanding HAB dynamics in fjords and coastal embayments. Coastal embayments with limited exchange to the open coast may serve as "seed beds" for benthic cysts or relict populations of HAB species. Such systems are particularly vulnerable to anthropogenic changes in the biological and chemical regime, and the introduction of exotic species via ship deballasting and transfer of aquaculture stock. Many fjords and coastal embayments are well characterised in terms of long-term plankton records and toxicity events. Optical data sets on ocean colour and relevant plankton patches are becoming increasing available from these systems. Furthermore, basic circulation models (both 2-D and 3-D) are already available from several locations around the world.

Overall Objective: To understand and quantify the critical processes underlying HAB population and community dynamics in fjords and coastal embayments at temperate latitudes.

Programme Duration: 2004-2009

Representative Designated Study Sites:

Australia (Tasmania), South coast
Chile, South central coast
Ireland, Southwest coast
Norway, Southwest coast
Canada, Pacific and Atlantic coasts
France, North coast
New Zealand, North coast of South Island
U.S., Pacific and Atlantic coasts

Selected Scientific Objectives:

- *Identify the characteristic HAB species, using morphology, molecular genetics, biochemical composition, and other cellular properties*
- *Determine the* in situ *intrinsic growth rate and population growth of HAB species*
- *Determine the role of grazing control in HAB dynamics, particularly the relative importance of benthic grazers versus planktonic forms*
- *Characterise environmental influences on life history events, including encystment and excystment*

(continued)

- *Establish sites of HAB initiation, and identify and quantify the physical processes responsible for the accumulation, transport, and dispersion of HABs within the small-scale basin and exchange processes causing advection into and out of the embayment*
- *Incorporate the role of basin morphology and physical forcing (tidal flux, wind-driven mixing, stratification, run-off effects) in creating physical aggregation and dispersive mechanisms*
- *Establish the role of nutrient cycling processes and varying nutrient ratios in the development of HABs in fjords and coastal embayments*
- *Determine the role of allelochemicals and other biologically active compounds on behaviour, reproduction, and species interactions*
- *Develop models to describe the coupling of physical, chemical, and biological processes important to HABs, thereby allowing distinction of local growth from advection*
- *Determine the applicability of regional prediction systems for other fjords and coastal embayments*

Example Core Project 4: HABs in Stratified Environments

A feature common to nearly all oceanic harmful algal events is that the phytoplankton populations typically build up to the highest concentrations in subsurface layers. These layers are usually related to water column stratification. HAB populations may then be advected to the coast, where they cause harmful events. Stratified water columns may be encountered in upwelling systems, coastal embayments and estuaries, as well as in confinement zones. The temporal and spatial scales of thin layers (intermittent and less than 1 m thickness) pose problems for sampling and modelling of harmful bloom populations. Coupling physical effects (turbulence, shear, advection) and biological behaviour (migration, physiological adaptation) holds the key to understanding vertical distributions, bloom dynamics, and patterns of toxicity. Some of these physical processes are not yet defined at the proper scale, yet may be crucial in the formation of harmful blooms. It is in these areas where our knowledge is weakest.

Models have thus far been restricted by insufficient ability to gauge the interactions between the biology of algal taxa and underlying physical processes. As an example of chemically mediated interactions that may be very important in highly stratified systems, certain harmful species can produce exotoxins that may have an allelopathic effect on competitors for substrate, or even inhibit grazers. From the biological perspective, the relative importance of biological processes occurring within or at the interface of thin layers, such as species-specific adaptations for heterotrophy and the role of the microbial food web, are also poorly understood.

Overall Objective: To determine the factors underlying the development of communities related to HABs in sub-surface micro-layers and the real-time dispersion of these microlayers as a function of turbulent and advective regimes.

Programme Duration: 2004-2009

Representative Designated Study Sites:

U.S., Puget Sound, NW coast
South Ireland (bottom-driven density fronts)
Bay of Biscay (river plumes and Ushant tidal front)
Iberian coast (Galician and Portuguese upwelling systems)

Selected Scientific Objectives:

- *Determine groups of co-occurring taxa or assemblages within these highly stratified environments, and define functional groups in which HABs are present*
- *Identify the biological and life-history characteristics common to these HABs species*
- *Define the essential control factors that determine the population development of harmful species in relation to their community*
- *Quantify the role of small-scale physical processes in maintaining harmful phytoplankton in discrete thin layers*
- *Demonstrate the importance of density-driven coastal flows and limit-layer dynamics in the advection of populations of these harmful species into other regions of commercially important aquaculture activities*
- *Validate different models of growth and advection*

Targeted Research Projects

Smaller in scope, but nevertheless equally important to the success of GEOHAB, are Targeted Research Projects. In most cases, subjects for Targeted Research will be identified by the SSC and certain activities may be directly promoted and solicited from the research community. As an open network, however, GEOHAB also encourages the submission of unsolicited proposals for endorsement as Targeted Research. Targeted Research studies address specific objectives outlined in the *Science Plan.* For example, modelling is essential and implicit within each Core Research Project, and each field study must incorporate model development and application from the earliest planning stage. Nevertheless, modelling has also been highlighted as a priority for Targeted Research within GEOHAB. In this context, it is expected that site-specific and general models will be the subjects of development, updating and validation throughout the life-span of the GEOHAB programme. The success of GEOHAB ultimately will depend on the application of different modelling approaches to the systems defined within the programme, and upon comparison of common features among models.

Scientific Approaches

Modelling

The development and comparison of models in GEOHAB will provide a deeper understanding of the components required to describe marine ecosystems, and specifically the processes and mechanisms controlling the population dynamics of HABs. Model development should be focused on a modular approach that retains the universal aspect, such that the models may be applicable to other regions. Modular model structures are also helpful in integrating models of different complexity.

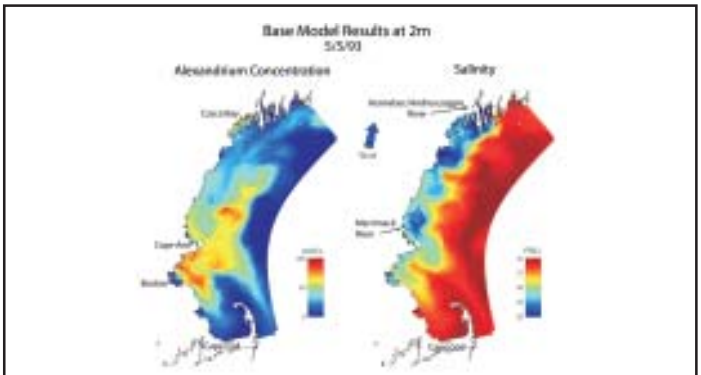
Informed decisions must be made regarding the priority of parameters to be included in each model. This major task could be addressed by ranking processes in particular models, based on research from laboratory and field studies. A hierarchy of models with different degrees of complexity, but specific to HABs and associated cellular processes, is required to integrate processes.

Models may be characterised with respect to spatial dimension and complexity. Box models can provide theoretical descriptions of experiments in small-scale laboratory systems, mesocosms, and also field ecosystems, such as semi-enclosed embayments. The simulations can be interpreted from experimentation and integrated to explore ecological interactions (e.g., processes associated with fluxes of system components, such as nutrients) and to predict whole community responses to major perturbations, such as eutrophication. Cellular processes that influence growth kinetics, such as nutrient assimilation, photosynthesis, and pigment synthesis, can be incorporated into advanced dynamic models. Such formulations are necessary to link nutrient assimilation and growth processes with variable nutrient quotas, cell pigments, and bio-optical signatures of phytoplankton.

One-dimensional water column models allow the inclusion of additional processes, such as mixing, sinking and buoyancy, nutrient uptake, and benthic-pelagic coupling in a vertically structured environment (light, salinity, temperature, and nutrients). Simulations can be related directly to experiments in mesocosms and to observations in the field, if advection is minor. Moreover, water column models can be run with very high vertical resolution to study processes in thin layers. One-dimensional models are also important in studies of adaptations involving vertical migration, buoyancy, aggregation, and mixing.

Extension to two-dimensional models is useful for examining the biological-physical-chemical interactions that influence the distributions and population dynamics of phytoplankton, for example, in coastal fronts. With the recognition that light and nutrient history have a major role in cell growth and metabolism, Lagrangian ensemble approaches may be necessary to explain population dynamics of HABs.

Because of their modular model structure, three-dimensional circulation models can be configured with different levels of complexity of the corresponding biological processes. Drifting cells that spread in response to wind-driven circulation or populations that accumulate at fronts are examples of systems that can be modelled with a simplified biological approach. More complex models incorporating physiological mechanisms, including intrinsic growth rates, chemical composition, and nutrient assimilation allow, in principle, comprehensive exploration of the physical, chemical, and biological interactions that determine population dynamics. These models also can be applied to the analysis of sinking, buoyancy, advection, shear flows, and small-scale turbulence. In addition to accounting for the physiology of algal growth and toxin production, behaviour (e.g., vertical migration and variable sinking rates), and the links between behaviour and physiology must be considered in the development of coupled three-dimensional models.



While models have been applied to HABs around the world, one well-studied/modelled bloom is *Alexandrium fundyense* in the Gulf of Maine. The intimate interaction of laboratory experiments, field sampling, and models has helped to generate a fundamental understanding of the dynamics underlying growth, transport, and landfall of the toxic blooms. Models are being used to test hypotheses concerning bloom initiation and demise, and to explore the utility of the sampling programme in generating statistically meaningful data. Source: C. Stock.

An important aspect of modelling is efficient visualisation of the model output, for modellers as well as non-specialists. However, where animation and interactive capabilities are integrated into model systems, access to modelling tools, including component models, should be available to researchers. These tools will be valuable for early warning of impending bloom events.

Data assimilation techniques can improve predictions of HAB-specific coupled models by assimilation of data from well-designed monitoring programmes to integrate real-time and near-real time observations into a running model. Data assimilation can thus provide now-cast predictions of conditions during process studies, which is particularly useful for adaptive sampling.

Laboratory Studies

Comparative laboratory investigations of particular HAB species or groupings of species are encouraged within GEOHAB, in an attempt to ascertain growth characteristics, physiological activities, and autecological reasons for persistence in specific ecosystems. A variety of culturing systems, including those for batch and continuous cultures, may be used on a representative variety of strains from a single area and from different geographic areas. Experiments may be conducted over a wide range of scales, from laboratory microcosms (tubes, flasks) to mesocosms and pilot-scale systems in view of application to field studies.

To determine tolerances and optima, growth rates should be determined under a variety of environmental conditions, for example, different temperature, salinities, light, and nutrient levels. Rates of cellular processes can be estimated with molecular and biochemical techniques; similar methods can be used for a suite of physiological processes within cells, such as nutrient uptake or limitation, nitrogen fixation, and photosynthetic activities. To provide support for the development of needed observation technologies, emphasis must be placed on analytical methods and diagnostic indicators that can be applied to individual cells, rather than on the more traditional bulk analyses that are applied to communities rather than species.

Laboratory and mesocosm experiments are essential to identify and isolate the effects of production of bioactive compounds and the interactions of the HAB species producing them with organisms at other trophic levels. The latter include effects on the egg, larval, juvenile, and adult stages of key grazers in the community. To evaluate long-term effects of exposure to algal toxins, it is essential to conduct grazing experiments on known toxic algal strains for several days to weeks, simulating *in situ* HAB conditions with typical algal abundances. Biological parameters to investigate include copepod grazing and egg production rates, as well as hatching rates and post-embryonic development of nauplii to adults. Reduction or inhibition of any of these rates would denote decreased potential grazing impact of predator populations and, consequently, possible development and/or longer persistence of HABs.

A combination of well-designed, co-ordinated, laboratory studies, mesocosm experiments, and field measurements will be required to adequately address the relationships between nutrient quality and supply, and physiological strategies for using these nutrients. Nutrient kinetics can be assessed in culture, but it will also be necessary to conduct these studies over a broad range of concentrations, and under a range of conditions, because environmental factors may substantially alter observed patterns. Some physiological measurements, such as those for enzyme reaction rates or other intracellular or extracellular kinetics, may prove useful for identifying nutritional pathways. For example, recent advances in understanding the roles of extracellular enzymes in nitrogen and phosphorus acquisition may be important to consider. All laboratory-derived parameters must be verified and compared with appropriate field measurements.

Initial Projects

The diversity of potential Targeted Research Projects that could be endorsed by GEOHAB is too large to circumscribe within the *Implementation Plan*. It is also expected that priorities and requirements for supplementary targeted studies will change over time and evolve from the results and progress of the Core Research Projects. Two key Targeted Research Projects are highlighted in the following Example Boxes.

Example Targeted Project 1: Modelling Harmful Algae

Models are essential tools toward defining the complexity of HAB events and cellular processes, with basic understanding being the first step for ultimate prediction of the population dynamics of HABs (e.g., species in a bloom and the bloom's intensity, areal extent, duration, and decline). A diversity of different types of models must be developed, combining site-specific or species-specific and universal aspects. However, modelling biological processes in detail is complicated by the equally important need to reduce biological complexity in ecosystem models, without compromising predictability. This reduction in complexity must be based on a sound knowledge of *in situ* biological and chemical processes. Then the linkage of physics and biology can be established by biological-chemical models embedded in circulation models. Predicting the outcome of successional processes on HAB development and maintenance in diverse ecosystems on time scales of days to weeks requires testing, comparison and modification of models, some of which may be developed within the Core Research Projects. On decadal time scales, the analysis of long-term data sets and input of climate change scenarios are required for hindcasting and predicting future HAB occurrences, respectively. The predictive goal can be pursued with simplified empirical models, which focus on specific processes, and with sophisticated physical-chemical-biological models, incorporating a broad range of process interactions.

Overall Objective: Develop and compare HAB models of different scales and complexity in diverse marine ecosystems to support fundamental research and predictive capabilities.

Programme Duration: 2004-2009

Representative Designated Study Systems:
Modelling is a cross-cutting research activity that will be applied to different systems, including the following:

- *Upwelling zones*
- *Fjords and coastal embayments*
- *Marginal and semi-enclosed seas*
- *Stratified systems*
- *Nutrient-driven and eutrophic systems*

Selected Scientific Objectives:

- *Quantify the essential control factors exerted* in situ *on different species in order to identify the complexity required for the model*
- *Identify the state variables according to life-history characteristics*
- *Determine the relative importance of various interactions of the key HAB species within the community (behaviour, competition, grazing, etc.)*
- *Define the mixed-layer dynamics and seasonal cycles of stratification*
- *Identify and quantify the characteristic mesoscale and large-scale flow patterns relevant for advection, retention, or dispersion of HABs*
- *Identify and quantify the physical processes responsible for the accumulation, sedimentation, and resuspension of cysts*
- *Model the response of HABs to varying nutrient inputs and their harmful properties in the laboratory and the field*
- *Quantify the effect of possible allelopathy in the regulation of community interactions*
- *Rank and quantify the importance of various factors, inducing life history transitions*

Example Targeted Project 2: Effects of Water Quality on Ciguatera

A targeted study endorsed by GEOHAB will address the effects of water quality parameters on the abundance and toxicity of the dinoflagellates responsible for ciguatera fish poisoning. This work is to be carried out on *Gambierdiscus toxicus* and related benthic dinoflagellates circumstantially linked to ciguatera in tropical regions. Within the GEOHAB framework, this research is relevant to the *Science Plan* Programme Elements on Biodiversity and Biogeography (PE1), and Nutrient and Eutrophication (PE2). Tropical benthic systems associated with ciguatera were highlighted as one of the key ecosystems that would yield benefits from comparative studies. In the current project, the comparative approach has been adopted in the selection of multiple study sites from tropical oceanic regions in the Indian Ocean, southeast Pacific, and Caribbean Sea. Sophisticated analytical techniques will be applied for elucidation of the ciguatera toxins from diverse components of the biota and this will be linked to detailed morphological criteria for identification of the causative dinoflagellates, supplemented with molecular biological tools. Cultures will be extensively used to study the influence of environmental factors on growth and toxicity, and these cultures will be archived for further research in several facilities around the world. Critical information to be provided by this study will include the determination of the importance of anthropogenic forcing on ciguatera prevalence.

Implementation through GEOHAB

Targeted Research Projects will be developed by the scientific community. They may also be recommended and solicited by the GEOHAB SSC. Applications for endorsement for such studies will be evaluated and reviewed by the SSC. Criteria for endorsement may vary depending on the type of project proposed, but all must be consistent with the mission and goals of GEOHAB as outlined in the *Science Plan*.

Regional/National Projects

Many activities are ongoing at the regional and national levels with objectives and missions that overlap those of GEOHAB. To the extent that these projects, or elements thereof, may benefit from an association with GEOHAB, they may apply for endorsement.

Scientific Approaches

The scientific approaches applied within Regional/National Projects will be highly variable. However, GEOHAB may provide guidance on common approaches for measurements that will be used in a comparative approach.

Initial Projects

To date, one Regional/National Project has developed with elements similar to those included in GEOHAB. As described in the following Example Box, only those research aspects that will ultimately be of comparative value are endorsed by GEOHAB.

Example Regional/National Box 1: The Chinese CEOHAB Programme

China recently awarded significant long-term (five-year) funding for CEOHAB – the Chinese Ecology and Oceanography of Harmful Algal Blooms programme. This national research programme provides support for an array of research teams within China to study HAB problems in three different regions – the Bohai Sea, the East China Sea, and the South China Sea. Some non-Chinese scientists may also join these CEOHAB programmes as advisors or participants, and the GEOHAB SSC has provided advice on co-ordination of GEOHAB-relevant research. One possible site for such a study would be the Bohai Sea, a site of massive red tides that appear to be linked to heavy pollution loading and significantly reduced freshwater inputs due to drought and/or land-use activities. Likewise, China has several large rivers that enter the ocean carrying both high nutrient loads and high levels of suspended sediment. The unique dynamics of the HABs in these regions have great relevance to blooms that occur in other parts of the world with similar hydrographic, environmental, and cultural characteristics. For example, anticipated changes in the flow and suspended sediment characteristics of the Yangtze River in the coming years due to the Three Gorges Dam project suggests a rich opportunity to investigate and explain the changes that will likely occur in plankton dynamics in the receiving waters of the East China Sea due to alterations in N:P, N:Si, and other nutrient ratios. This national programme incorporates supplementary elements that are not endorsable by GEOHAB. Nevertheless, GEOHAB recognizes that the significant and growing eutrophication problem along the Chinese coast provides a unique opportunity for the global HAB community to investigate high biomass, nutrient-driven bloom phenomena.

Implementation through GEOHAB

It is recognised that for many Regional/National Projects, only specific subprojects or elements may be appropriate for inclusion within the GEOHAB Programme. The SSC will take a lead in working with Regional and National Programmes to achieve mutually beneficial aims.

Framework Activities

Scientific Networking and Co-ordination of Resources

The GEOHAB SSC and the IPO will identify and communicate opportunities for co-ordination of resources that can add value to ongoing and planned projects. Through such efforts, the emergence of a truly global synthesis of scientific results should be achieved. Scientific networking will be implemented through workshops, open science meetings, task teams, a newsletter, and the GEOHAB web site. The GEOHAB SSC and IPO will organise workshops to address specific issues, such as the preparation of science agendas and practical working documents for research, but these may also include training components. They will also organise open science meetings (national, regional, and international) to disseminate information, initiate planning of GEOHAB research, and eventually present results of GEOHAB research. The SSC will recommend to SCOR and the IOC the establishment of Task Teams with specific short-term goals, such as the intercomparison of specific methods. The SSC and IPO will use the Internet and the GEOHAB web site extensively for dissemination of results and information. Research activities can be highlighted through the GEOHAB web site and via IOC *Harmful Algae News* (http://ioc.unesco.org/hab/news) to provide information on GEOHAB developments to the broad scientific community. A continually updated document on the status of GEOHAB implementation and its component projects will be available on the GEOHAB web site.

Data Management

The development of an appropriate GEOHAB data management plan is a fundamental and critical activity upon which the ultimate success of GEOHAB will depend. The collective value of data is greater than their dispersed value. Data management and exchange are therefore important components of GEOHAB research projects and should be addressed within each application for endorsement. Each Open Science Meeting will be asked to discuss data management and to include data management plans within the research plans produced.

GEOHAB data are relevant to scientists and managers beyond the GEOHAB community. Therefore, GEOHAB will participate in co-operative non-governmental and intergovernmental data management systems. GEOHAB will co-operate with the framework for research data being developed for SCOR and IGBP projects (see Table 3). GEOHAB will also participate in data management processes of the International Oceanographic Data and Information Exchange (IODE) activity of IOC. The Intergovernmental Panel on Harmful Algal Blooms (IPHAB) has recommended that "the IOC ensure that data-quality management and data exchange relevant to GEOHAB be given due consideration, in accordance with the Terms of Reference for the Group of Experts on Biological and Chemical Data Management Exchange Programme (GE-BCDMEP), and that a GEOHAB representative be included in the GE-BCDMEP."

Table 3. Data Management Framework for IGBP and SCOR Large-Scale Ocean Research Projects *

Based on the data management experience of mature programmes (JGOFS, WOCE, LOICZ and GLOBEC), it is clear that the following actions are extremely beneficial to projects:

- Establishment of a Data and Information Management Unit at the outset.
- Development of distributed, scalable data management
- Adoption of standards to facilitate interoperability of data and information
- Utilization of existing infrastructure, but with additional resources to ensure it fulfils international rather than national specifications and standards
- Provision of services and data access that match the needs of scientists
- Provision of data through alternative media, for example, CD-ROM, for those without Internet access
- Development of a close working relationship between data managers and scientists through means such as "end-to-end" project data management and the provision of data access tools

Recommendations for New Large-Scale Ocean Research Programmes

1. Projects should establish a data policy at the outset to address the following issues:
   - Data sharing within the programme, between programmes and the entry of data into the public domain
   - Data quality issues
   - Long-term security of the data
2. All new programmes should dedicate resource to the development of a project meta-database that will form the project data inventory. This should conform to appropriate international standards (e.g., ISO19115 for spatially referenced data) to facilitate integration and exchange of information between programmes. Previous experience has shown that this resource is most effective if located in the IPO.
3. Projects should establish a data management working group such as the JGOFS Data Management Task Team or the WOCE Data Products Committee. Past experience has shown that these groups are more effective if they comprise both data managers and scientists.
4. National science programmes should address data management in a credible manner, including giving consideration to capacity building, if appropriate.

* This information resulted from a special workshop at the 2003 IGBP Congress in Banff, Canada. The session was chaired by Roy Lowry (British Oceanographic Data Centre), with Bernard Avril (JGOFS IPO) as rapporteur.

GEOHAB will use a decentralised data management and distribution system with a centralised index. The components, centralised under the supervision of the IPO, will include a comprehensive inventory of databases relevant to GEOHAB, as well as meta-data, with links to their locations and contact persons. All investigators should be prepared to share their data and data products within two years from the time those data are processed, and should recognise the "proprietorship" (rights to first publication or authorship) of data acquired from other investigators. Each GEOHAB project should address the long-term archival of observational data and data products to ensure a lasting contribution to marine science. Data management issues will be handled by a small GEOHAB Data Management Committee, which will be responsible for ensuring that the GEOHAB data management policy is followed by participating projects and will assist the International Programme Office in data-related issues. The GEOHAB data management policy will be posted on the GEOHAB web site.

Identification of Protocols and Quality Control

GEOHAB encourages the use of existing standard protocols and guidelines for sampling and experimental methods. Open science meetings for the Core Research Projects will be asked to specify core parameters that will be measured initially in each location, as well as standard measurement protocols. In addition, GEOHAB recommendations on methods and measurements will be disseminated through the IPO and GEOHAB web site. Task Teams will be established, when necessary, to define methods to be applied or recommended in GEOHAB projects and to organise intercomparison of methods and models. GEOHAB will identify relevant existing modelling activities through a Task Team that has the responsibility to organise model inter-comparison exercises, including comparison of predictive models for HABs. GEOHAB investigators retain the primary responsibility for quality control and assurance. It is essential that the methods adopted to ensure quality control and the protocols used for data collection are fully documented in information files (meta-data) accompanying data sets.

Capacity Building

GEOHAB can meet its objectives through international co-operative research only if well-trained scientists from a wide range of countries that experience HABs are involved. GEOHAB will arrange training through courses, summer schools, and training sessions on relevant science workshops, and will encourage means of exchange of scientists between international, regional, and national projects. This approach provides the opportunity to train marine scientists in the use of instruments relevant to HAB monitoring and in the conduct of research in ecosystems that are relevant to their respective countries or regions.

Training activities can be organised by the SSC and proposals for training activities can be submitted to the SSC for endorsement as GEOHAB activities. GEOHAB encourages incorporation of a training and capacity-building component in all GEOHAB Core and Targeted Research projects, as well as in regional and national GEOHAB projects. Projects including exchanges of scientists between research institutions in developing and developed countries will be organised, thereby enhancing research capacity and infrastructure in participating countries. Training activities will be supported to develop and strengthen scientific networks globally, with particular attention devoted to developing scientific capacity in developing countries. GEOHAB will also facilitate the adoption of up-to-date technology and research methodologies world-wide through the organisation of specific workshops (see Example Framework Activity Box 1 as an example).

Example Framework Activity Box 1: Workshop on Real-time Coastal Observing Systems for Ecosystem Dynamics and Harmful Algal Blooms (HABWATCH)

The development and implementation of methods, instrumentation, and systems for real-time coastal observation of HABs was identified as a GEOHAB priority. Accordingly, as a Framework Activity, GEOHAB endorsed and contributed to the planning of an advanced workshop on this topic (Villefranche-sur-Mer, France, 11-21 June 2003). Recent advances in instrumentation, communications, and modelling capabilities have led to the design of prototype real-time observation and prediction systems for coastal ecosystems. Nevertheless, many of the new approaches in ocean observation are unfamiliar to potential users, particularly within the community of HAB researchers. Certain systems that have been developed for other purposes (e.g., estimation of primary production, diagnostics of nutrient limitation, taxonomic probes) may be critical to the achievement of GEOHAB goals. Through plenary lectures, contributed presentations, demonstrations, and practical tutorials, real-time systems applicable for observation, modelling, and prediction were considered, with special emphasis on relevance to HAB dynamics. Underlying theory, a review of existing knowledge and potential advances and constraints for future research were presented and will be published in a proceedings volume (*Monographs in Oceanographic Methods*, UNESCO). Annotated presentations and other information will also be disseminated via CD.

A comprehensive HAB capacity-building effort has been undertaken over the past 10 years by the IOC and other organisations. GEOHAB will continue to benefit from these initiatives and may specifically draw on the experience and resources of the IOC Science and Communication Centres on HABs.

Co-ordination of Modelling Activities

The SSC has established a GEOHAB Modelling Task Team to co-ordinate modelling within GEOHAB Core and Targeted Research projects. The Team is responsible for encouraging collaboration and information exchange on the development of models, and will assist in increasing the general availability of models developed or used within GEOHAB. The Modelling Task Team will also promote activities such as model verification and inter-comparison, and will provide advice on the development, testing, and use of predictive models in core and targeted activities by identifying expert assistance. In addition, advice on the use of models in planning field studies will be provided to the respective scientific research groups. The Modelling Task Team will also co-ordinate modelling activities with those of other international programmes such as GLOBEC, LOICZ, and SOLAS (see below) through cross-representation with their modelling working groups. Finally, the Modelling Task Team will report annually to the SSC the periodic assessment of modelling activities within GEOHAB, specifically those related to improving HAB predictions. The GEOHAB Modelling Task Team will report its conclusions to the SSC.

Interaction with Other International Programmes

The GEOHAB Programme is designed to co-operate with other international programmes, including those supported by the Intergovernmental Oceanographic Commission (IOC), the Scientific Committee on Oceanic Research (SCOR), and/or the International Geosphere-Biosphere Programme (IGBP). Those projects most relevant to GEOHAB include the Global Ocean Ecosystem Dynamics (GLOBEC) project, Land-Ocean Interactions in the Coastal Zone (LOICZ) project, Integrated Marine

Biogeochemistry and Ecosystem Research (IMBER) planning activity, and the Surface Ocean-Lower Atmosphere Study (SOLAS) (see Figure 3 and Table 4). The Global Ocean Observing System (GOOS), particularly its coastal element, is also an important partner of GEOHAB. Links between regional programmes will be established and will contribute to the overall achievement of GEOHAB (see Example Framework Activity Box 2).

Figure 3. GEOHAB will co-operate and coordinate with relevant national, regional, and international programmes.

Example Framework Activity Box 2: The EU-US Collaborative Programme on Harmful Algal Blooms: A Joint Initiative by the European Commission – Environment and Sustainable Development Programme and the U.S. National Science Foundation

For the first time, joint research in Europe and the United States is being proposed to address these problems of mutual concern, through financial support from the European Commission (EC) and the U.S. National Science Foundation (NSF). This effort builds on a collaborative agreement signed between the EC and NSF to foster scientific collaboration. This initiative was launched by a joint workshop in September 2002 in Trieste, Italy, during which scientists collectively assessed the state of the science, identified gaps in our knowledge, and developed a plan for co-operative, comparative studies. This workshop was endorsed by GEOHAB. A workshop and planning document is available at http://www.whoi.edu/redtide/announcements.html.

There are several areas where such collaboration will lead to significant progress that would not be possible if similar studies were undertaken independently. First, there are environments in Europe and the United States where comparisons of similar processes controlling bloom dynamics should lead to new understanding. Second, apparently similar species occur in Europe and the United States, but they differ in growth dynamics and expression of harmful attributes. Third, major anthropogenic and/or natural forcings, such as nutrient loading and climate variability, appear to have some differing impacts on HAB bloom dynamics in Europe and the United States, and understanding this gradient of responses may lead to better insight and better management of HAB events. Advances will be mutual and both research communities will benefit.

Dissemination, Synthesis, and Integration

Harmful Algae News is distributed regularly by IOC and will be used to announce events, call for proposal contributions, and make known the availability of annual reports. The *Science Plan* is based on comparative approaches. As a consequence of this strategy, the structure of the programme has been established in order to facilitate integration and synthesis of results. For instance, it can be noted that the Core Research Project on stratified environments cuts across the three other Core Research Projects while including other hydrodynamical regimes. Annual summary reports of the Core Projects and related Targeted Research Projects will be circulated to the GEOHAB community through the *Harmful Algae News*, the GEOHAB web site, and other venues as appropriate.

Table 4. International Programmes with which GEOHAB May Interact

In general, GEOHAB will encourage scientists, especially those from the following projects/ programmes, to participate in the Open Science Meetings planned for the GEOHAB Core Projects. GEOHAB will also explore other options for developing co-operative activities in areas of common interests, including the participation of GEOHAB SSC members in related projects.

GLOBEC (IGBP, IOC, SCOR) — The primary focus of GLOBEC is to investigate how the physical environment affects the productivity of zooplankton and fish in marine ecosystems. One strength of GLOBEC is research in upwelling regions, which can be extremely productive, but can also experience severe HABs. GEOHAB will invite scientists from GLOBEC's Small Pelagic Fishes and Climate Change (SPACC) project to participate in the GEOHAB Core Research Project on HABs in Upwelling Systems. GEOHAB is also participating with GLOBEC and the International Council for the Exploration of the Seas (ICES) in a workshop on "Future Directions for Modelling Physical Biological Interactions in the Ocean" planned by the ICES Study Group on Modelling Physical/Biological Interactions for 2003.

LOICZ (IGBP, IOC) — The primary focus of LOICZ has been to collect information on material fluxes from the land to the ocean in order to construct flux estimates related to diverse environment types. Information and techniques available from LOICZ can be important sources for GEOHAB research and prediction activities. One of the themes in the second phase of LOICZ will be on the fate and transformation of materials in coastal and shelf waters; therefore, co-operation with LOICZ on process studies in these areas could benefit both projects.

IMBER (IGBP, SCOR) — The IMBER project is developing to become the focal program for IGBP and SCOR in the area of ocean biogeochemistry and the interactions of elemental cycles and ecosystems. Some of IMBER proposed research areas concern phytoplankton dynamics, making this project a likely partner with GEOHAB for co-operative research. GEOHAB will explore with IMBER the possibility of sharing a data management system (through participation in data management planning meetings), since both projects will have some similarity of data types.

SOLAS (CACGP, IGBP, SCOR, WCRP) — SOLAS focuses on biological and chemical processes that occur at the air-sea interface. GEOHAB interaction with SOLAS is important because materials entering the ocean from the atmosphere (e.g., nitrogen and iron) can promote HABs. GEOHAB will begin to explore common research interests and possible co-operative activities.

CLIVAR (WCRP) — The primary focus of CLIVAR is the study of climate variability and the development of tools for predicting climate change and variability. CLIVAR is therefore a necessary partner of GEOHAB since HABs can be controlled by climatic conditions. GEOHAB will request to make a presentation to the CLIVAR SSC to begin to explore common research interests and possible co-operative activities.

GOOS (ICSU, IOC, WMO) — GOOS is designed to monitor the ocean and develop sufficient understanding of environmental variability to achieve the goals of sustainable development and integrated management of the marine environment and its natural resources. GOOS has been charged with promoting the development of observation systems that will improve documentation and prediction of the effects of human activities and climate change on marine ecosystems and the living resources they support. GOOS could provide important information, especially in terms of new opportunities for long-term continuous monitoring that will be needed to understand processes in the ocean and predict their outcomes, such as the development of harmful algal blooms. One of GEOHAB's first Framework Activities is the Workshop on Real-time Coastal Observing Systems for Ecosystem Dynamics and Harmful Algal Blooms (see Framework Activity Box 1), endorsed by GOOS.

INVITATION TO PARTICIPATE

The GEOHAB Programme provides the opportunity for scientists to participate in an important multidisciplinary programme of ecological and oceanographic research. GEOHAB recognises that different levels of participation are possible, as described in this *Plan*. Scientists are invited to participate in GEOHAB by designing research studies in keeping with the goals and objectives of GEOHAB, by applying for endorsement of such research, and by participating in Framework Activities. The benefits and obligations of participation in GEOHAB are described herein, but they should be recognised as guidance rather than strict rules. Specific obligations may differ as a function of the level of a project's involvement in GEOHAB. Procedures for endorsement, including an Application Form, are included below.

Benefits and Responsibilities

GEOHAB provides the opportunity for individual scientists and national programmes to participate in an important multidisciplinary programme of HAB research. Given the potential diversity of involvement and the global nature of the scientific agenda of GEOHAB, there must be appropriate integration and dissemination of the results of all participants.

Benefits

Individuals and research teams that participate in international GEOHAB will receive a number of benefits from their association with GEOHAB. These benefits include:

- *Assistance in project development, adoption of protocols, data management, and co-ordination of modelling activities. As mentioned earlier, GEOHAB will convene a series of Open Science Meetings for the purpose of providing opportunities for scientists from every nation to participate in planning comparative research worldwide on ecosystems subject to HABs.*
- *Establishment of close working links with other relevant international programmes and related projects.*
- *Wide dissemination of project information through newsletters, web sites, and other communication mechanisms.*
- *Improved understanding of processes in local areas through comparisons with other ecosystems and through acquisition and application of data and models obtained with common protocols and methodologies.*

Responsibilities

- *Contribution to and participation in appropriate Framework Activities.*
- *Adherence to the GEOHAB data policy, which is under development.*
- *Communication of project progress with the GEOHAB SSC and IPO for inclusion in the newsletters, web sites, and other communication mechanisms.*
- *Acknowledgement of endorsement by GEOHAB in scientific publications, and provision of copies of scientific publications to the IPO for listing as GEOHAB Programme outputs.*

Procedures for Submission and Criteria for Endorsement

All applications to be considered by the SSC for endorsement as GEOHAB activities must be submitted to the GEOHAB IPO (see bottom of page 34) on the following Application Form. Inclusion of supplementary information, for example, proposals submitted for funding, is encouraged but is not a requirement. Both funded and unfunded projects or proposals may be submitted for endorsement. Potential applicants are encouraged to consult the SSC and IPO during the development of projects to be submitted for endorsement. The SSC will not judge the scientific merit of applications *per se*, but will expect that this has been, or will be done, at the regional or national level by respective funding agencies. However, SSC members may act individually, on request, as referees. Endorsement of proposals as GEOHAB activities will be based on their relevance to GEOHAB objectives and strategies. Applications will be categorised by the SSC as Core, Targeted, or Regional/ National, or Framework Activities. The GEOHAB SSC may propose extension or modification of the proposed research to meet the scientific goals of GEOHAB. The SSC will advise on potential comparative studies, collaboration and the provision of expert advice for planning, data management, and modelling.

G E O H A B

APPLICATION FORM FOR ENDORSEMENT OF ACTIVITIES

This Form should be completed in English and should be NO MORE THAN 5 PAGES. For further guidance, consult the Chairman of the GEOHAB SSC or the GEOHAB IPO. The Application Form can be obtained in Word format at http://ioc.unesco.org/hab.

1. TITLE:

Activity Duration: _____ to: _____

2. APPLICANTS

Leading Applicant:

Name:
Organisation / affiliation:
Address:
Tel:
Fax:
E-mail:

Other Key Participants:

Name:
Organisation/affiliation:

Name:
Organisation/affiliation:

Name:
Organisation/affiliation:

3. OBJECTIVES, STRATEGY AND ACTIVITY PLAN

Brief description of **activity objectives**:

Brief description of **research strategy** (if relevant):

Brief description of the **activity plan**:

Timetable for **activity implementation**:

4. OUTPUTS

Scientific:

Specify data to be delivered:

Planned dissemination of results (check all the apply):

International journals: _____ National journals: _____

Conference presentations: _____ Other: _____

What provisions/plans have been made for data management, archival, distribution and curation of samples?

Training:

Specify training to be provided by the activity (check all that apply):

Graduate training: _____ Undergraduate training: _____

Technical training: _____ Other training: _____

Are courses open to participants from other countries? Yes: _____ No: _____

5. *GEOHAB SCIENCE PLAN* PROGRAMME ELEMENT(S), OBJECTIVE(S), AND TASK(S) ADDRESSED

Specify which Programme Elements, Objectives, and Tasks of the *GEOHAB Science Plan* the activity will address:

For research projects, specify how the activity contributes to the overall GEOHAB strategy of comparative research:

6. BENEFITS FROM GEOHAB

How will the activity benefit from endorsement by GEOHAB?

How might the GEOHAB SSC assist the activity?

7. SCOPE FOR INTERNATIONAL PARTICIPATION AND CONTRIBUTION

Specify whether the activity will involve international participation:

8. LINKAGES WITH OTHER PROGRAMMES

Is the project part of a National Programme? Yes: _____No: _____
If yes, provide title:

Is the activity part of, or affiliated with, other international/regional programmes?
Yes: _____ No: _____
If yes, provide programme title:

9. SUPPORTING INFRASTRUCTURE AND FACILITIES

Specify the infrastructure and facilities available to participants:

10. FUNDING

Has funding been obtained? Yes: _____ No: _____
If yes, specify source(s):
If no, specify potential source(s) of funding:

11. ENCLOSE SEPARATELY:

(i) Short ***Curriculum Vitae*** of the leading applicant including a list of 6 (max.) most relevant publications:

(ii) Short ***Curriculum Vitae*** for key participants including a list of 6 (max.) most relevant publications:

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12. SIGNATURE(S) OF APPLICANT(S):

I/We accept the responsibilities associated with endorsement by GEOHAB:

_____	_____
Leading Applicant	Date
_____	_____
Key Participant	Date
_____	_____
Key Participant	Date
_____	_____
Key Participant	Date

This application form should be sent by mail and e-mail to either:

Henrik Enevoldsen, Programme Co-ordinator
IOC Science & Comm. Centre on Harmful Algae
Botanical Institute, University of Copenhagen
Øster Farimagsgade 2D
DK-1353 Copenhagen K, Denmark
E-mail: hab@bot.ku.dk

Edward R Urban, Jr.
Executive Director, SCOR
Department of Earth & Planetary Sciences
The Johns Hopkins University
Baltimore, MD 21218 U.S.A.
E-mail: scor@jhu.edu

APPENDICES

APPENDIX I: Functions of GEOHAB Scientific Steering Committee

The GEOHAB SSC is nominated jointly by IOC and SCOR to:

- Oversee the development and implementation of the GEOHAB programme;
- Promote, organise and co-ordinate core research;
- Establish task teams with precise objectives and promote targeted research on critical topics;
- Evaluate and endorse research projects fulfilling the requirements defined in the *Science* and *Implementation Plans*;
- Establish appropriate data management policies to ensure sharing and preservation of GEOHAB data, including maintaining a comprehensive inventory of databases;
- Promote awareness of GEOHAB and disseminate information within appropriate scientific communities;
- Establish links with related programmes;
- Co-ordinate IPO activities; and
- Monitor progress and achievements of the programme and periodically report to IOC and SCOR.

APPENDIX II: Functions of the GEOHAB International Programme Office

The IPO is appointed by SCOR and IOC to:

- Administer the programme on a day-to-day basis under guidance of the SSC;
- Co-ordinate research efforts and contribute to the planning of field activities;
- Promote projects to ensure international participation;
- Establish and maintain links with relevant national and regional programmes;
- Disseminate information and research results through the *Harmful Algal News* and other appropriate media (e.g., the GEOHAB web site);
- Secure support for the operation of the IPO and the SSC;
- Co-ordinate and implement the development of a GEOHAB data management plan;
- Collect and catalogue GEOHAB research publication list;
- Provide day-to-day support to the activities of the SSC; and
- Provide the technical secretariat for the meetings of the SSC and other meetings convened by the SSC within the framework of GEOHAB.

APPENDICES

APPENDIX III: Membership of the GEOHAB SSC

Members

Donald Anderson	USA	(1999-)
Marcel Babin	France	(2001-)
Susan Blackburn	Australia	(1999-2001)
Allan Cembella	Canada	(1999-)
John Cullen	Canada	(1999)
Malte Elbrächter	Germany	(1999)
Marta Estrada	Spain	(1999-)
Wolfgang Fennel	Germany	(1999-)
Yasuwo Fukuyo	Japan	(1999-2001)
Ken Furuya	Japan	(2003-)
Patrick Gentien	France	(1999-)
Patricia Glibert	USA	(1999-)
Leonardo Guzman	Chile	(2002-)
Kaisa Kononen	Finland	(1999-2002)
Nestor Lagos	Chile	(1999-2001)
Tom Osborn	USA	(1999-2001)
Grant Pitcher	South Africa	(1999-)
Robin Raine	Ireland	(2003-)
Arturo Sierra-Beltran	Mexico	(1999-)
Steve Thorpe	UK	(1999-)
Jing Zhang	China	(1999-)

Ex-officio Members (IPHAB Chair)

Beatriz Reguera	Spain	(2002-)
Adriana Zingone	Italy	(1999-2002)

Liaisons to Sponsoring Organisations

Henrik Enevoldsen	IOC	(1999-)
Elizabeth Gross	SCOR	(1999-2000)
Ed Urban	SCOR	(2000-)