Implementation of GEOHAB Core Research Project – HABs in Upwelling Systems (2006)

Introduction

The GEOHAB report on *HABs in Upwelling Systems* (GEOHAB, 2005) specified that GEOHAB would form a subcommittee for the Upwelling Core Research Project to "…work with scientists involved in the Upwelling CRP [Core Research Project] to ensure that they are coordinating their research, using the same measurement protocols, sharing data, and contributing to model development." The Subcommittee began its work with a meeting in Villefranche, France on 18-21 January 2006. All four major eastern boundary current upwelling systems were represented: the Benguela Current (Grant Pitcher and Trevor Probyn), Iberian Current (Teresa Moita and Francisco Figueiras), California Current (Raphael Kudela and Vera Trainer), and Humboldt Current (Sonia Sánchez).

The Subcommittee reviewed the eight key research questions described in *HABs in Upwelling Systems* and summarized ongoing and planned research in the four upwelling systems relevant to the eight key questions. The Subcommittee developed potential research projects related to six of the eight key questions, for which some research is already ongoing and could provide a core set of scientists for GEOHAB-related research. Descriptions of the research projects follow, including the motivation for the projects, likely participating regions, a project coordinator and participants (the intention is that this list will expand as more scientists worldwide link their research to these projects), project objectives, project approach and work plan, example projects, and expected project output. These descriptions were distributed for comment to the individuals listed for each project and their comments were incorporated in the current draft of this document.

Following the project description are details of project implementation, as far as the Subcommittee could describe them, recognizing that the details will change depending on which activities are funded. This document will be updated annually as the projects are implemented and as the Subcommittee continues its work.

Research Projects

Effects of nutrients on HAB population dynamics in upwelling systems.
Climate and HABs in upwelling systems.
Genetic comparisons of HABs in upwelling systems.
Coastal morphology and its influence on HABs in upwelling systems.
Seeding strategies within upwelling systems.
The role of across-shelf and alongshore currents in the transport of HABs in upwelling systems.

Project: Effects of nutrients on HAB population dynamics in upwelling systems

Motivation
A defining attribute of upwelling systems is the periodic supply of nutrients from deeper waters that provides appreciable scope for phytoplankton growth and concomitant effects on higher trophic levels. Given the compelling evidence for a global increase in HABs, and their established negative impacts in coastal upwelling environments (Picher and Calder 2000, Smayda 2000), it is important to understand how this potential production is channeled into HABs as opposed to, or as a successional stage of, the more benign/beneficial blooms that generally characterize these regions. In this regard, there appears to be a dearth of information in coastal upwelling ecosystems relating specifically to the nutritional aspects of HABs compared to the more typical non-HAB, diatom-dominated assemblages.

Participating Regions
Based on existing areas of research, these studies will be undertaken predominantly in the California Current, Benguela Current and Iberian Current systems. In the Benguela, the area of focus is the greater St Helena Bay region of the southern Benguela (33ºS), though opportunistic studies will be undertaken with blooms as and where they occur. The focus in the United States is central California, and the Washington State coastline. There may also be interested investigators in Oregon and southern California. In the case of the Iberian Current, the study area will be the Spanish Rías Baixas where existing data sets and ongoing research and monitoring programmes provide the opportunity for checking the variability of nutrient ratios and their influence on HABs.

Project Coordinator: T. Probyn [Marine & Coastal Management, Cape Town]

Collaborators
California Current – Coordinator: R. Kudela (UC Santa Cruz). Collaborators: W. Cochlan (San Francisco State University), J. Largier (UC Davis), K. Bruland (UC Santa Cruz), M. Wells (U. Maine), P. Strutton (Oregon State University), C. Trick (Canada)
Benguela Current – Coordinator: T. Probyn (M&CM, Cape Town). Collaborators: S. Seeyave, D. Purdie (NOC, Southampton), G. Pitcher (M&CM, Cape Town), S. Bernard, M. Lucas (U. Cape Town)
Iberian Current – X.A. Álvarez-Salgado (IIM-CSIC), C.G. Castro (IIM-CSIC), M.D. Doval (ITECMAR)

Project objectives
- Quantify the importance of upwelled nutrients to HABs as the f-ratio (N-based).
- Provide physiological understanding of HAB species' nutrition (N, P, Si) and biological supply mechanisms (regeneration).
- Determine the role of trace metals in HAB dynamics.
- Identify how nutrient availability and speciation may affect cellular toxicity (N, P, Si, trace metals).
- Provide input to HAB biogeochemical models.

Approach and Workplan

a) Macronutrients – This effort will focus on standard field-based, ^{15}N tracer studies of new/regenerated production based on NO_3, NH_4 and urea (and other organic sources) utilization under different bloom scenarios. These studies should be supplemented with C productivity measurements. Use of size fractionation may provide important insight to the particular species under consideration and the general usefulness of a life-form approach to HAB nutrition. A combination of field measurements of N assimilation and toxin content (where relevant) could provide supporting information on N-speciation effects on cell toxin content. The "definitive" work in this regard would be addressed in culture studies, initially intended to focus on *Alexandrium* spp. and *Pseudo-nitzschia* spp. Nutrient addition bioassays (N, P, Si) with field samples, can be similarly employed for potential effects on cell toxin content. Measures of nutrient kinetics will allow parameterization of uptake, growth and toxin responses to concentration, light and temperature.

b) Trace metals – For some organisms, such as *Pseudo-nitzschia*, trace metals, particularly Fe and Cu, are thought to be critical factors in determining toxicity. These effects will be addressed similar to the macronutrient studies, including the use of laboratory studies to examine, for example, growth and transport kinetics. Field incubations can be carried out with metal additions or, alternatively, with chelators such as DFB (an Fe-binding compound). Non-invasive methods, such as variable fluorescence, may also be useful for rapidly assessing micronutrient status in relation to environmental conditions.

c) In addition to the incubation-based approaches mentioned above, routine measurements of nutrient concentrations (macro and micro) and ratios, coupled with detailed taxonomic studies and toxin content, could provide valuable insight to the controlling effects of nutrients on key HAB processes. Such measurements would address both particulate and dissolved concentrations as is deemed important.

These studies will make use of ongoing field studies and cruises as well as dedicated research cruises. Exchange of cultures from the different regions would be highly beneficial for comparative laboratory studies.

Example projects

- In the California Current System (CCS), several recent or ongoing projects have collected N, C, and occasionally Si uptake data in various locales, including Monterey Bay, Bodega Bay (north of San Francisco), and coastal Oregon/Washington, typically during May-September. The focus of these studies has been on *Pseudo-nitzschia* spp. dynamics, while blooms of *Ceratium furca*, *C. dens*, *Heterosigma akashiwo*, and *Cochlodinium polykrikoides* have been opportunistically studied during these programs. Ongoing nutrient-related fieldwork in this region involves F. Chavez, W. Cochlan, R. Kudela, C. Trick, M. Wells, and others. Laboratory work with isolates from the CCS include *Pseudo-nitzschia*, *Alexandrium*, and *Heterosigma*.

ECOHAB PNW: Ecology and Oceanography of *Pseudo-nitzschia* Blooms in the Pacific Northwest.
PIs: B. Hickey (U. Washington), V. Trainer (NOAA Fisheries)

Relevant Investigators: W. Cochlan, C. Trick and M. Wells
This study is concerned with the role of the Juan de Fuca Eddy in the initiation of *Pseudo-nitzschia* spp. blooms that impact the outer coast of Washington State (USA) and the processes responsible for their shoreward transport. As a component of this research effort, field data on C, N and trace metals are being collected.

Center for Integrated Marine Technology (CIMT)
PI: Gary Griggs (UC Santa Cruz)
Relevant Investigators: F. Chavez, R. Kudela
CIMT is an ongoing monthly monitoring project in the Monterey Bay region. It includes surface (and some depth) sampling for macronutrients, trace metals, HAB organisms, and ancillary measurements. It also incorporates high-frequency radar, remote sensing, mooring arrays, and physical models (ROMS). Although C, N uptake rates are not routinely included, approximately annually there is a more intensive field program that includes rate measurements. The Monterey Bay Aquarium Research Institute (MBARI) performs rate measurements (C and N) on a subset of stations monthly, as part of a related programme.

CoOp WEST: Wind Events and Shelf Transport.
PI: J. Largier (UC Davis)
Relevant Investigators: R. Dugdale, F. Wilkerson, R. Kudela
This project examined the influence of wind stress on coastal productivity in northern California. Although not specifically targeted towards HAB dynamics, information on C, N, Si and Fe was collected in a region often dominated by HAB organisms.

- In the Benguela ongoing efforts are focused on an annual, intensive 3-4 week sampling period off Lambert's Bay during the late summer (March). Unpublished N and C uptake data exist for this region from the last 5 years comprising a number of different blooms, including *Mesodinium rubrum*, *Ceratium* spp., *Gyrodinium zeta*, *Prorocentrum triestinum*, *Syracosphaera pulchra* etc. In addition, a brief study has been conducted on an *Alexandrium minutum* bloom in the Cape Town harbour. Future nutrient-related fieldwork in this region will involve, specifically, S. Seeyave, T. Probyn and G. Pitcher, though other researchers may join these efforts. Collaboration with international scientists is strongly encouraged. Culture studies on cellular toxicity and uptake/growth kinetics are intended to be undertaken at NOC, Southampton, UK (S. Seeyave, D. Purdie).

In the Iberian system, inorganic nutrients and dissolved organic carbon are currently determined as part of a regular HAB monitoring programme implemented in the Rías Baixas. This data set, which is complemented with phytoplankton composition, is derived weekly from sampling at 40 stations, initiated at least 5 years ago.

IMPRESION
PI's: X.A. Álvarez-Salgado (IIM-CSIC); F.G. Figueiras (IIM-CSIC); M. Varela (IEO)
This project utilized mesocosms to study the structure and functioning of the microbial community in the Ría de Vigo under various oceanographic conditions. Organic and inorganic nutrients and phytoplankton composition were determined as a core part of the sampling programme.

Project output

- Improved understanding of HAB nutrient dynamics in upwelling systems, relating both to the different phases of bloom development and decline, and to cellular toxicity.
- Realistic parameterization of biogeochemical models for the regions under study.
- Informed advice to managers regarding, for example, consumer safety and potential HAB threats to the marine ecosystem.
- Post-graduate student training.

References

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Project: Climate and HABs in upwelling systems

Motivation

Changes in upwelling intensity provide one of the substantiated lines of evidence for warming climatic trends (Bakun 1994), although the specific regional responses are still being established (e.g., Diffenbaugh et al. 2004). Several research groups have documented a correlation between HAB events (frequency and magnitude) and changing climate indicators. For example, HAB events are believed to be occurring more frequently during El Niño/Southern Oscillation (ENSO) events in the Humboldt Current system when low abundance of diatoms coincides with increasing numbers of new species (primarily dinoflagellates, including some toxigenic species) resulting in serious problems to the anchovy fishery (Rojas de Mendiola 1981, Rojas de Mendiolo et al. 1985), while ENSO events have also been correlated with toxic HAB events in Mexico (Ochoa 2003). There is a need to compare interannual variability of HABs among upwelling systems as well as at different latitudes within a system. The study of regions in different hemispheres will allow comparisons to be made on the effects of the seasonal timing of arrival of climatic signals on HABs. For example, the ENSO signal arrives in the summer in one hemisphere, but in the winter in the other hemisphere; similarly, each basin has unique climatic signals, such as the Pacific Decadal Oscillation (PDO) in the Pacific versus the North Atlantic Oscillation (NAO) in the Atlantic.

Influences of climate require well-documented time series of a sufficient duration to characterize the underlying mechanisms. Research needed to establish linkages between HABs and climate change includes data-mining efforts for short-term time series (examination of time series and satellite data, e.g. Sacau-Cuadrado et al. 2003), as well as projects involved in micro-paleontology (dating and characterizing sediment cores) for longer time series, and finally development of hindcast and forecasting models to help apply the knowledge gained to our understanding of HAB dynamics.

However, comprehensive, complete, long-term HAB datasets and corresponding environmental data are rarely available. Many HAB data are collected by managers only when necessary for the protection of public health, resulting in incomplete time series or inconsistent datasets. Effective time-series analysis requires very large data sets; an appropriate data policy conducive to data sharing (i.e., individual investigators will be willing to share data knowing that it will only be used for meta-analysis) will need to be established. Furthermore, care will need to be taken to differentiate climatic effects from other long-term changes such as urbanization and land-use practices, fresh-water diversion, etc.

Participating regions: Iberian, Californian, Benguela, Canary, Humboldt

Project Coordinator: V. Trainer (NOAA, USA)

Collaborators

Iberian: T. Moita (IPIMAR), A. Rocha (U. Aveiro), Y. Pazos (CCMM, Spain), L. Valdez (Spain, RADIALES project), A. Amorim (U. Lisbon).

California: V. Trainer, B. Peterson (NOAA), N. Mantua, B. Hickey, R. Horner (U. Washington), R. Kudela (UCSC), F. Schwing (NOAA, ARD), F. Chavez (MBARI), P Strutton (OSU), E.

Venrick (Scripps), G. Gaxiolla (Mexico), John Hunter, SWFSC, P. Strutton (Oregon State University), M. Wood (University Oregon) and Tim Baumgartner, CICESE/Scripps.
Humboldt: S. Sánchez (IMARPE, Peru).
Benguela: B. Dale (U. Oslo, Norway).

In addition, several international research projects with climate aspects are underway, providing opportunities for collaboration with the above-mentioned GEOHAB collaborators. These projects and programs include GLOBEC, IMBER, CLIVAR, LOICZ, IMAGES, CPPS, ERFEN.

The GEOHAB Core Research Project on Eutrophication has also identified climate change and HABs as one of their areas of focus. We anticipate working closely with this group.

Project Objectives
To investigate potential correlations between "long-term" HAB monitoring data (shellfish toxicity, toxigenic species, continuous plankton recordings) and local environmental data (e.g., nutrients, wind, temperature) as well as regional and global climate indicators (ENSO, PDO, NAO).

Approach and Workplan
Biological data for addressing climate impacts on HABs within each region should include the following: phytoplankton species distribution (with a focus on HAB species), shellfish toxin levels, numbers of shellfish closures, and sediment cores that provide information on the history of HAB species through their presence in the sediments either as vegetative or cyst stages. Meteorological (wind speed and direction, temperature), physical (ocean current direction and speed, temperature, salinity, river flow), and chemical (nutrients, oxygen levels) records that can be correlated with biological datasets should all be collected and quality controlled. Although satellite data are only available for the past two to three decades, these should be included to determine trends in temperature and biomass over larger spatial regions.

Regions will collaborate to determine best methods for data analysis and comparison, including statistical analysis, modeling, and development of forecasting capabilities. Important to this work will be agreements on data sharing and quality control of data.

Example Projects
- Studying the impact of climate change in Portuguese coastal waters - the Aveiro coastal ecosystem – SIMCLAVE

PIs: J. Fortes, coordinator (Universidade de Aveiro), T. Moita (IPIMAR), A. Rocha (Universidade de Aveiro)
This project will contribute to a better understanding of the relationship between climate change and the variability of the phytoplankton population structure and productivity within the nearshore Aveiro upwelling system. An ecological model for the Aveiro coastal waters will be applied to simulate past and present-day conditions, as well as scenarios related to climate changes on a longer time scale. This project may provide better knowledge of the Portuguese coastal upwelling system in a climate change perspective, and its results may constitute a tool for better environmental management of the coastal zone.

Data types and analyses: Long-term weekly monitoring of HAB species (20 yr, since 1987 from Ria de Aveiro – T. Moita, including *Pseudo-nitzschia* spp., *G. catenatum, D. acuta, D. acuminata*), supported by local environmental data (T. Moita, A. Rocha, temperature, wind, salinity), and ecological (J. Fortes) and climate modelling (A. Rocha) are available.

- Towards a decadal time-series of the abundance of *Pseudo-nitzschia* off the central Oregon coast and analysis of spatial variability in distribution off the coasts of Oregon and Washington

PIs: W. Peterson (coordinator, NOAA Fisheries, Newport, OR), V. Trainer, NOAA Fisheries, Seattle, WA)
This project will provide a comparison of the seasonal, interannual and decadal variations in abundances of *Pseudo-nitzschia* to local meteorological and hydrographic data (e.g. winds, sea surface temperature and water column stratification), and to basin-scale climate indices such as the PDO and MEI. This work will allow us to determine if blooms are initiated at all points across the shelf, if a bloom propagates across the shelf, or if they are initiated only in the nearshore zone.
Data types and analyses: *Pseudo-nitzschia* spp. abundance since 1995 along the Newport, Oregon hydrographic line (44° 39'N) at stations located from 1 to 25 miles offshore (W. Peterson and V. Trainer), environmental and climate data (W. Peterson). Development of forecast and modeling products geared towards informing ecosystem-based management of public health risks (W. Peterson).

Project Output

- An understanding of which environmental conditions are conducive to HAB occurrences and whether the same environmental variables are important to the initiation of HABs in comparable upwelling systems and at different sites within an upwelling system.
- Determination of whether environmental and climate indicators can be used to determine which HAB events are due to anthropogenic factors (such as increased nutrient inputs) or climate change (such as ENSO).
- The synthesis of predictive models that can forecast the years in which HAB events might be most severe. This will provide advice to managers who could respond, for example, by increasing their monitoring effort during these years.
- Identification of endemic organisms versus those that appear suddenly in a time series, owing, for example, to human-mediated transport.

References

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Project: Genetic comparisons of HABs in upwelling systems

Motivation
This project will address the role of genetic predisposition versus environmental conditions in toxin production in different upwelling systems within a given genus or species. It is well known that toxigenic HAB species exhibit variability in toxin production, both at the species and genus level, within a given upwelling system. Multiple environmental factors have been shown to influence HAB toxicity and ecology and it is possible that the entire range of observed spatial and cell-specific variability in toxin production is a response to subtle environmental cues. However, variability in genotypes is a common feature of phytoplankton. These genotypic differences are responsible for markedly different phenotypic expression in response to environmental cues within the same putative species. Therefore, the variability in toxin production is likely caused by a combination of genotype and environmental conditions. A genetic comparison of HAB organisms among regions is useful for differentiating between genetics and environment. Although there are several genetic comparisons that could be identified, here we focus on four potential targets that are found in all regions: *Pseudo-nitzschia* spp., *Protoceratium reticulatum, Lingulodinium polyedrum,* and *Alexandrium catenella*.

Participating Regions: Benguela, California Current System, Iberian Peninsula

Project Coordinator: R. Kudela, University of California Santa Cruz (USA)

Collaborators
Benguela: C. Marangoni, G. Pitcher, T. Probyn
California Current System: V. Armbrust, L. Busse, P. Franks, B. Jenkins, R. Kudela, P. Miller, G. Rocap, C. Scholin, G. Smith, P. Strutton, V. Trainer, M. Wood
Iberian Peninsula: A. Amorim, S. Fraga, T. Moita, B. Paz

Project Objectives
- Molecular characterization (e.g. sequence analysis for application of RNA/DNA molecular probes) for harmful algal species in each region
- Based on (1), determine whether HAB producing organisms are genetically distinct for the comparable regions
- Utilize differences in cell toxin quota of a given species in separate upwelling regions to allow characterization of genes and biochemical pathways important for toxin synthesis

Approach and Workplan
To address these questions, a combination of comparative field and laboratory approaches is required:

1) A critical baseline component for genetic comparison would be accurate characterization of the organisms by traditional taxonomic methods in coordination with the genetic work, to ensure that molecular databases are compatible with traditional identification methods.
2) For the molecular work, a first step would be to assemble a collection of isolates from the three regions for each HAB species of interest for evaluation of physiological and genetic variability under controlled (laboratory) conditions. At minimum, the following

laboratory work is envisioned:
- Isolation and culture of representative organisms
- Molecular phylogeny (ITS sequences, etc)
- Characterization of growth rates, maximum cell density, and toxicity in relation to:
    - light, temperature, macronutrients
    - genetic expression using, e.g., targeted probes from previous studies*

3) Field studies. Guided by the results and questions from laboratory studies, molecular genetic approaches should be applied to field data to:
- Test molecular probes (for species identification and/or biochemical pathways) on natural field assemblages
    - this will provide information on cross-reactivity and specificity
- Correlate genetic signatures to environmental factors
    - methods such as RFLP or micro-satellite analysis can be used to differentiate genetically distinct sub-populations within a species*
    - Comparative studies may help to identify environmental factors that consistently trigger genes of interest
- Vectors (e.g., shellfish, planktivorous fish) for HAB toxins should also be examined for differences in toxin retention, since regional variability in HAB events may be less related to the genetic/environmental characteristics of the algae, and more a function of the vectors (e.g., different species of shellfish will exhibit widely different toxicity)

* *Developing new molecular information (e.g., subtraction libraries, RFLPs, etc.) is costly, and would require substantial project support. Application of existing molecular probes is considerably less expensive, and could serve as the basis for future funding.*

Example Projects
Although the topic of Molecular Genetics and HABs is quite broad, two specific examples that lend themselves to the comparative approach emphasized by GEOHAB include ongoing efforts on *Pseudo-nitzschia* in the CCS, Benguela, and the Iberian Peninsula, and a comparison of *Lingulodinium polyedrum* between the Iberian Peninsula and the CCS.

- *Pseudo-nitzschia* spp.

There are many groups worldwide working on *Pseudo-nitzschia* molecular ecology. An example of an emerging project relevant to GEOHAB involves the comparison of *Pseudo-nitzschia australis* between California, Iberia, and the Benguela. On the U.S. west coast, *Pseudo-nitzschia* has been regularly identified as a domoic acid producer since the early 1990s, and is also known to produce toxin in the Iberian system; in contrast, the Benguela system has potentially toxigenic *Pseudo-nitzschia*, including *P. australis*, but domoic acid production has never been verified in either the laboratory or field samples. Following the *Approach and Workplan* outlined above, a comparison of *P. australis* between systems is proposed. This will involve:

1) Transfer of cultures from South Africa to the United States for molecular characterization
2) Field collection of domoic acid samples (e.g., shellfish, planktivorous fish) and cells in South Africa
3) Field application of molecular probes for species identification in South Africa.

Currently rDNA probes are available (Scholin et al. 1997), while new PCR-based probes based on ITS sequencing have been developed by both Hayashi and Smith (pers. comm.) and Hubbard et al. (2005).
4) If Benguela isolates are shown to be non-toxic, then a direct comparison of *P. australis* using, for example, cDNA subtraction libraries will be carried out.
5) If Benguela strains can be induced to produce domoic acid, then efforts will focus on a comparison of the environmental conditions conducive to toxin production in California and Iberia versus the Benguela.
6) Newly developed molecular probes which are correlated to toxin production and growth rates in California isolates (Smith et al. 2005) can also be tested in South Africa and the Iberian system, providing further validation of these molecular techniques.

- *Lingulodinium polyedrum*

There are two known biological origins of yessotoxin. The dinoflagellate *Protoceratium reticulatum* was the first confirmed producer of both yessotoxin and the analog 45,46,47-trinor-yessotoxin. Another dinoflagellate, *Lingulodinium polyedrum* (formerly called *Gonyaulax poledra* F. Stein 1883, reclassified by Dodge, 1989; synonymous with *L. polyedra*) was determined to produce yessotoxin, as well as the analog, homoyessotoxin in isolates from Italy, the Iberian Peninsula, Ireland, New Zealand, and most recently, California. *L. polyedrum* is typically identified by morphological features and it is likely that there are genetic differences among strains isolated in different geographic regions. For example, Scholin et al. (1994) compared sequences of the large subunit ribosomal rRNA gene (LSU) and found that different lineages of *Alexandrium tamarense* from different geographic regions are more divergent compared to sequences within a regional population. Therefore, genetic differences may exist between subpopulations. Because yessotoxin is an emerging issue, the molecular characterization of *Lingulodinium* is at an early stage, and is an ideal candidate for a comparative analysis between the Iberian Peninsula and California. This will involve:

1) a comparison between the rRNA sequences of several isolates from California, Norway, Italy, the United Kingdom, and the Iberian Peninsula will be used to determine whether there is a geographic pattern linked to diversity of *L. polyedrum* populations.
2) rRNA sequence information will facilitate the development of probe-based detection methods for *L. polyedrum.*
3) Existing characterization of *L. polyedrum* cultures shows widely disparate toxin production under similar growth conditions (e.g., Armstrong et al. 2006); molecular phylogeny from this project will be correlated to toxin variability, to identify potential genetic versus environmental differences in toxicity.

Project Output

Ideally, molecular techniques for toxic algae would focus on the detection of genes that are “turned on” during toxin production, not merely on cell or toxin detection alone (Plumley 1997). New molecular techniques such as subtractive hybridization permits the identification of genes that are differentially expressed in organisms grown under different conditions, for example, those that induce toxin production and those that do not induce toxin synthesis. If genetically related organisms can be identified which produce toxin in one region but not another, it is much more likely that “toxin genes” or pathways can be identified. Output from this project would generate the following:

- Species-specific rDNA probes for each region (ideally “global” probes)
- Regional cross-reactivity and sensitivity assays for rDNA probes
- Phylogenetic map of variability between regions
- Ideally, toxic and non-toxic strains would be identified
- For toxic/non-toxic strains, gene expression libraries would be obtained
- Correlation of molecular data to specific regional environmental conditions
- Probes for toxin genes or pathways allowing ID of most threatening strains may ultimately be developed, with direct application to monitoring/forecasting programs

References

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Project: Coastal morphology and its influence on HABs in upwelling systems

Motivation

Alongshore variability of coastal upwelling is mainly controlled by the interaction of the wind-forced shelf flow with coastline and bottom topography, resulting in the amplification and or reduction of upwelling-downwelling processes (Figueiras et al. in press). Consequent spatial variability in upper mixed layer characteristics and shelf flow related to coastline discontinuities, such as pronounced capes, coastal embayments or Rias (in northwestern Iberia), often favours HAB development by enhancing vertical stratification and by forming regions of retention. Comparative research within these regions will serve to assist in identifying the underlying physical processes responsible for the higher incidence of HABs within these regions.

Participating regions

Considerable overlap is found in the HAB species of interest in upwelling systems. *Alexandium catenella* is responsible for PSP in both the California Current System and Benguela, whereas *Gymnodinium catenatum* causes PSP off the Iberian Peninsula. PSP has been recorded in the Humboldt but the causative organism has yet to be identified. A number of species of *Dinophysis* (e.g., *D. acuminata*) are common to all regions and are in most cases associated with DSP. Yessotoxins appear common and are produced by either *Protoceratium reticulatum* or *Lingulodinium polyedrum*. Other red tide-forming dinoflagellates are associated with anoxia in the Benguela and Humboldt currents. ASP is a concern in most regions, particularly in the California Current System, and the diatom *Pseudo-nitzschia australis*, typically responsible for ASP, is common to all regions. Blooms of the raphidophyte *Heterosigma akashiwo* are also of concern to most regions. The development of high biomass blooms of the above species are often associated with coastline discontinuities which result in alongshore variability giving rise to areas of convergence or retention. Initial studies will focus on the following embayments:

California Current System – Monterey Bay 37^{o}N, Bodega Bay 38^{o}N, Willapa Bay 46^{o}N
Iberian Upwelling System – Lisbon Bay 38^{o}N, Rias 42^{o}N
Benguela Upwelling System – St Helena Bay 33^{o}S
Humbolt Current System – Paracas Bay 14^{o}S

Project Coordinator: G. Pitcher (Marine & Coastal Management, Cape Town)

Collaborators

California Current System: N. Banas, S. Bograd, J. Goldberg, B. Hickey, R. Kudela, J. Largier, J. Ryan, P. Strutton, M. Wood

Iberian Upwelling System: A. Amorim, P. Oliveira, J. de Silva, A. Peliz, M. Santos, T. Moita, V. Brotas (Lisbon Bay) X. Álvarez-Salgado, D. Barton, F. Figueiras, S. Fraga, Y. Pazos, B. Reguera, C. Castro, P. Montero, M. Villareal, R. Torres, S. Groom, J. Allen [Rias]

Benguela Upwelling System: S. Bernard, N. Burls, A. Fawcett, P. Penven, G. Pitcher, T. Probyn, C. Whittle

Humboldt Current System: L. Carbajo, E. Delgado, R. Flores, S. Sánchez, J. Tam

Project objectives

To establish the importance of coastline morphology and bathymetry in:

- creating local upper mixed layer conditions favourable for the selection and development of HABs and;
- determining bay circulation patterns favouring bloom development through retention.

Approach and workplan

Circulation patterns for each study area need to be determined in an effort to identify bloom transport mechanisms and regions of convergence and retention important in the development of blooms. For this purpose, measures of ocean currents and the construction of hydrodynamic models incorporating data from meteorological stations, and themistor and current meter moorings are important. Phytoplankton distributions need to be linked to spatial variations in upper mixed layer characteristics and to circulation patterns, primarily through ship-based measurements, but may be supplemented by near-shore monitoring programmes. Attempts may be made to track bloom development and transport by means of mooring systems, drogue deployments, AUV surveys and satellite observations, and hydrodynamic models should be used to support observations.

Example Projects

Present activities within participating regions that will contribute to the objectives of this project, are summarized:

- California Current System

Monterey Bay, Bodega Bay, Willapa Bay – Several buoys are deployed within these bays incorporating meteorological packages, thermistors, salinity, fluorometers and ADCPs. Models provide spatial wind data, high frequency radar systems provide information on surface currents, and hydrographic models (ROMS, GETM) incorporating nested models provide high resolution output for each bay. Phytoplankton data are provided from weekly shore-based monitoring, monthly (2-day) ship surveys, and monthly AUV surveys. The monthly cruises incorporate sampling for nutrients (including trace metals), and toxicity tests (if HABs are present). Satellite observations include temperature and ocean colour.

- Iberian Upwelling System

Lisbon Bay – Meteorological data are provided from Cape Carvoeiro. A single mooring of thermistors and current meters in 30m water is supplemented by monthly CTD casts, and sampling of phytoplankton/zooplankton. Satellite information is derived from AVHRR, SAR, SeaWiFS and MERIS. A phytoplankton time series is maintained and supplemented by HPLC data from a single station (sampled weekly since 2001), and surface sediment samples provide information on the presence of cysts (every 2 months since 2000). Ship-based studies were conducted during August/September 1999, August/September 2005, and are planned for September 2006. An operational hydrographic model (ROMS) has been constructed for the region, and a nested model of the Bay is under development.

Rias – A phytoplankton monitoring programme, incorporating weekly sampling at several near-shore stations [CTD, fluorescence, pigments, phytoplankton counts] is maintained. Moorings including thermistors and ADCPs are periodically deployed. Cruises, incorporating the collection of phytoplankton assemblage data and satellite observations of the adjacent shelf are supported by various physical models and studies of residual circulation. Intensive field studies within the Ria de Vigo are intended to investigate relations between forcing mechanisms, 3-d circulation and phytoplankton in late summer, when HABs are most frequent. Turbulence measurements to characterize the upper water column will be taken during these field experiments. A coupled physical-biogeochemical model (POLCOMS-ERSEM) has been developed and incorporates toxic motile dinoflagellates. Data assimilation algorithms are being developed to support the physical and biogeochemical components of the model, and coupled ocean-atmosphere models of Galician shelf and Rías are also being implemented. Since January 2006, hourly high frequency radar observations of surface currents, in a 100x100 km^2 area, off the Rías are available, and a permanent hydrographic mooring on the continental shelf, reporting real-time is also under consideration.

- Benguela Upwelling System

St Helena Bay – Meteorological data are available from several adjacent shore-based sites. Daily phytoplankton monitoring is conducted at a single coastal station. A single mooring is maintained and includes a thermistor, fluorometer, hyperspectral radiometer and ADCP]. An intensive boat-based 3-week study each year incorporates a time series of measurements at the mooring station, periodic offshore transects, bloom tracking by means of drifter deployment and satellite information [SeaWiFS, MERIS, AVHRR]. A ROMS model has been developed for the region and it is intended that a nested model of the St Helena Bay region be developed.

- Humbolt Current System

Paracas Bay – Several stations within the bay are sampled every 15 days and the sample frequency is increased during bloom periods. Sampling incorporates underway ADCP measurements [supplemented by current meter moorings], CTD-fluorescence, chlorophyll, nutrients [nitrate, phosphate, silicate], pH, oxygen and phytoplankton [net sample and water sample at surface and 1m from the bottom]. Satellite-derived temperature and chlorophyll data [MODIS] provide spatial information, and the development of a hydrographic model of the region [ROMS] is presently being undertaken.

Project output

- Identification of similar or contrasting patterns of local modulation of the upwelling process in response to time-varying wind forcing and spatially variable coastal morphology and bathymetry, important in establishing areas of higher bloom incidence.

- Determination of common processes driving spatial and temporal changes in the upper mixed layer characteristics, responsible for changes in the community composition, incorporating those species responsible for harmful blooms.

- Establishment of common circulation patterns, driven by similar processes, important to the introduction, concentration, retention or dissipation of blooms.

- Advancement of predictive skills of HABs based on understanding the physical forces underlying these areas.

References

Figueiras F.G., G.C. Pitcher and M. Estrada (In Press) Harmful algal bloom dynamics in relation to physical processes, In *Ecology of Harmful Algae*, Graneli, E. and T.J. Turner (eds), Springer, Ecological Series, **189**:

Project: Seeding strategies within upwelling systems

Motivation

The identification of seed or over-wintering populations and the establishment of seeding strategies are important in understanding the development of HABs in upwelling systems, which are recurrent but not always predictable. To better understand and model HABs, species-specific life-history transitions, which may determine the initiation or termination of a bloom, must be considered as an important source of variance. In upwelling systems, advective processes are important in determining species-specific over-wintering and seeding strategies. For example, the encystment and excystment of dinoflagellates is often used to explain seasonal patterns, however very few studies have been conducted in the field. In areas where these studies have been preformed results indicate that closely related species differ markedly in their adaptive strategies despite their similarity in life-history transitions and habitat (e.g. Montresor *et al*. 1998). Dale and Amorim (2000) suggested three different seedbed strategies for HAB dinoflagellates: (1) those species without resting cysts, (2) those species heavily dependent on seedbeds, and (3) those species that produce large numbers of cysts but are seemingly independent of seedbeds. Thes strategies should be investigated for different dinoflagellate species within and between upwelling systems. Diatom populations such as *Pseudo-nitzschia* are often associated with thin layers both in the water column and near-bottom (e.g. Rines *et al.* 2002). Cells under these low light conditions are found to be viable, indicating that *Pseudo-nitzschia* may be present as “shade flora” in stratified water masses, which may function as seed-beds under favorable conditions. Other physical settings, including mesoscale eddies and frontal systems, have also been found to favour the accumulation of *Pseudo-nitzschia* populations. The existence of a *Pseudo-nitzschia* resting stage has been suggested, but no clear seeding strategy has been established.

Understanding and comparing species-specific seeding strategies in different upwelling systems will be useful in the development of models aimed at forecasting blooms and their impacts in coastal regions. A collaborative approach using standardized methods will benefit attempts to establish the sites of seedbeds and to determine the seeding strategies for HAB species in upwelling systems.

Participating regions: California Current System, Benguela, Iberian coast

Project Coordinator: A. Amorim (U. Lisbon, Portugal)

Collaborators
Iberian: A. Amorim (U. Lisbon), B. Dale /U. Oslo), T.Moita (IPIMAR), I.Bravo (IEO), F.G. Figueiras (IIM-CSIC)
Benguela: L. Joyce and G. Pitcher (M&CM)
California Current System: M. Vernet (Scripps I.O.), R. Horner (U. Washington), M. Silver (U. California, Santa Cruz), P. Strutton (Oregon State University), M. Wood (University Oregon)

Project Objectives

- To identify seed populations of particular HAB species in relation to oceanographic features important to their development.
- To describe sedimentary processes determining the location and accumulation of seedbeds (e.g. dinoflagellate cyst beds).
- To describe the seeding and overwintering strategies of particular HAB species.
- To determine the role of environmental parameters in species-specific seeding strategies (e.g., in establishing cyst dormancy, germination, growth, and the periodicity of blooms).
- To determine whether strategies of seeding between upwelling regions are similar.

Approach and Workplan
Comparative field and laboratory approaches are required:

1. Mapping of cyst beds. Surveys of bottom sediment should be conducted to map cyst populations. Hydrological features related to cyst beds should also be determined focusing on areas with a history of HAB events.
2. Establish the distribution of HABs during non-bloom periods. Overwintering populations occurring in frontal systems, within pycnoclines, nitraclines, within near-bottom layers, etc., should be identified and the viability of cells should be established. Simulated upwelling of these populations can also be used to examine viability and growth.
3. Excystment and encystment studies. Time series of cyst germination will be based on collection of surface sediment samples (cysts may be collected by vacuum harvesting of sediment floc and others devices) and laboratory experiments. Dormancy periods of each target species should also be established through laboratory experiments.
4. Encystment within the field may be established by means of sediment trap deployments. Corresponding environmental data will be collected to determine those factors influencing encystment and excystment.

Example Projects

- US Puget Sound

PIs: R. Horner, C. Greengrove (U. Washington)
Sediment cores will be taken throughout Puget Sound to determine *A. catenella* cyst numbers. Sediments will be dated using ^{210}Pb in order to determine historical frequency and intensity of blooms at sites throughout Puget Sound. PSP blooms due to *A. catenella* have more recently appeared in S. Puget Sound due to transport processes, so it is speculated that cyst populations in this region will appear only in more recent sediments.

- ProFit - Interdisciplinary study of processes underlying the phytoplankton dynamics in the Portuguese upwelling system

PIs: A. Amorim (U. Lisboa), P. Oliveira, T. Moita (IPIMAR)
This project was developed based on conclusions from previous studies, which indicate that some areas along the Portuguese coast may act as retention zones favoring phytoplankton growth. In 2001 a long-term time series study was started at a coastal monitoring site. Phytoplankton samples have been collected weekly and sediment samples have been collected every 2 months for the description of dinoflagellate cyst assemblages. Relevant chemical and physical parameters are also recorded. The project aims to describe the diversity and succession patterns of phytoplankton and assessing seasonal patterns of dinoflagellate cyst production over the annual cycle in relation to planktonic populations. Emphasis is given to the description of

HAB events (eg. *G. catenatum*, *L. polyedra*, *Alexandrium* spp.). Infrared, ocean color, and SAR data, for periods preceding the phytoplankton blooms are being processed using state-of-the-art algorithms to study the evolution of thermal fronts, and their spatial relationship to phytoplankton pigment distributions and SAR signatures.

- Life cycle transformations among HAB species, and the environmental and physiological factors that regulate them (SEED)

PIs: E. Garcés (ICM-CSIC, Spain), D. Anderson (Woods Hole, US), S. Fraga, I. Bravo (IEO, Spain)
SEED aims to understand the transition between different life history stages, by identifying the environmental and physiological factors that regulate these transitions, and to integrate recently acquired knowledge in the development of new simulation models. SEED will focus on several target species, from the genera *Alexandrium, Pseudo-nitzschia* and *Gymnodinum.* Fieldwork is centered on areas where ongoing monitoring programs, and baseline information on the distribution of species and their physical-chemical environment, already exists (e.g., NW Iberia - Rías Baixas). Recognition of different life stages within bloom development, timing of sexual reproduction, and a comparison of the dynamics of species will be made. Sediment traps will be deployed to collect and quantify the flux of cysts to the sediment. The physiological mechanisms and tolerances underlying dormancy stages formation and germination will be characterized.

- Dinoflagellate cyst studies within the Benguela Current Large Marine Ecosystem

PIs: L. Joyce, G. Pitcher (M&CM).
Dinoflagellates cysts within the sediments of the Benguela current have been mapped, encystment studies within the field have been conducted by deployment of sediment traps and the characteristics of cyst germination of *Alexandium catenella* have been established in laboratory studies.

Project Output

- To describe the most probable areas and periods for bloom initiation for inclusion in species-specific models (*G. catenatum*, *Alexandrium* spp., *Pseudo-nitzschia* spp.).
- To determine whether the same factors control cyst deposition and excystment in different upwelling regions.
- To identify overwintering and non-bloom period strategies for organisms that do not produce cysts.

References

Dale B. and A. Amorim (2000) Dinoflagellate resting cysts as seed beds for harmful algal blooms. Conference Abstracts of the IX International Conference on Harmful Algal Blooms, 7-11 February, Hobart, Australia.

Montresor M., A. Zingone and D. Sarno (1998) Dinoflagellate cyst production at a coastal Mediterranean site. *Journal of Plankton Research*, **20**: 2291-2312.

Rines J.E.B., P.L. Donaghay, M.M. Dekshenieks, J.M. Sullivan and M.S. Twardowski (2002) Thin layers and camouflage: hidden *Pseudo-nitzschia* spp. (Bacillariophyceae) populations in a fjord in the San Juan Islands, Washington, USA. *Mar. Ecol. Prog. Ser*. **225**: 123-137.

Project: The role of across-shelf and along-shore currents in the transport of HABs in upwelling systems

Motivation
Upwelling systems are essentially heterogeneous with mesoscale structures such as eddies, fronts, filaments and river plumes interacting with alongshore and across-shelf currents. These currents are among the most important physical features of upwelling systems and frequently interact to influence HABs in upwelling regions (e.g. Fraga et al. 1988, Pitcher et al. 1998, Trainer et al. 2002). Along-shore currents are able to transport blooms from their sites of initiation while on-shore transport, associated with downwelling, often favours bloom accumulation in coastal waters where they impact fisheries and tourism. Offshore transport resulting from upwelling promotes their dispersion from coastal systems. Understanding the relative contribution of alongshore and across-shelf flow to the transport of harmful algae to and from the coast will be important in the development of accurate physical-biological models. Comparison among systems will aid to reinforce observations and refine models.

Participating regions: California Current,
Benguela, Iberian, Humboldt

Project coordinator: F.G. Figueiras (IIM-CSIC, Spain)

Collaborators
California Current: B. Hickey (U. of Washington), M. Foreman (Institute of Ocean Sciences, Sydney, Brithish Columbia, Canada), A. MacFadyen, F.Chavez (MBARI), J. Ryan (MBARI), R. Kudela (UCSC), L. Washburn (UCSB), P. Franks (Scripps), P. Strutton (Oregon State University), V. Trainer (NOAA Fisheries), M. Wood (University Oregon)

Benguela: S. Bernard (U. Cape Town), A. Fawcett (U. Cape Town), P. Penven (U. Cape Town), G. Pitcher (M&CM), T. Probyn (M&CM), C. Whittle (U. Cape Town)

Iberian: D. Barton (IIM-CSIC), X. Alvarez-Salgado (IIM-CSIC), F.G. Figueiras (IIM-CSIC), G. Rosón (U. Vigo), B. Reguera (IEO-Vigo), T. Moita (IPIMAR), P. Relvas (U. Algarve), J. Silva (IH), J. Vitorino (IH), R. Neves (IST), P. Oliveira (IPIMAR), A. Peliz (U Aveiro), P. Chambell (IST)

Humboldt: L. Pizarro (IMARPE), C. Grados (IMARPE), S. Sanchez (IMARPE)

Project objectives
Main objective: To determine the relative importance of alongshore and across-shelf transport within the 4 regional upwelling systems in the initiation, accumulation, and transport of harmful algae to coastal environments.

Specific objectives:
1) To describe similarities/differences in the wind regimes and consequent current patterns, including:

- Short-term wind events and seasonal wind patterns paying particular attention to transitional periods.
- Interaction with coastal morphology and bathymetry (canyons, banks, shelf-break, width of the shelf).

2) To compare:

- Seasonal and short-term circulation patterns, from local to mesoscale.
- Mesoscale physical structures relevant to HABs (upwelling and convergence fronts, eddies, buoyancy plumes, pycnoclines).

3) To develop empirical relationships (models) between winds and transport (upwelling-downwelling, across-shelf and alongshore currents, counter currents).
4) To identify similarities/differences in:
Variability, including latitudinal differences, in HAB assemblages and their relationship to the physical-chemical environment (empirical or probabilistic relationships).
5) To establish the extent to which the dynamics of HABs are influenced by the physical transport of HAB populations versus the modification of environmental conditions via transport mechanisms.

Approach and workplan
Two phases are identified:
First Phase (comparative analysis of historical and ongoing records)
Wind regimes: analyze wind records from different locations within each system.
Circulation patterns: analyze current records, buoy deployments with meteorological and physical-biological sensors, drifters, models, and remote-sensing facilities.
Databases: compile historical data obtained from mesoscale and short-term cruises and monitoring programmes to determine the hydrographic fields and the temporal and spatial distributions of phytoplankton, with an emphasis on HABs.

Second phase (depending on the outputs of the first phase)
To design multidisciplinary large and mesoscale field observations during the HAB season (spring to autumn) to identify areas of higher HAB prevalence.
To plan multidisciplinary cruises of short duration to specifically address the transport of HABs. For example, a series of across-shelf transects could be occupied alongshore during a HAB event to document transport processes.
Genetic identification of populations may assist in determining if populations or conditions propagate alongshore.

Example Projects
DYBAGA: Dynamics and Biogeochemistry of the Galician shelf waters: Short-term variability
PIs: F.F. Pérez, X.A. Alvarez-Salgado, F.G. Figueiras (IIM-CSIC)
This project addresses the role of onshore transport in the generation of HABs in the NW Iberian margin. The study combines wind, surface currents and phytoplankton composition from a weekly sampling programme over a year-long period in shelf waters. The objective of this project is to investigate the growth of HAB species in shelf waters and their subsequent transport to the interior of Rias by onshore currents developed during the autumn upwelling-downwelling transition.

ECOHAB PNW: Ecology and Oceanography of *Pseudo-nitzschia* blooms in the Pacific Northwest
PIs: B. Hickey (University of Washington), V. Trainer (NOAA Fisheries)
This project is researching the role of a seasonally retentive counterclockwise eddy, the Juan de Fuca Eddy, in the initiation and development of *Pseudo-nitzschia* blooms that impact the Washington State (USA), outer coast. The primary objectives are to determine why the Juan de Fuca Eddy region is more conducive to toxigenic blooms than the coastal upwelling zone, the transport processes that result in toxification of coastal shellfish, and the combination of interannual variables that result in toxic blooms reaching shore.

NEMEDA: Network to Mitigate the Effects of *Dinophysis* spp. in Aquaculture
PIs: R. Raine (MRI), T. Moita (IPIMAR), B. Reguera (IEO), Y. Pazos (INTECMAR), F.G. Figueiras (IIM-CSIC).
One of the objectives of this project is to identify preferred areas for the initiation of *Dinophysis acuta* blooms and their possible along-shore transport along the Iberian coast. Maximum abundances of *Dinophysis acuta* are compiled from data sets derived from coastal monitoring stations and cruises along the NW coast of Iberia.

NICC: Northwest Iberian Coastal Current
PIs: L. Bastos (CIMAR-Porto), T. Moita (IPIMAR), J. Silva, J. Vitorino (IH)
The project aims to provide a base study of the Northwest Iberian Coastal Current system to improve understanding of the autumn- to spring-related dynamic processes over the NW Iberian shelf. The purpose is to develop an integrated methodology based on the collection of different kinds of data, both historical and present, that may serve as a basis for developing, testing and validating circulation models. The project will also provide information on possible pathways for the transport of HABs to the Galician area in the NW Iberian Peninsula.

DYNCOSTAL: Physical and Biogeochemical Dynamics of Coastal Countercurrents: A Study Case in Algarve Luff
Principal Investigators: M.P. Abreu (U. Lusofona), T. Moita (IPIMAR), P. Relvas (U.Algarve), H. Coello (MARETEC)
The main objective of DYNCOSTAL is to conduct physical and biogeochemical characterisation of the coastal counter-current off Algarve luff and to implement a 3-D ocean model to study the Portuguese coastal counter-current. It will provide information on the structure of planktonic assemblages and on the alongshore transport of HABs.

BENGUELA: Alongshore advection of HABs
PIs: S. Bernard (U. Cape Town), A. Fawcett (U. Cape Town), G. Pitcher (MNCM)
This project is an extension of the St. Helena Bay programme and aims to study the poleward transport of HABs from the southern Namaqua shelf by a combination of drifter deployments and satellite observations, supported by near-shore monitoring of phytoplankton assemblages.

Project Output

- To determine the relative importance of alongshore and across-shelf and poleward *vs.* equatorward processes in the accumulation, transport and dispersion of HABs and/or toxicity in the four eastern boundary upwelling regions.

- To model and forecast the appearance of HABs (toxicity) in coastal environments.

References

Fraga, S., D. M. Anderson, I. Bravo, B. Reguera, K.A. Steidinguer and C.M. Yentsch (1998) Influence of upwelling relaxation on dinoflagellates and shellfish toxicity in Ría de Vigo, Spain. *Est. Coast. Shelf Sci.* **27**: 349-361.

Pitcher G.C., A.J. Boyd, D.A. Horstman and B.A. Mitchell-Innes (1998) Subsurface dinoflagellate populations, frontal blooms and the formation of red tide in the southern Benguela upwelling system. *Mar. Ecol. Prog. Ser*. **172**: 243-264.

Trainer V.L., B.M. Hickey and R.A. Horner (2002) Biological and physical dynamics of domoic acid production off the Washington coast. *Limol. Oceanogr*. **47**(5): 1438-1446.

Implementation Activities

Following elaboration of specific research projects to implement the key research questions of the Upwelling CRP, the Subcommittee determined the next steps (and their timing) to advance this CRP.

Each project will have an international coordinator, whose responsibility will be to work with people in each region included in the project, to gather their comments on the draft document, revise their section of it, and transmit the revised section to Grant Pitcher, who will coordinate overall changes to the document. The coordinators will be:

Seeding Strategies (Key Question B): Ana Amorim
Nutrients (Key Question D): Trevor Probyn
Genetics (Key Question E): Raphe Kudela
Morphology and Bathymetry (Key Question F): Grant Pitcher
Cross-shelf and Along-shore Transport (Key Question G): Francisco Figueiras
Climate effects (Key Question G): Vera Trainer

The timetable for action on the plan from the meeting will be as follows:

Jan. 30 – Any additional sections/comments/revisions due from Subcommittee to Grant Pitcher

- Grant Pitcher will format and send the revised report to Subcommittee
- Subcommittee will send the draft report to the other people listed as potential participants

Feb. 24 – Comments due from all participants to project coordinator
March 3 – Comments due from project coordinator to Grant Pitcher
March 10 – Report revised by Grant Pitcher and placed on CRP Web page for community comment.

Other Actions:

- Vera Trainer will draft a short article about the meeting and update on Upwelling CRP for *Harmful Algal News*. The purpose of this article will be to point readers to the information on the CRP Web page and to stimulate more people to get involved in the projects in this CRP.
- Henrik Enevoldsen to modify GEOHAB IOC Web site to create a specific page for the Upwelling CRP. This page should be accessible from the “Core Research” button (make a separate link there for each CRP) on the front GEOHAB page. The CRP page should include
  - Link to Upwelling OSM Web page
  - Link to download report from Upwelling Meeting
  - Link to download report from this meeting
  - Summaries of each of the six proposed projects
  - Form for expressions of interest for individuals to participate in the six projects
  - CRP data policy

- List of participants who have agreed to participate, with links to their email addresses
    - Lists of example projects and links to them
    - Links to key publications for each project

  This CRP page may contain further links to a page for each of the six projects. The Web page should be modified in time for the meeting report to be posted on it (i.e., by March 10) and the HAN article should be published as soon as possible after that.

- Encourage each project group to write a synthesis paper on their topic to serve as a foundation for future cooperative research and stimulate international cooperation on their topic. Ideally, these papers should be written in the next 12 months.
- Arrange a special session for the HAB XII meeting in Copenhagen and a "town meeting" for one evening there to discuss the CRP progress and stimulate wider involvement. Subcommittee members attending the meeting may also arrange a meeting of up to one day in length to discuss progress since January.
- Arrange next meeting of Subcommittee in 12-18 months, subject to funding availability and progress on the group's action items.

Issues for Overall CRP

Finally, the Subcommittee discussed the sections of GEOHAB (2005) related to Framework Activities (pp. 57-60) and Next Steps (pp. 61-64):

Scientific Networking and Coordination of Resources—These activities will be carried out as the six projects are implemented and do not require specific action from the Upwelling CRP Subcommittee, apart from periodic evaluation of progress.

Data Management and Data Sharing—The Subcommittee affirmed the statements on data sharing given in GEOHAB (2005), with a slight expansion on the rights of data originators. The revised statement, which will be posted on the CRP Web page, is as follows:

> The collective value of data is greater than its dispersed value and comparative research requires effective data sharing among scientists working in different regions; therefore, data management and exchange are important components of GEOHAB CRPs. The development of an appropriate GEOHAB data management plan is a fundamental and critical activity upon which the ultimate success of GEOHAB will depend, and GEOHAB is working with other international marine research projects to develop basic guidelines for data management and sharing (see www.jhu.edu/DataMgmtActivity.htm). Each CRP will need to develop its own specific plans, conforming to the principles adopted by GEOHAB.

GEOHAB will use a decentralised data management and distribution system with a centralised index. The components, centralised under the supervision of the GEOHAB International Programme Office (IPO), will include a comprehensive inventory of databases relevant to GEOHAB, as well as meta-data, with links to their locations and contact persons. Each CRP will create an inventory of data and data products. The GEOHAB Data Manager will assist the CRP by tracking planned, ongoing, and completed research, and by providing links to research information. All investigators should be prepared to share their data and data products with other investigators in their research projects as soon as possible, and with the general scientific community 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. The receiving investigator should not publish any paper based on the received data during the publication rights period, should co-author results with the originating investigator, and should not redistribute the data. Each GEOHAB project should address the long-term archival of observational data and data products to ensure a lasting contribution to marine science. Specifically, data from the CPR- HABs in upwelling systems will be contributed to the World Data Centre for Marine Environmental Data (WDC-MARE) at the end of the project, with the assistance of the GEOHAB IPO data manager.

Protocol and Quality Control—Individual projects will be responsible to ensure that their cooperative research is conducted with comparable methods and quality-control procedures that are sufficient to make it possible to compare data among regions.

Capacity Building—Projects will be responsible to encourage cooperative research between scientists from developed countries and scientists from developing countries. This will be particularly important for this CRP, because two of the four upwelling regions included border developing countries.

Co-ordination of Modelling Activities—Each project will involve modellers in each region and will encourage international cooperation among modellers within the project, as appropriate.

Interaction With Other International Programmes and Projects—GEOHAB (2005) gives examples of interactions that the Upwelling CRP could pursue with other international programmes and projects and the projects will be encouraged to pursue these interactions and others, as appropriate. The most obvious interactions are the Seeding Strategies and Climate projects with IMAGES and other projects that have and are collecting sediment cores in upwelling regions; the Climate project with CLIVAR; the Nutrient project with LOICZ; the GLOBEC project in relation to modelling; and the GOOS Programme and other observation programs where long-term observations are needed.

The Next Steps described in GEOHAB (2005) were incorporated in the research projects in some cases and each project will be encouraged to review this section of GEOHAB (2005) to identify other actions listed there that should be pursued.

References

GEOHAB. 2005. *Research Plan on HABs in Upwelling Systems*. IOC and SCOR, Paris.