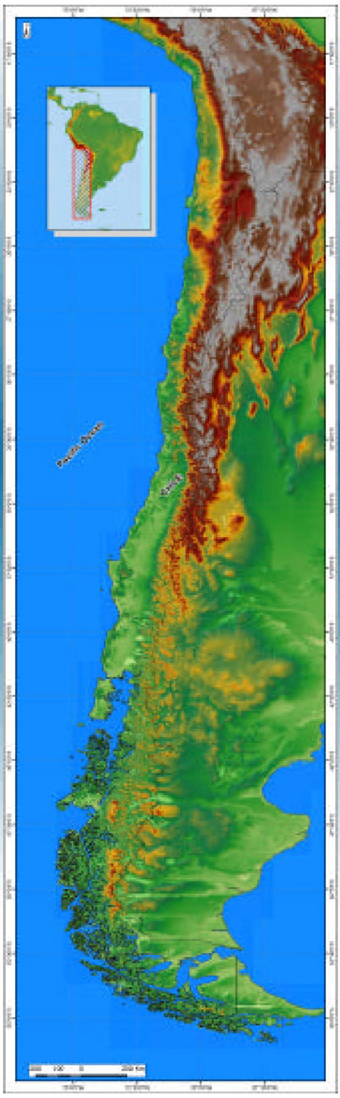
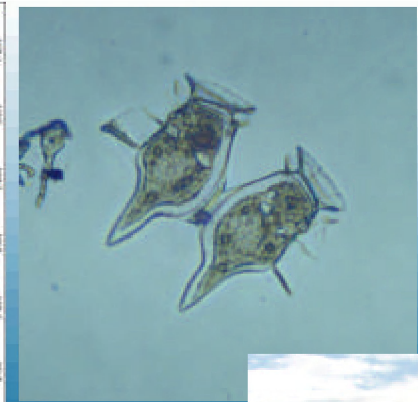
GEOHAB

Global Ecology and Oceanography of Harmful Algal Blooms





GEOHAB CORE RESEARCH PROJECT:
HABs IN FJORDS AND COASTAL EMBAYMENTS

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GLOBAL ECOLOGY AND OCEANOGRAPHY OF HARMFUL ALGAL BLOOMS

GEOHAB CORE RESEARCH PROJECT: HABs IN FJORDS AND COASTAL EMBAYMENTS

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

Edited by: A. Cembella, L. Guzmán, S. Roy and J. Diogène

The report was developed following workshop discussions with the Ocean Science Meeting International Organizing Committee and attending members of the GEOHAB Scientific Steering Committee, including Allan Cembella (Germany), Einar Dahl (Norway), Patricia Glibert (USA), Leonardo Guzmán (Chile), Bengt Karlson (Sweden), Grant Pitcher (South Africa), Robin Raine (Ireland), and Suzanne Roy (Canada). We further appreciate the contributions to this document provided by those presenting plenary lectures on the key topics.

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This report is also available on the Web at:

www.geohab.info

Cover photos: Left, remote-sensing view of the coast of Chile (courtesy of Leonardo Guzmán, unpublished); top right, micrography of paired cells of *Dinophysis caudata* (courtesy of Suzanne Roy, unpublished); middle right, picture of the Saguenay fjord in Canada (courtesy of Urs Neumeier, unpublished), and bottom right, remote-sensing image of the Ebre delta, NW Mediterranean, courtesy of the Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Centre, url: eol.jsc.nasa.gov and reproduced from Cembella *et al.*, 2005, Oceanography, vol. 18, No. 2, page 159, url: www.tos.org/oceanography/issues/issue_archive/ 18_2.html.

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Global Ecology and Oceanography of Harmful Algal Blooms
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Executive Summary

The Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) programme was initiated in 1999 by the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO to develop a research programme on the ecological and oceanographic mechanisms underlying the population dynamics of harmful algal blooms (HABs). The end goal of this programme is to allow the development of observation systems and models that will enable prediction of HABs, thereby reducing their impacts on the health of humans and marine organisms, as well as their economic and social impacts on societies.

The GEOHAB *Implementation Plan* (GEOHAB, 2003) specifies the formation of Core Research Projects (CRPs) related to four ecosystem types—upwelling systems, fjords and coastal embayments, eutrophied systems, and stratified systems.

This report summarizes the Open Science Meeting (OSM) held in April 2004 and provides the proceedings, progress and synthesis of research efforts on the study of HABs in fjords and other coastal embayments. At this OSM, participants had the opportunity to present and discuss research findings in a variety of coastal embayments and to begin the development of a research agenda for coordinated studies. The meeting served to identify interested participants and research regions and to bring together the international community to design core research. Meeting participants discussed a wide variety of research topics related to HABs in these coastal systems, which the Core Research Committee distilled into seven key questions:

- Are there definable adaptive strategies that characterize HAB species in confined and semi-confined systems?
- What is the importance of life history transitions and cyst distribution in bloom initiation and maintenance — endogenous seed beds *versus* exogenous introduction?
- How do physical dispersion and aggregation processes within a semi-confined basin affect HAB growth and distribution?
- What is the relative contribution of nutrient flux and supply ratios to HAB dynamics in eutrophic *versus* non-eutrophic coastal embayments?
- What is the importance of spatial scale and retention time in the expression and effects of allelochemicals/toxins in semi-confined systems?
- How do embayment morphology, bathymetry and hydrodynamic flux affect HAB dynamics?
- Are the effects of anthropogenic activities (e.g. aquaculture) and global climate change on HAB dynamics magnified in enclosed and semi-enclosed embayments?

Our understanding of and ability to predict HABs in coastal embayments over the next 5-10 years will reflect the extent to which this GEOHAB CRP can answer these questions. The practical implementation of Core Research activities in coastal embayments has advanced since field work was initiated in 2005.

The OSM programme, including the list of participants and abstracts, can be found at: www.geohab.info (Research Activities, Core Research Projects, Fjords and Coastal Embayments).

List of Acronyms

ASP	amnesic shellfish poisoning
CAISN	Canadian Aquatic Invasive Species Network
CONA	Comité Oceanográfico Nacional de Chile
CRP	Core Research Project
DIVAST	Depth Integrated Velocities and Solute Transport
DSP	diarrhetic shellfish poisoning
DST	diarrhetic shellfish toxins
DTX1	dinophysistoxin-1
ENSO	El Niño-Southern Oscillation
GEOHAB	Global Ecology and Oceanography of Harmful Algal Blooms programme
GLOBEC	Global Ocean Ecosystem Dynamics project
GTX	gonyautoxin
HAB	harmful algal bloom
HAEDAT	Harmful Algae Event Database
ICES	International Council for the Exploration of the Seas
ICSU	International Council for Science
IMAGES	International Marine Aspects of Global Change project
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research project
IMR	Institute of Marine Research (Norway)
ISSHA	International Society for the Study of Harmful Algae
IOC	Intergovernmental Oceanographic Commission (UNESCO)
NAO	North Atlantic Oscillation
OA	okadaic acid
PICES	North Pacific Marine Sciences Organization
PSP	paralytic shellfish poisoning
SCOR	Scientific Committee on Oceanic Research (ICSU)
SHOA	Servicio Hidrográfico y Oceanográfico de la Armada
SPM	suspended particulate material
SSC	scientific steering committee
STX	saxitoxin
WoRMS	World Register of Marine Species

I. Introduction

The GEOHAB *Science Plan* (2001) and *Implementation Plan* (2003) provide the background and justification for the GEOHAB programme. The purpose of this document is to follow-on from the *Implementation Plan* to describe in greater detail the research that will be conducted for the GEOHAB Core Research Project (CRP) – **HABs in Fjords and Coastal Embayments**. It will serve as a foundation for continued planning and will be augmented as research is planned and funded, results are obtained, and new questions are formulated. This report is based on a planning meeting held with international experts on HABs in these environments.

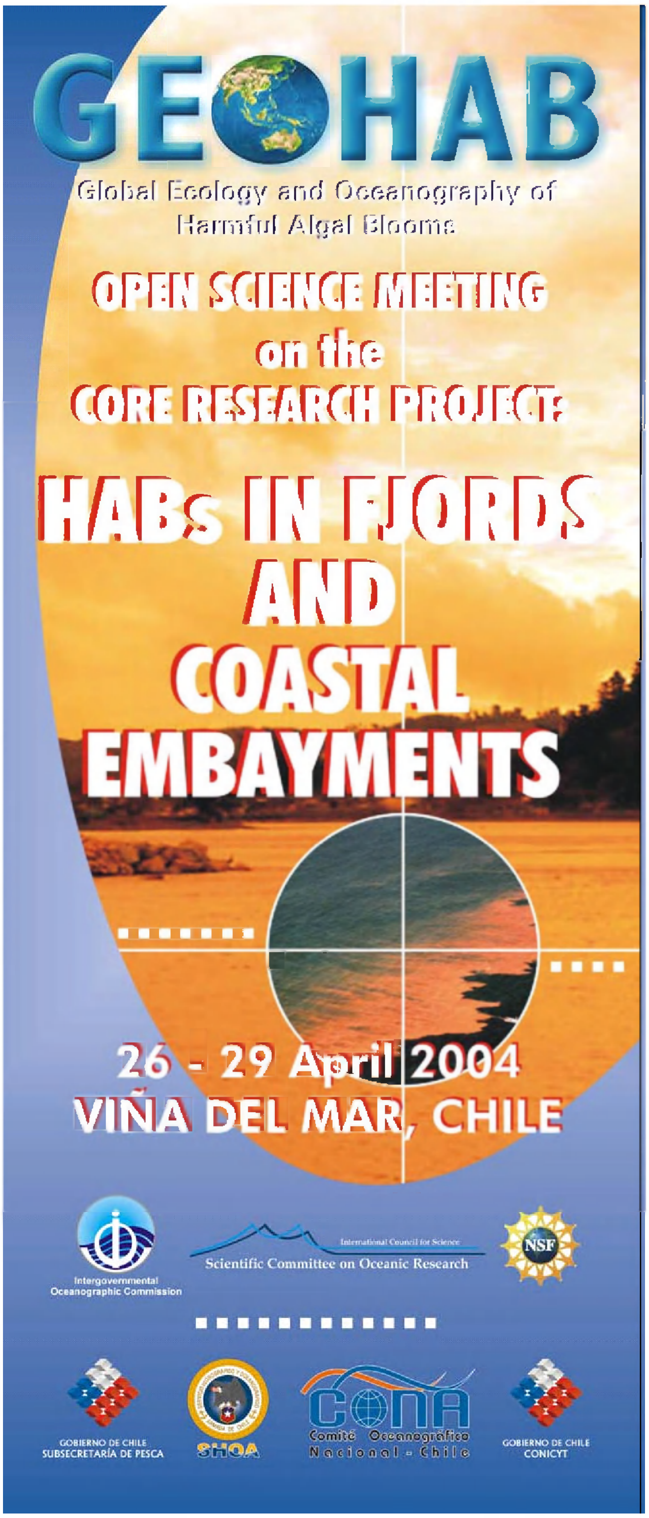


Fig. 1. OSM meeting poster

The GEOHAB SSC convened an Open Science Meeting on Harmful Algal Blooms in Fjords and Coastal Embayments in Viña del Mar, Chile (April 26-29, 2004) under the co-direction of Allan Cembella (Alfred Wegener Institute, Germany) and Leonardo Guzmán (Instituto de Fomento Pesquero, Chile) (Fig. 1). The objectives of this meeting were fourfold: 1) to introduce the GEOHAB approach to Core Research to the international community; 2) to foster the development of national and international links to GEOHAB, specifically to Core Research; 3) to review and assess existing knowledge and future prospects for research on HABs in coastal embayments, and 4) to initiate the development of an action plan for implementation of the Core Research Project. An international panel of experts participated as the Core Research Project Co-ordinating Committee to plan the research agenda, in conjunction with several members of the GEOHAB SSC.

The invitation to the OSM was issued to all prospective participants in the emerging international Core Research Project; however, strong participation from Latin America was particularly noteworthy. More than 60 participants attended at least part of the meeting, which featured 11 key lectures, 28 posters presented by participants and an extensive and lively discussion and question periods following each theme. To stimulate maximal scientific interaction, all posters were presented orally.

The programme was opened with short welcome addresses from Chilean dignitaries, including representatives of the Comité Oceanográfico Nacional of Chile, the SCOR Executive Director and the IOC HAB Programme Executive Secretary. After the conclusion of the plenary key lectures, theme break-out workshop groups were formed to discuss comparative approaches and integration of physical *versus* biological and chemical factors, and the incorporation of hydrodynamic and ecosystem models into this research framework. A series of recommendations and considerations emerged from these theme workshop groups, such as key importance of physical constraints in determining hydrodynamics and species outcomes in coastal embayments and the significance of benthic-pelagic coupling. The critical importance of water residence time was also noted. On the day following the closure of the plenary meeting, the co-convenors met with the GEOHAB Chairman, the international Core Project Coordinating committee, and representatives of the GEOHAB SSC to plan the research agenda and to prepare this report. Specific issues addressed included: 1) identification of key processes and mechanisms that must be studied in such ecosystems to define HAB dynamics; 2) determination of the key questions and working hypotheses; 3) consideration of opportunities, differences and commonalities to be addressed in studies of coastal embayments; 4) discussion of potential key field study sites where research could be implemented; and 5) possibilities and constraints for national and international funding support for research initiatives.

Summaries of the poster presentations of the OSM are provided on the GEOHAB Web site under the sub-link to the CRP on Fjords and Coastal Embayments (see www.geohab.info – Documents).

The GEOHAB Scientific Steering Committee (SSC) is grateful for the generous financial and logistical support for this meeting from the Intergovernmental Oceanographic Commission (IOC); Scientific Committee on Oceanic Research (SCOR); U.S. National Science Foundation (Division of Ocean Sciences); Comité Oceanográfico Nacional (CONA); and Gobierno de Chile, through Subsecretaría de Pesca (SUBPESCA) del Ministerio de Economía, Fomento y Reconstrucción, and Servicio Hidrográfico y Oceanográfico de la Armada de Chile (SHOA) and Comisión Nacional de Investigación Científica y Tecnológica (CONICYT). The programme officers, Edward Urban (SCOR, Executive Director) and Henrik Enevoldsen (IOC HAB Programme Coordinator), as well as the local Chilean organizing committee, provided much-appreciated contributions.

SUBSECRETARÍA DE PESCA

II. The GEOHAB Approach to the Study of Harmful Algae in Fjords and Coastal Embayments

GEOHAB Core Research Projects address the goals of the GEOHAB *Science Plan*, and are conducted as specified in the *Implementation Plan*. The CRP on **HABs in Fjords and Coastal Embayments** will identify key HAB species in these systems and determine the ecological and oceanographic processes that influence their population dynamics. The physical, chemical and biological processes that define or characterise these systems will be identified and the response of HAB species to these processes will be quantified. The prediction of HABs can be improved by integrating biological, chemical and physical studies supported by enhanced observation and modelling. Models for HABs must be developed to support fundamental research and to provide prototypes of early warning and predictive capabilities. The use of observation technologies can provide a useful comparison of predictions with observations.

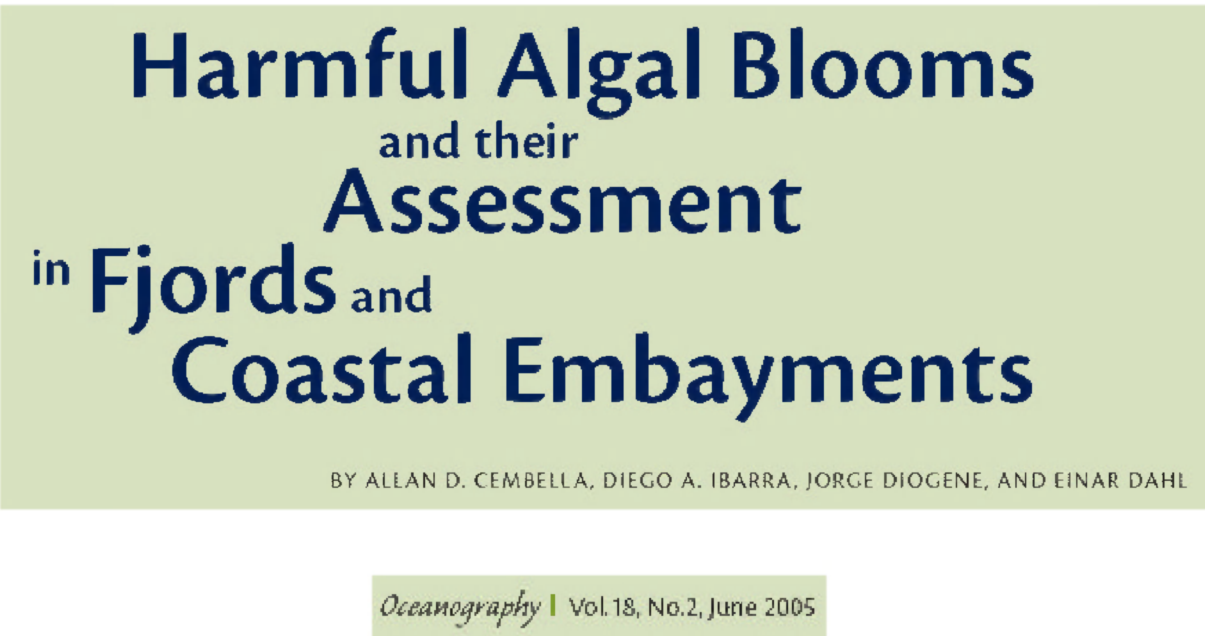
In accordance with the GEOHAB strategy, the approach of the CRP is *comparative* from the cellular to the ecosystem level. Research that is *interdisciplinary*, focusing on the important interactions among biological, chemical, and physical processes will be fostered. Research will also be *multifaceted* as the problems relating to HABs in fjords and coastal embayments are complex and interactions and processes occur over a broad range of scales. Finally, research will be *international* in scope to encompass the global issues of HAB events and benefit from the skill and experience gained by HAB investigators world-wide.

The GEOHAB CRPs are built on the premise that understanding the ecology and oceanography of HABs will benefit from a *comparative approach*, whereby the characteristics of various ecosystems are described, defined and classified with respect to their similarities and differences. In most cases, rigorous experimental controls are not feasible in such ecosystem studies, even in small-scale systems. As an alternative, where such controls are not available, the comparative approach is the method of choice, and represents a potentially powerful alternative for drawing scientific inference regarding HABs. Although fjords and coastal embayments comprise a wide spectrum of apparently heterogeneous ecosystems, the comparative approach offers the basis for scientific inference via recognition of informative patterns of naturally occurring temporal and spatial variations. Comparisons with respect to HABs will first incorporate the grouping of species found primarily or exclusively in coastal embayments, as a preliminary attempt to define functional groups based upon habitat characteristics. Attempts will be made to define the fjords and coastal embayments subject to HABs according to their hydrographic regimes, bathymetry and nutrient status as a prerequisite for the development of a classification scheme, similar to that available for estuaries in eastern North America. Comparison of the extent to which HAB species respond in a similar way within these various systems will allow for the establishment of criteria to estimate probabilities for their occurrence and abundance, and for determining the oceanographic processes that influence their population dynamics and community interactions. Equally important is the identification of coastal systems which may appear to be similar but nevertheless contain dissimilar HAB species or groupings. Finally, comparative studies on the response of harmful algae to perturbations within small-scale semi-enclosed coastal systems will assist in identification of robustness and stability of HABs and in evaluating the importance of divergences from predicted responses.

III. An Overview of HABs in Designated Fjords and Coastal Embayments

A. General Description of the Fjords and Coastal Embayments Systems

Fjords and coastal embayments are highly diverse in terms of size, depth, isolation from the open coast and hydrodynamic regime, among other characteristics. Such ecosystems do, however, share common features that distinguish them from open coastal systems or offshore upwelling zones. Their relative degree of enclosure may, for example, favour the development and retention of blooms. Study of the similarities and differences of HAB-impacted fjords and coastal embayments should help identify the major processes influencing population dynamics of HABs. Four factors stand out as characteristic of these semi-enclosed environments: the importance of 1) residence time, 2) exchange with outside waters, 3) amount of freshwater from river run-off, melting glaciers and rainfall, and 4) increased pelagic-benthic coupling in relatively shallow areas. A more detailed description of fjords and coastal embayments, of harmful algal blooms occurring within these systems, and of methods for detection and surveillance of these blooms was published by Cembella *et al.* (2005) in volume 18(2) of *Oceanography*, a journal of The Oceanography Society (Fig. 2). Readers are strongly encouraged to consult this text (www.tos.org/oceanography/issues/issue_archive/vol_18.html).


Harmful Algal Blooms and their Assessment in Fjords and Coastal Embayments

BY ALLAN D. CEMBELLA, DIEGO A. IBARRA, JORGE DIOGENE, AND EINAR DAHL

Oceanography | Vol. 18, No. 2, June 2005

Fig. 2. Title of publication by Cembella et al. in Oceanography 18(2)158-171 Used with permission from The Oceanography Society.

B. Representative Systems for Comparison

1. The Chilean Fjordal Systems (SE Pacific)

The fjords and channel systems in Chile encompass a vast area from 43 to 55 °S including the Los Lagos, Aysén and Magellan regions (Fig. 3). Geomorphologically, this region reflects the relatively recent glaciations that occurred from 40000 to 10000 years BP. At present, numerous glaciers continue to flow into the sea,

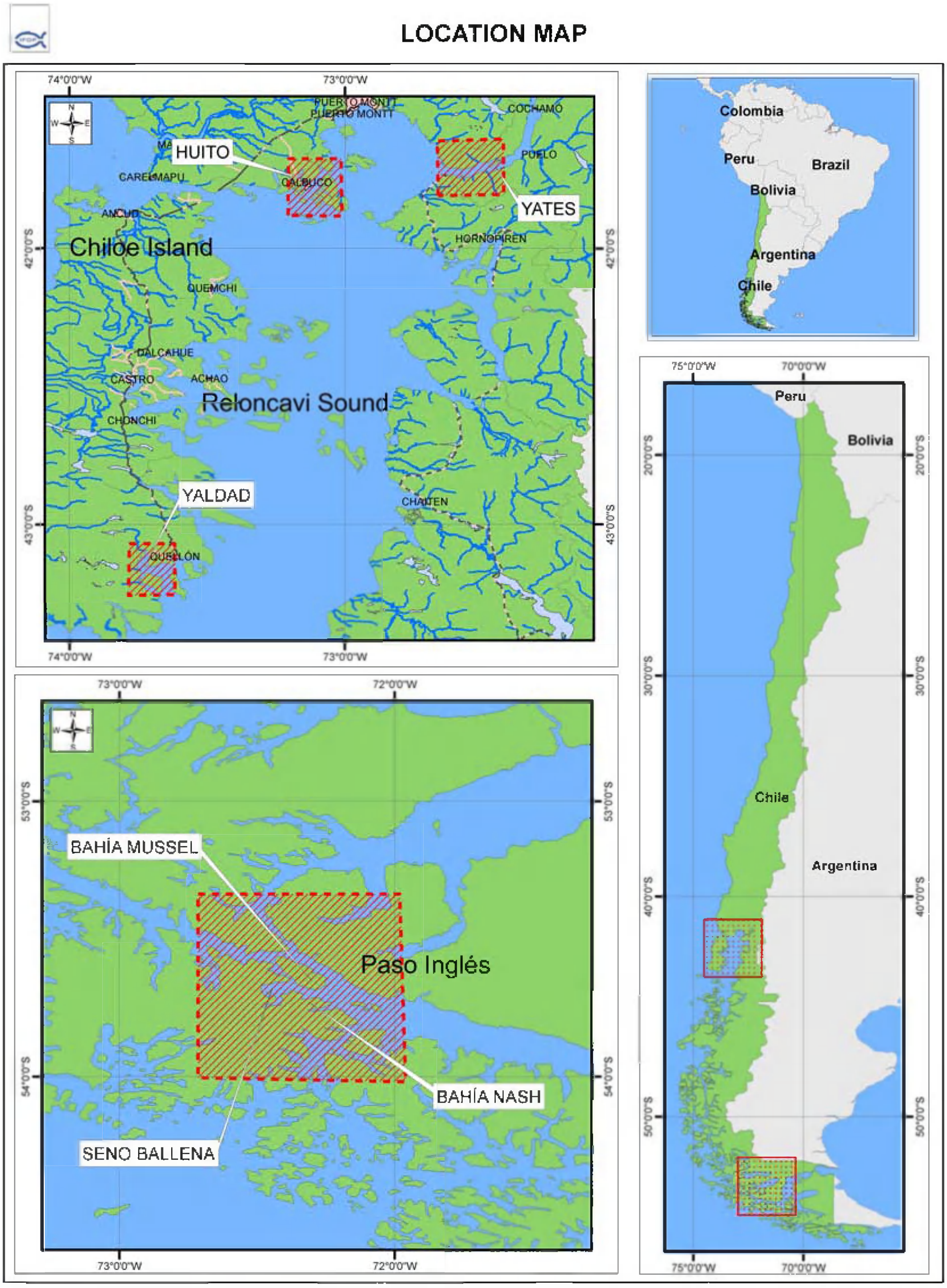


Fig. 3. Map of Chile, including areas of interest in Los Lagos (top left) and Magellan regions (bottom left), along the fjordal system. The Aysén region extends between the Los Lagos and Magellan regions. The Francisco Coloane marine park is located off Paso Inglés. The maps were produced using ARC Editor 9.3, Environmental Systema Research Institute (ESRI).

particularly in the southernmost area of Chile. In general, human impacts on the fjordal systems are greatest in the northern area, where human populations are the largest. These fjordal ecosystems are subject to a wide spectrum of climate regimes and oceanographic features, and thus a diversity of HAB events and different species are observed along this latitudinal gradient. The coastal marine ecosystems support a varied wild fin-fishery and shellfish industry, in addition to providing a propitious environment for aquaculture, with higher productivity and more intense cultivation in the northern area.

In the northern extreme of the fjordal system (Los Lagos region, see Fig. 3, top left), Bahía Yates, Bahía Calbuco and Estero Yaldad are among several strategically significant embayments that may be affected by HABs. They are located near Puerto Montt and Reloncaví Sound, in a sector of Chiloé Island inner sea. This area is influenced by numerous small population centres active in wild harvest fishing and aquaculture (salmon and mussel culture). Seno Ballena, Bahía Mussel and Bahía Nash are in the austral zone of this system (53ºS), near the Pacific Ocean (Fig. 3, bottom left). The austral sites are located in the protected marine area adjacent to the recently created (2003) Francisco Coloane Marine Park. This ecologically diverse and productive sector is almost unpopulated and it is characterized by extractive fishing and a few salmon culture centres, as well as the migratory route of humpback whales (Gobierno de Chile, 2006).

Marine phycotoxins and HABs have been found in the northern and southern areas, although paralytic shellfish poisoning (PSP) is more frequent and higher toxicity values are detected in southern localities, at sites located in the Aysén and Magellan regions (Figs. 4 to 6), particularly since the 1990s. In the northern fjordal region near Chiloé Island, in addition to the sporadic detection of PSP toxins, those associated with diarrhetic shellfish poisoning (DSP) and amnesic shellfish poisoning (ASP) have also been detected, with the diarrhetic toxins being more frequently present (Guzmán *et al.*, 2002; Suárez-Isla *et al.*, 2002). In some areas, such as Chiloé Island, PSP and DSP toxins can be detected simultaneously in mussel samples (García *et al.*, 2004). There is evidence that domoic acid (ASP toxin) is present at trace levels all along the fjordal system, particularly during autumn (L. Guzmán *et al.*, unpublished data). Pectenotoxins and yessotoxins have also been detected (L. Guzmán *et al.*, unpublished data).

Bathymetric and hydrological features vary among the embayments of the Chiloé region. While the 40 m deep Bahía Yates is strongly stratified over the first 20 m, the other two bays present a homogeneous surface layer

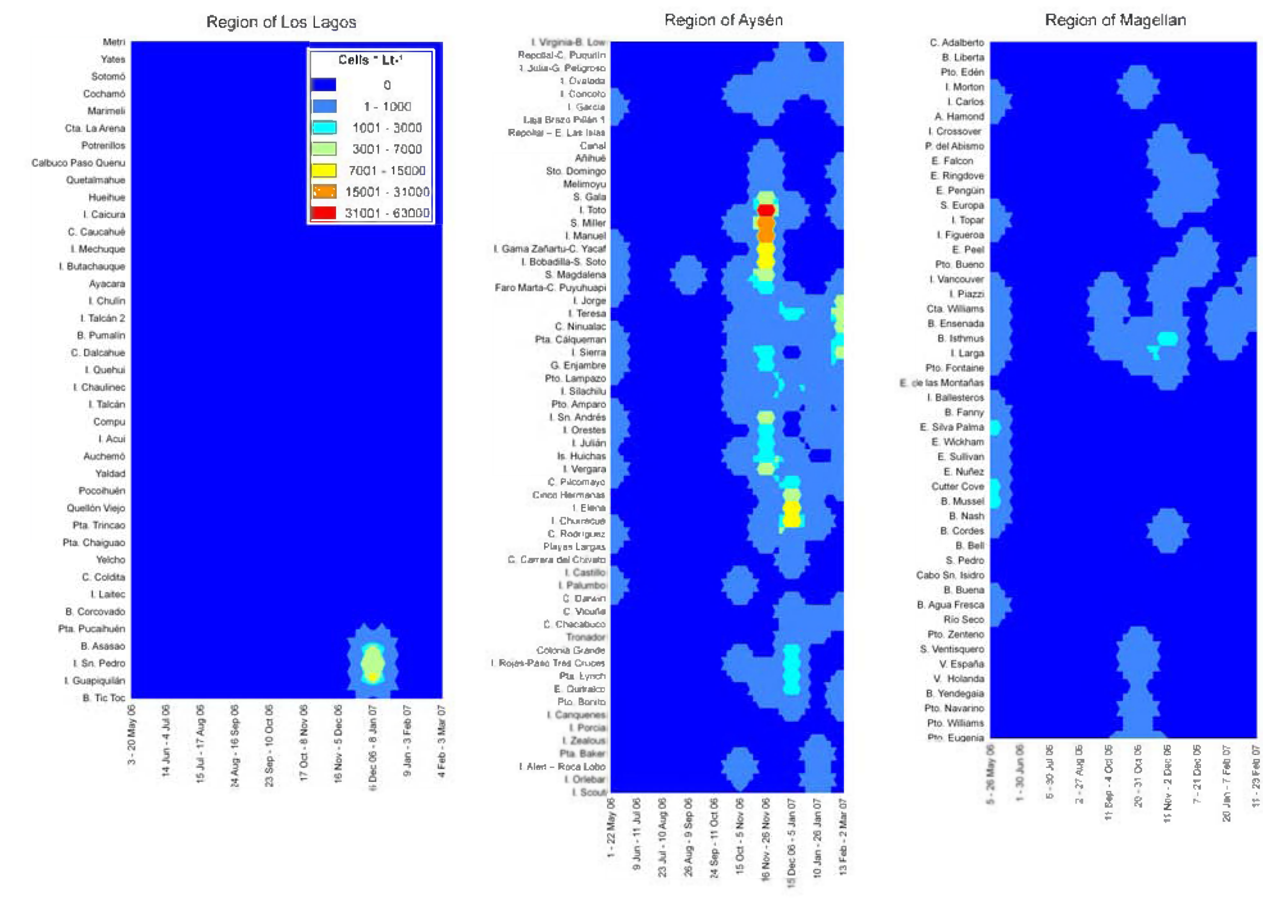


Fig. 4. Concentration maps of Alexandrium catenella *(from surface to 10 m) for the period between May 2006 and February 2007 for various localities in the regions of Los Lagos, Aysén and Magellan (L. Guzmán* et al.*, unpublished data).*

over the top 10 (Bahía Calbuco) or 20 m (Estero Yaldad). Surface summer temperatures are around 15 to 18°C in all three bays, but surface salinity is much lower (between 2.5-6.5 psu) in Bahía Yates due to strong river discharge. Phytoplankton productivity is very high in Bahía Yates (Lunven *et al.*, 2004). Phytoplankton is typically dominated by diatoms in all these bays, but naked dinoflagellate blooms have been observed at Estero Yaldad during autumn, a period during which phytoplankton populations are numerically dominated by this group (Vidal *et al.*, 2006).

DSP toxins have been sporadically detected in the above-mentioned localities of the northern area. The species considered responsible for these events is *Dinophysis acuta*, but *D. acuminata* could also be a primary source of these toxins. PSP toxicity has been recently detected in this region, and has been found more frequently since the beginning of 2002 along the east coast of Chiloé Island, from Canal Dalcahue to the south. Estero Yaldad has been affected by PSP toxins, but not Bahía Calbuco. The primary source organism is *Alexandrium catenella*. Since the 2002 PSP toxin outbreak, detected concentrations have been low, below the mouse bioassay regulatory level, and always occurred during spring and summer. Blooms of *A. catenella* have been observed in spring and summer or during autumn. In December 2006 and January 2007 a short bloom of *A. catenella* (up to 10200 cells l^{-1}, Guzmán *et al.*, 2007) occurred over four weeks, associated with a PSP toxin outbreak (reaching 619 µg STX eq. 100 g^{-1} shellfish meat) and affecting the southernmost area of Chiloé Island. Recently a bloom occurred in the same region between mid-March and mid-April 2009, reaching densities of 800 cells l^{-1} and 1422 µg STX eq. 100 g^{-1} (L. Guzmán *et al.*,unpublished data). Domoic acid, the toxin associated with ASP, has been detected occasionally at trace concentrations at the end of summer and in autumn. The primary source of this toxin is assumed to be *Pseudo-nitzschia* cf. *australis* (Vidal *et al.*, 2006). Other harmful or potentially toxic species also present include *Alexandrium ostenfeldii*, *Protoceratium reticulatum*, and *Pseudo-nitzschia* cf. *pseudodelicatissima*, the first two mostly in Aysén and the Magellan regions (Guzmán *et al.*, 2007).

The localities in the Magellan region present different bathymetric and hydrological conditions in comparison to sites located around Chiloé Island. Bahía Mussel, located on Isla Carlos III, is a bay of approximately 3 km in length by 2 m in width, with a maximum depth of 90 m, which is directly influenced by the water of Paso Inglés. This bay is highly productive, as evidenced by frequent observations of humpback whales feeding in the area. The water column is very homogeneous in terms of both temperature (near 7-8ºC) and salinity (30-31 psu)

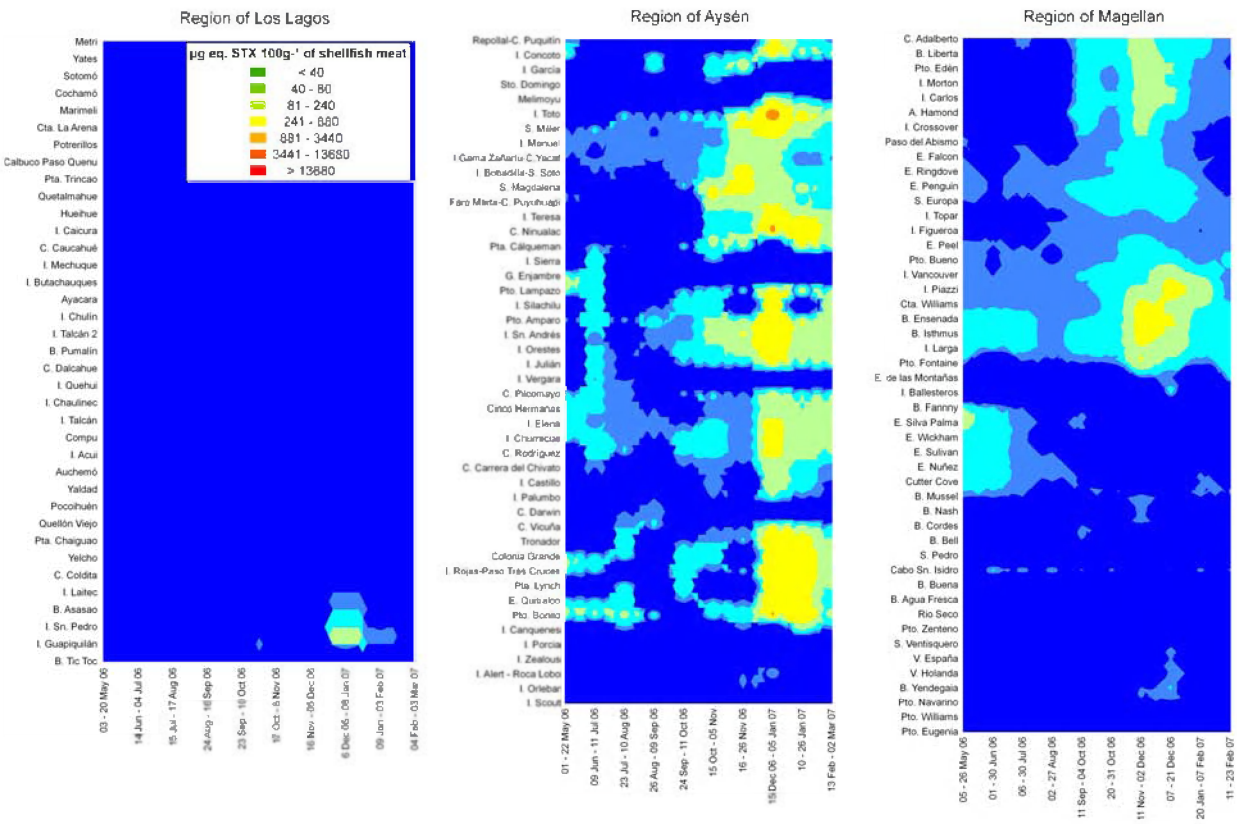


Fig. 5. Maps of PSP levels along the regions of Los Lagos, Aysén and Magellan, for the period between May 2006 and February 2007 (L. Guzmán et al.*, unpublished data). Values are monthly averages for mussels collected from 5 to 10 m.*

between the surface and 30 m depth. Phytoplankton is numerically dominated year-round by diatoms, although the presence of *Alexandrium catenella* stands out, typically between October and December at concentrations less than 3000 cells l^{-1} (Fig. 4). Since 2002, PSP toxicity values have been as high as 3200 µg STX eq. 100 g^{-1} shellfish tissue, but values are normally less than 300. Spring, summer and autumn are the seasons with highest probabilities for PSP toxin outbreaks. Corresponding relative abundance of *A. catenella* cells is rather low — not higher than level 3 (on a scale of 8), in spite of the fact that high PSP toxin values have been detected (Figs. 5 and 6). The presence and abundance of *A. catenella* are apparently not a good proxy for the toxin levels in mussels (Guzmán *et al.*, 2005).

Bahía Nash shows winter and summer temperatures and salinities very similar to those found in Bahía Mussel, and very homogeneous over the approximately 50 m deep water column. Phytoplankton is numerically dominated by diatoms. PSP toxicity has also been detected in this bay, but toxicities are not as high as in Bahía Mussel. Since 2002, PSP toxicity has never exceeded 600 µg STX eq. 100 g^{-1} in shellfish and frequently values are lower than 100. This is associated with a rather low relative abundance of *A. catenella* cells, not higher than level 2 (Guzmán *et al.*, 2005).

Seno Ballena is approximately 15 km long and typically less than 1 km wide (no bathymetry available), and it is characterized by a glacier at the head of the fjord and a tall sill, at less than 3 m water depth, located approximately 7 km from the glacier. The sill divides the sound in two regions. Between the glacier face and the sill, depths are typically less than 100 m, temperatures are lower in the top 5 m (6-7°C) and salinities are also rather low (22-29 psu). From the sill to the sea, depths increase to more than 200 m, and temperatures and salinities are higher (7.5°C and 30-31 psu). Tides are mixed, with semi-diurnal predominance and typically range about 2 m. Hydrographic information is available from Valle-Levinson *et al.* (2006). The area is characterized by a tidal pumping mechanism transporting saltier water over the sill and freshwater renewal landward of the sill. Tidal intrusion fronts and plume-like fronts are evident to the sill. Water with oceanic salinity can be advected to the near-surface from depths of approximately 30 m as flood flows accelerate from approximately 10 cm s^{-1}, seaward of the sill, to approximately 60 cm s^{-1} at the sill crest. The plunging of salty water over the sill creates dramatic

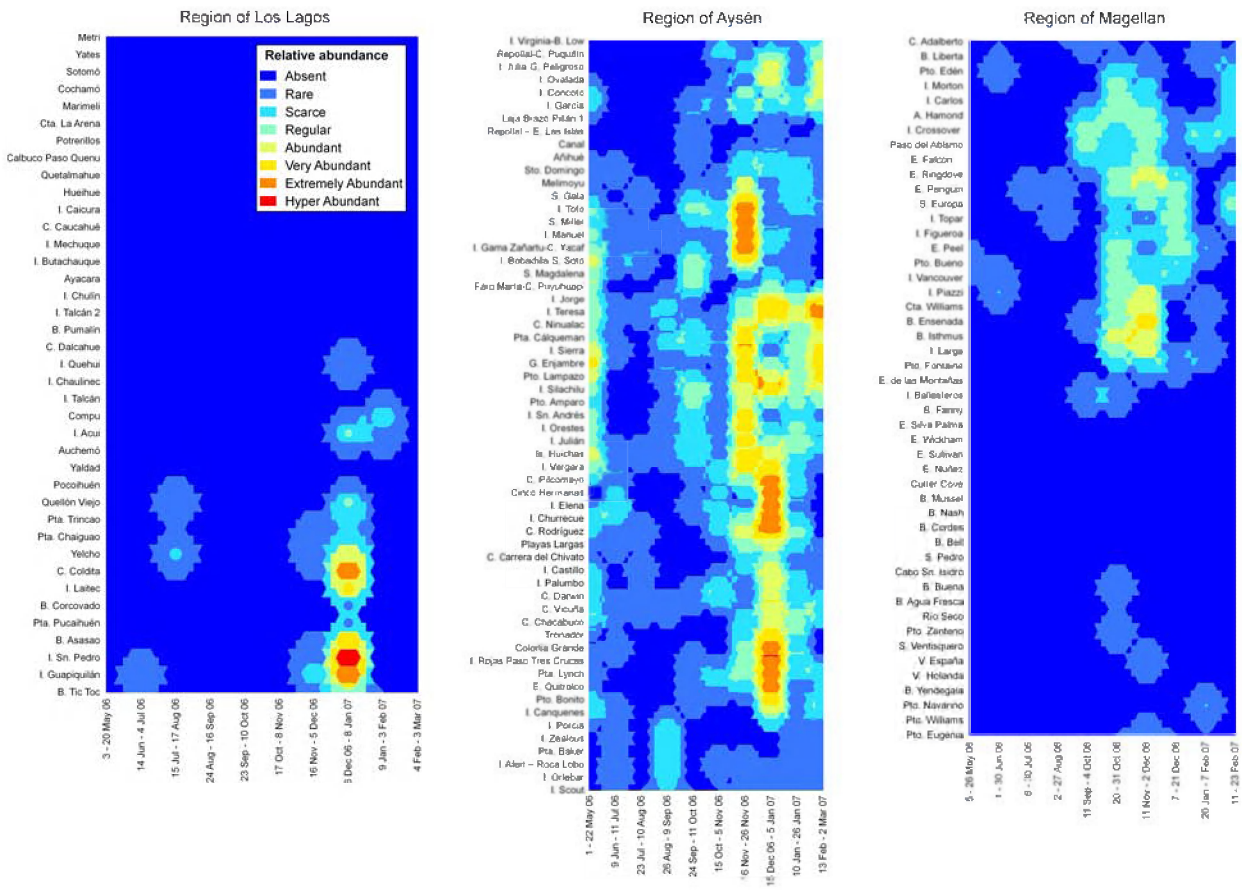


Fig. 6. Maps of relative abundances for Alexandrium catenella *along the regions of Los Lagos, Aysén and Magellan for the period between May 2006 and February 2007 (L. Guzmán* et al.*, unpublished data). Values are averages of 6 vertical net tows from surface to 20 m.*

tidal intrusion fronts only a few tens of meters from the sill crest and pumping of salt with every flood period. During ebb periods, the low salinity waters derived from the glacier and a small river near the glacier converge at the sill crest. After some mixing, the buoyant waters are released within a thin layer (~3 m deep), led by a plume-like front that can remain coherent for a few hundred meters seaward of the sill (Valle-Levinson *et al.*, 2006). Phytoplankton is numerically dominated by diatoms, whereas *A. catenella* is rare, reaching only very low concentrations, less than 100 cells l^{-1} at 5 m depth. Consequently, this sound is rarely affected by PSP outbreaks, in contrast to Bahía Mussel and Bahía Nash.

There is little information on cyst beds compared to that on vegetative cells. Highest cyst concentrations have been found at Canal Quitralco (77 ± 16.6 cysts ml^{-1}) in the region of Aysén and Canal Ballenero (73 ± 19.5 cysts ml^{-1}) in the southern area of the Magellan region (not shown but near the bottom right corner of the Magellan region map in Fig. 3); other regions show low cyst concentrations (Lembeye and Sfeir, 1997, 1999a 1999b).

2. Coastal Embayments of the Ebre Delta (NW Mediterranean)

Alfacs and Fangar bays are the two coastal embayments of the Ebre Delta in Spain, and are among the most prominent embayments in the northwestern Mediterranean Sea. These embayments have been formed through riverine sedimentary processes in conjunction with estuarine and oceanographic factors. A tentative comparison of Alfacs Bay in the early 18th Century with its present configuration illustrates the geomorphological evolution of this bay (Fig. 7), which is undergoing continuous change. Regardless of possible misinterpretations due to mapping errors in the 18th Century, definitive changes are evident, such as the river mouth position and the size of embayments and inner lagoons. In the present configuration, the Ebre Delta is bisected by the Ebre River emerging into the Mediterranean Sea at the eastern part of the delta. The Ebre Estuary delivers into the Mediterranean a mean freshwater flow of approximately 426 $m^3 s^{-1}$ (data from 1960-1990) (Ibáñez *et al.*, 1996).

The dominant coastal currents are southwesterly. An estuarine salt wedge enters the Ebre River with a maximum saline intrusion of 32 km. The Ebre Estuary sediment input to the delta has been reduced in the 20th Century by the construction of the Flix (1945), Ribarroja (1967) and Mequinenza (1964) dams, respectively situated 123, 137 and 170 km up-river. Dam construction in the 1960s has resulted in an estimated 99% reduction in sediment transport in the Ebre River (from 3.0 x 10^7 Mt y^{-1} to 0.1-0.2 x 10^6 Mt y^{-1}) (Ibáñez *et al.*, 1996). Freshwater runoff into the Mediterranean Sea and sediment input (north and south of the Ebre mouth) are important processes that, in conjunction with coastal currents and winds, define the present and evolving configuration of Alfacs and Fangar bays, such as the depth and width of the bay mouths and the width of the narrow threads of sand barriers.

Alfacs Bay, on the southern side of the Ebre Delta, is 50 km^2 with a 3-km wide mouth, and a maximum water depth of approximately 6 m. The mouth is oriented to the southwest and thus is exposed to the dominant southwesterly winds in the region, but it is protected by the Montsià Mountains against the strong northwesterly winds descending through the Ebre valley. Fangar Bay, on the northern side of the Ebre Delta, has a water surface area of 12 km^2 and a 1 km wide mouth, with a maximum water depth of approximately 4 m. Since the mouth is facing northwest, it is thus exposed to both strong northwesterly winds from the Ebre valley and to strong northeasterly and easterly winds from the open sea. Due to its location within the Ebre Delta, Fangar Bay is essentially protected from the dominant southwesterly winds in the region.

Coastal currents, wind, and freshwater input from agriculture (mainly rice fields), affect circulation patterns and thus the retention time of water and phytoplankton within these bays. As a hypothesis, it may be suggested that these physical factors primarily determine the dynamics of harmful algal blooms. Presently, there is no defined model that explains water circulation within these bays and the retention time of water has not been precisely estimated. The influence of freshwater runoff from agricultural activity into the bays, 228 x 10^6 m^3 yr^{-1} into Fangar Bay and 365 x 10^6 m^3 yr^{-1} into Alfacs Bay (Camp and Delgado, 1987), has been described as an important driving force that would accelerate water exchange between the open sea and the bay at the time that freshwater is released from the rice fields into the bays.

Both bays are active sites for production of mussels (*Mytilus galloprovincialis*) and oysters (*Crassostrea gigas*) from rafts that are fixed to the bottom of the bay. The estimated annual production in 2004 for mussels was approximately 1700 metric tons and for oysters 850 metric tons. In addition, there is an active production of clams (*Ruditapes decussatus* and *Ruditapes philippinarum*) within both bays. The embayments are monitored comprehensively for the presence and concentrations of harmful microalgae, and marine toxins, microbiological (bacterial) components, organohalogenates, heavy metals and dioxins in molluscs. Established in 1991, the monitoring programme has indicated the presence of the toxins associated with DSP and PSP in bivalves, as well as the causative organisms in both Fangar and Alfacs bays. Species of dinoflagellates that have been linked to

DSP events and which are regularly present in these bays include *Dinophysis sacculus* and *D. caudata*. In addition, *D. rotundata* and the benthic okadaic acid-producing species *Prorocentrum lima* have also been described. *Alexandrium minutum* is responsible for PSP events within these bays (Delgado *et al.*, 1990). Other species of this genus have also been found in these bays, including *A. tamutum, A. insuetum,* and *A. pseudogonyaulax*. The ichthyotoxic species *Karlodinium veneficum* and *K. armiger* are present in

Fig. 7. The Ebre Delta, NW Mediterranean. 18th Century engraving (top panel, J. Diogène, private collection) and photograph from space (bottom panel), courtesy of the Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Centre. Url: eol.jsc.nasa.gov and reproduced from Cembella et al.*, 2005, Oceanography, vol. 18, no. 2, page 159, url: www.tos.org/oceanography/issues/issue_archive/18_2.html. Alfacs and Fangar bays are located respectively at the left and right sides of the Ebre Delta.*

Alfacs Bay (Garcés *et al.*, 2006; Fernández-Tejedor *et al.*, 2007) and were previously referred to in Alfacs Bay as *Gyrodinium corsicum*, causing fish kills during fall-winter months (Delgado and Alcaraz, 1999; Garcés *et al.*, 1999; Fernández-Tejedor *et al.*, 2004). Since 2003 the blooms of these species occur in spring-summer months (Diogène *et al.*, 2008), with maximum concentration at about 4 m depth (IRTA, unpublished data). *Pseudo-nitzschia* spp. are regularly present in the bays and in 2008, ASP toxins were found in bivalves but without identification of the toxin-producing species (IRTA, unpublished data).

The monitoring programme, which has evolved in parallel with international programmes on HABs and Spanish and European Union regulations in shellfish production areas, is presently strongly linked to ongoing research projects on harmful microalgal dynamics and the identification of marine toxins. Weekly monitoring for environmental data and harmful microalgae gives a reliable picture of the species of harmful algae present within these bays and accompanying water conditions (Figs. 8 and 9). Strong water temperature fluctuations year-round result in differences of 20°C between winter and summer, with maxima up to 30°C. These conditions have an effect on bivalve physiology and bloom dynamics and can lead to anoxic conditions in summer. Freshwater runoff from adjacent rice fields next to the Ebre bays is responsible for salinity fluctuations in surface waters.

Interestingly, in spite of the proximity of Fangar and Alfacs bays within the Ebre Delta system and their apparently similar environmental conditions, the HAB species present, their bloom dynamics and related events are very distinct between these respective embayments. As an example, Fangar Bay, although much smaller than Alfacs Bay, receives a similar freshwater flow from agricultural activity, resulting in stronger salinity fluctuations and increased water exchange with outer waters. This may have a profound influence on HAB population dynamics. The differences in geomorphology and wind exposure between the bays offer potential for other comparisons. In Alfacs Bay, the sand barrier is somewhat inefficient to separate the inner waters of these bays from the open Mediterranean Sea since strong easterly winds generate waves that break through the narrow sand barrier. The plasticity in the bay boundaries determines water exchange between the bays and open sea. This may have immediate consequences on the incidence and dynamics of harmful microalgae (both vegetative cells and resistant forms such as cysts) within the bays. Additionally, environmental forces (mainly winds) and human activity in the Ebre Delta, such as agricultural activity, artificial control of freshwater runoff

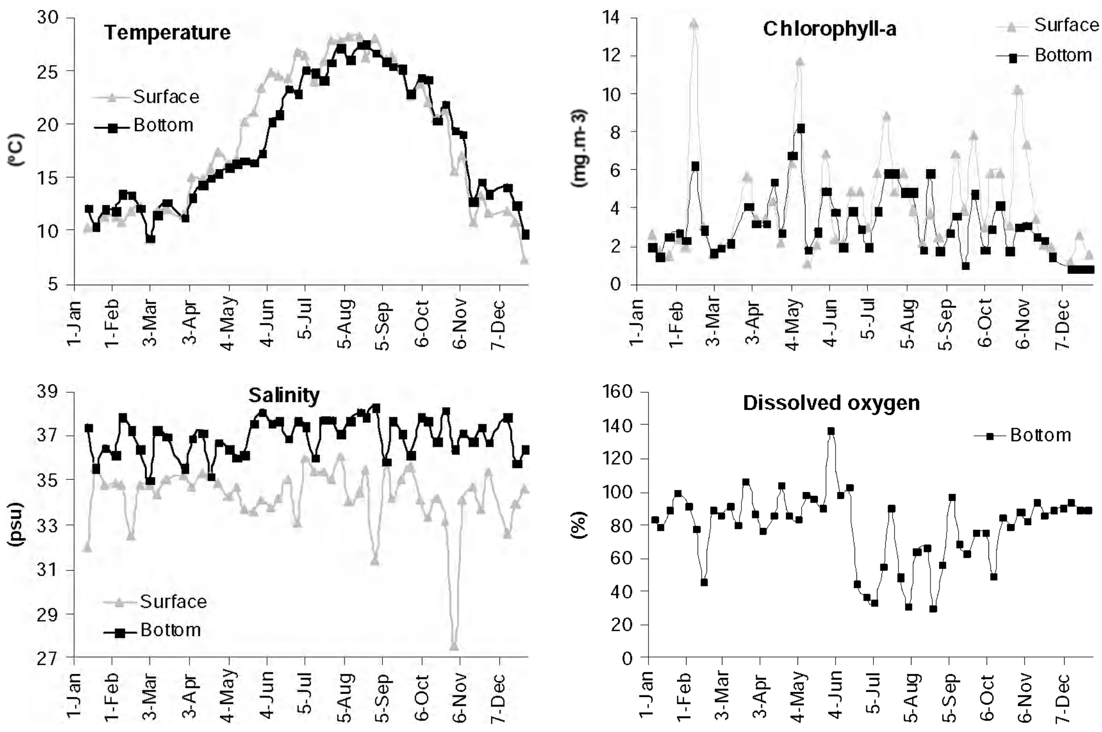


Fig. 8. Temperature, salinity, dissolved oxygen and chlorophyll a *concentration in surface (ca 1 m) and bottom (ca 5 m) waters at the central station within Alfacs Bay during 2004 (M. Fernández, unpublished data).*

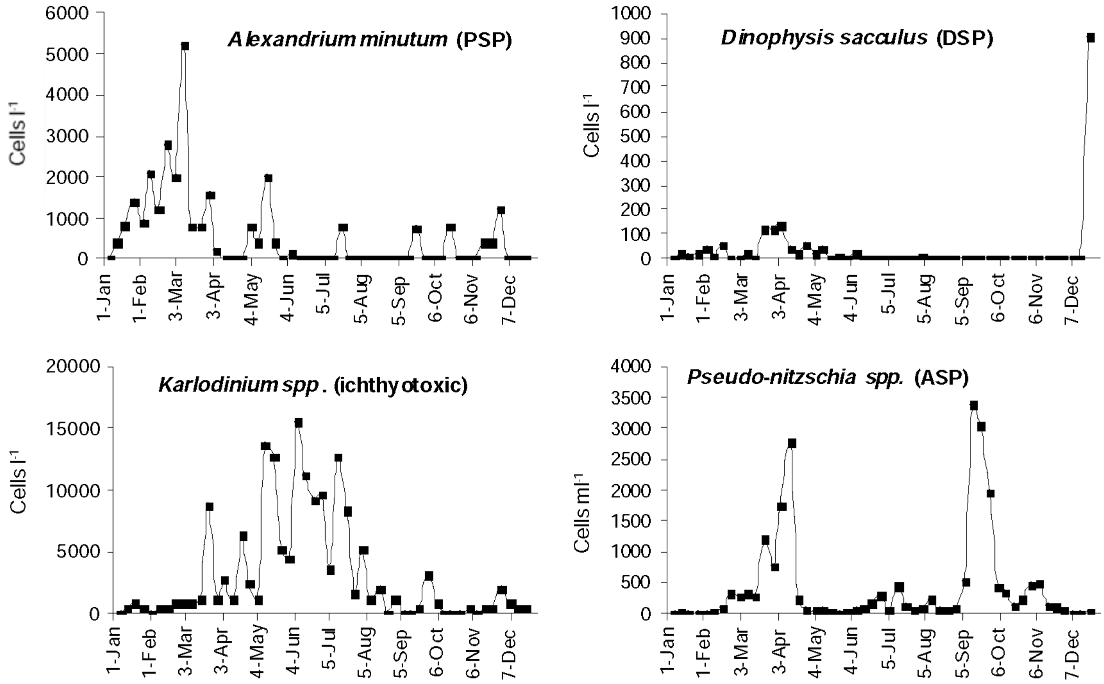


Fig. 9. Maximum cell concentration of selected HAB species in Alfacs Bay during 2004 (M. Fernández, unpublished data). Note that the abundance of Pseudo-nitzschia *spp. is in cells ml^{-1}, while the units for the other three species are cells l^{-1}.*

into the bays, nutrient inputs, etc., may also play an important role in harmful algal dynamics in these bays.

3. Coastal Embayments of Eastern Canada (NE Atlantic)

Three regions are of major interest for HABs in eastern Canada: the St. Lawrence marine system (estuary and gulf), the Bay of Fundy and the coastal embayments in Nova Scotia. DSP and ASP toxins are occasionally present, but the major toxic events are associated with PSP. In the Bay of Fundy, *Alexandrium fundyense* is the major toxic species present, while elsewhere, *A. tamarense* and less importantly, *A. ostenfeldii*, dominate (Levasseur *et al.*, 1998). In the St. Lawrence, harmful algal blooms can be observed throughout the marine part of the estuary and in the Gulf of St. Lawrence, notably along the south shore of the Gaspé Peninsula. Blooms of *Alexandrium* in the St. Lawrence marine waters are highly toxic: 1000 cells l^{-1} are sufficient to cause shellfish harvest closure (> 80 µg STX eq. 100 g^{-1} tissue: Blasco *et al.*, 2003).The spatial scale of the St. Lawrence marine system is large compared to other fjords and coastal embayments around the world: it is the world's largest estuary, spreading more than 1500 km from the Saguenay Fjord to the Atlantic Ocean (Fig. 10). Major features include large amounts of freshwater drainage from the Great Lakes and St. Lawrence River, ice cover for several months of the year, shallow troughs and a deep (300 m) channel bringing Atlantic water far inland. Water circulation is essentially estuarine, but it is complicated by the large size of the system, with mesoscale eddies and cross currents that can last a few weeks (Koutitonsky and Bugden, 1991). Winds and freshwater runoff are considered key forcings for setting up blooms, retaining them generally close to major rivers that flow into the St. Lawrence, and dispersing them around. A recent biological-physical coupled model illustrates the importance of these factors (Fauchot *et al.*, 2008). Although the large-scale picture is relatively well described, understanding of bloom dynamics inside smaller local bays is generally lacking, particularly with respect to the connection between blooms in the water column and cysts in the seabed.

An example of a local bay with an important aquaculture activity is Gaspé Bay, located at the eastern margin of the Gaspé Peninsula in Quebec (eastern Canada) (Fig. 10), and opening on the Gulf of St. Lawrence. The inner harbour (average depth: 20 m) is separated from the outer bay by a 500-m wide sand bar. Three rivers empty into the bay: the Dartmouth, York and Saint-Jean rivers. Temperature and salinity conditions, as well as enhanced protection afforded by surrounding mountains, have favoured the development of aquaculture since 1990. In 2003, commercial mussel cultures covered more than 300 ha, with an annual harvest of 30 tons. Maximum harvesting capacity for the whole bay has been assessed at about 50 times that amount. Local jobs related to this activity represent 30% of all jobs in aquaculture in the Gaspé region. The provincial research laboratory of the Ministère de l'Agriculture, des Pêches et de l'Alimentation du Québec holds two aquaculture parks covering 50 ha within the bay, and the Maurice-Lamontagne Institute (Department of Fisheries and Oceans Canada, DFO) maintains a monitoring station at Penouille, in the inner harbour.

Recurrent blooms of harmful algae, namely *A. tamarense*, limit shellfish harvesting to the period outside the months of June to October. The seasonal maximum abundance of this toxic dinoflagellate generally occurs in June, but a secondary maximum is often observed at the end of August (Blasco *et al.*, 2003). The toxigenic species *A. ostenfeldii* often co-occurs with *A. tamarense* and is present in Gaspé Bay (Levasseur *et al.*, 1998). Toxins differ between these two species, with spirolides present in *A. ostenfeldii*, in contrast to PSP toxins in *A. tamarense*. The distribution of resting cysts of *Alexandrium* spp. was examined in 1988 in surface sediments (top 5 cm) of the Estuary and Gulf of St. Lawrence as well as in Gaspé Bay. Cyst concentrations in the bay were generally <250 cysts cm^{-3}, with lower concentrations than in coastal regions of the lower Estuary or Gulf of St. Lawrence (Turgeon *et al.*, 1990, Fig. 11).

Higher concentrations found at the mouth of the bay suggest that *Alexandrium* blooms inside the bay have an external origin, from water entrained into the bay by the Gaspé Current (a coastal jet current bordering the Gaspé coast), but this has not been tested yet. Blooms inside the bay tend to occur earlier than in the lower estuary or the gulf, suggesting local initiation (from bottom cysts) rather than advection. Cyst concentrations in the sediment, measured in 1997, showed high and variable values at sediment depths between 5 and 10 cm (Fig. 12).

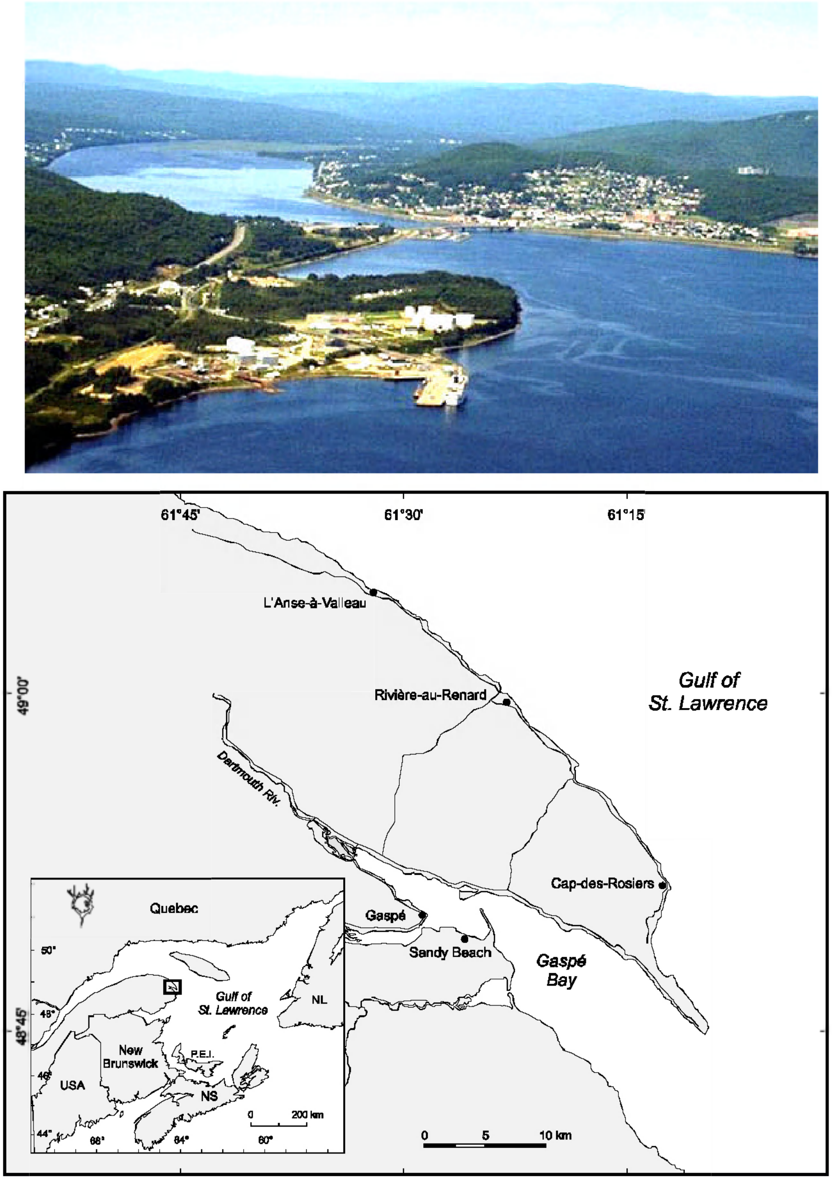


Fig. 10. Photograph (top, from www.douglastown.net/baie-sud-ouest-zoom.jpg) and map (bottom) of the Gaspé Bay region, located at the eastern end of the Gaspé Peninsula (eastern Canada) (from S. Roy, unpublished).

This cyst increase is thought to reflect a local bloom which took place in July that year (DFO monitoring at Penouille, E. Bonneau, personal communication). Sediment (and cyst) resuspension events are caused by storms, due to the relatively calm conditions inside the bay, with bottom currents around 5-10 cm s^{-1} and tidal reworking affecting only the top 1-2 cm of sediment (Roy *et al.*, 1999). A predicted increase in storm frequency for Eastern Canada associated with climate change ('From Impacts to Adaptation: Canada in a Changing Climate 2007' (http://www.adaptation.nrcan.gc.ca/)) suggests that cyst resuspension may occur more frequently in the future, possibly resulting in more-frequent PSP events.

Concerning other HABs, no shellfish contamination by DSP toxins has been found in Gaspé Bay (Levasseur *et al.*, 2001), even though three potential DSP toxin producers (*Dinophysis acuminata*, *D. norvegica* and *D. rotundata*) are occasionally present in low abundance (Blasco *et al.*, 1998). DSP incidents have been reported, however, from lagoons of the Magdalen Islands in the nearby Gulf of St. Lawrence, likely associated with the presence of *Prorocentrum lima* and *P. mexicanum* (Levasseur *et al.*, 2003). The diatom *Pseudo-nitzschia multiseries*, responsible for the Prince Edward Island domoic acid contamination in 1987, has not been detected in the bay. Two other potentially toxigenic *Pseudo-nitzschia* species, *P. seriata* and *P. delicatissima*, are present in other regions of Québec, but no ASP

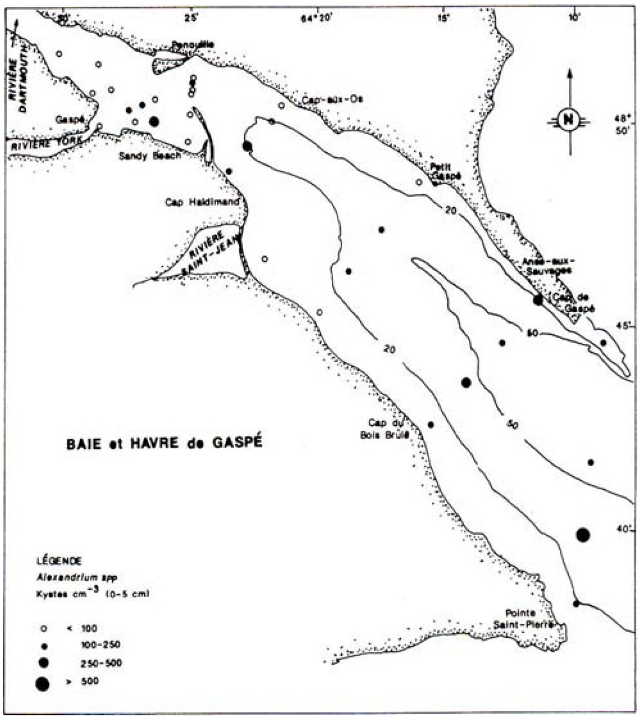


Fig. 11. Map of Alexandrium *spp. cyst distribution in the top 5 cm of sediment in Gaspé Bay (modified from Turgeon, 1989, M.Sc. thesis from Université du Québec à Rimouski, Figure 9, page 31).*

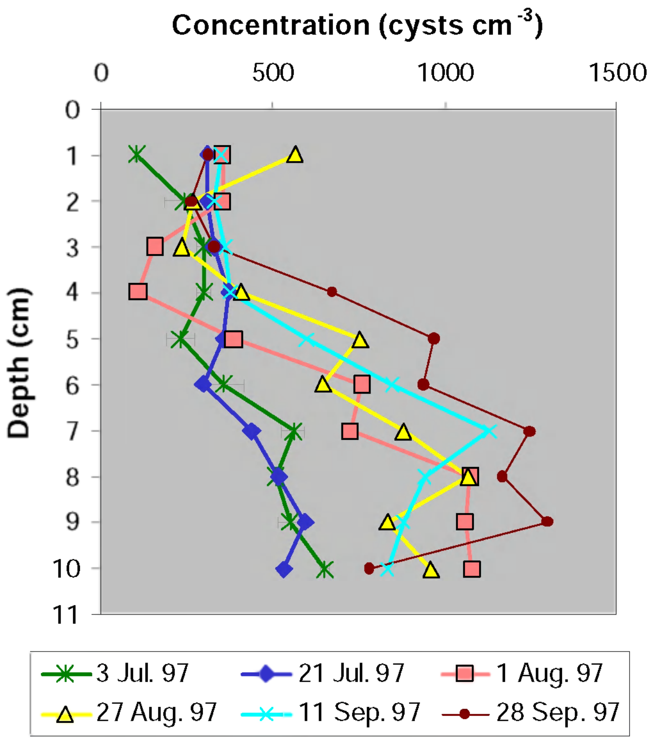


Fig. 12. Vertical distribution of A. tamarense *cysts in sediment collected in Gaspé Bay in 1997 (S. Roy, unpublished data).*

contamination has been detected in Gaspé Bay (Couture *et al.*, 2001). Interest in developing a GEOHAB-related study in Gaspé Bay stems from the relatively small size and protected character of this bay, the presence of governmental aquaculture parks that could be accessible for research purposes and more than 10 years of HAB monitoring by DFO, with continued interest in maintaining this database in the future. In addition, physical oceanographic conditions have been well studied in this bay (e.g., Pettigrew *et al.*, 1991) and a hydrodynamic model has been developed (V.G. Koutitonsky, personal communication).

4. The Scandinavian Fjords and Coastal Embayments (North Sea and Skagerrak)

4.1. Southern Norway Bays

The Skagerrak and the southern coast of Norway are downstream from the North Sea and the Baltic (Kattegat). Water bodies of different origin enter and influence the area, mainly as a result of shifts in wind conditions, and create high hydro-physical and chemical variability in the surface layer of the Skagerrak. Figure 13 shows a simplified, general picture of the current patterns. The Jutland Water Current (JWC) may have skewed N:P proportions above the Redfield ratio due to elevated nitrogen (nitrate) values. The Norwegian

Coastal Current (NCC) starts in the eastern Skagerrak and flows westward as a large, stratified current with low-salinity water, mainly of Baltic origin, as the top layer. The upper 30 m of the NCC outside Arendal is mainly influenced by JWC and Baltic Water (BW) coming via the Kattegat (Aure *et al.*, 1998). Easterly winds accelerate the NCC and force it closer to the southern coast of Norway, whereas westerly winds retard the NCC and force it off the coast and thereby cause wind-driven near-shore upwelling and anti-clockwise recirculation of upper layers in the Skagerrak. The region is characterized by strong seasonal variations in temperature, light and nutrient conditions.

In this region, the small Flødevigen Bay (<1 km^2, with a maximum depth of 20 m, Fig. 13) is representative of semi-exposed bays heavily influenced by the NCC. Water exchange with the NCC is efficient, with a mean flow westwards along the Skagerrak coast. Phytoplankton assemblages are transported by this current. Algal blooms in Flødevigen Bay are thereby typically advected, and sometimes concentrated to high densities alongshore at the surface due to onshore currents. The phytoplankton assembly sampled in Flødevigen Bay is a proxy for abundance along the coast within the NCC (Dahl and Tangen, 1993; Dahl and Johannessen, 1998).

The Institute of Marine Research (IMR) has performed regular monitoring of HABs in the Skagerrak and in Flødevigen Bay since the 1980s. The phytoplankton sampling frequency in Flødevigen Bay has been three times per week. Environmental parameters such as temperature, salinity and nutrients are sampled about every second week at Station 2 (Fig. 13). Results of the monitoring both support short-term warnings («predictions») of risk of harmful events and generate data for scientific purposes. For example, long-term data on selected harmful species and environmental parameters are used in statistical analyses to elucidate potential ecological and oceanographic mechanisms underlying bloom dynamics. Such data are also essential for tuning and evaluation of models and for comparative studies of harmful algal bloom dynamics in different countries.

Many harmful blooms have occurred along the southern coast of Norway over the last few decades (Dahl and Tangen, 1993; Dahl and Johannessen, 2001; Dahl *et al.*, 2005) and some toxic events are recurrent. Some of these species are ichthyotoxic and may create dense blooms with relatively high biomass and thereby kill fish, while others usually occur in low numbers, but are toxic, and may cause accumulation of algal toxins in

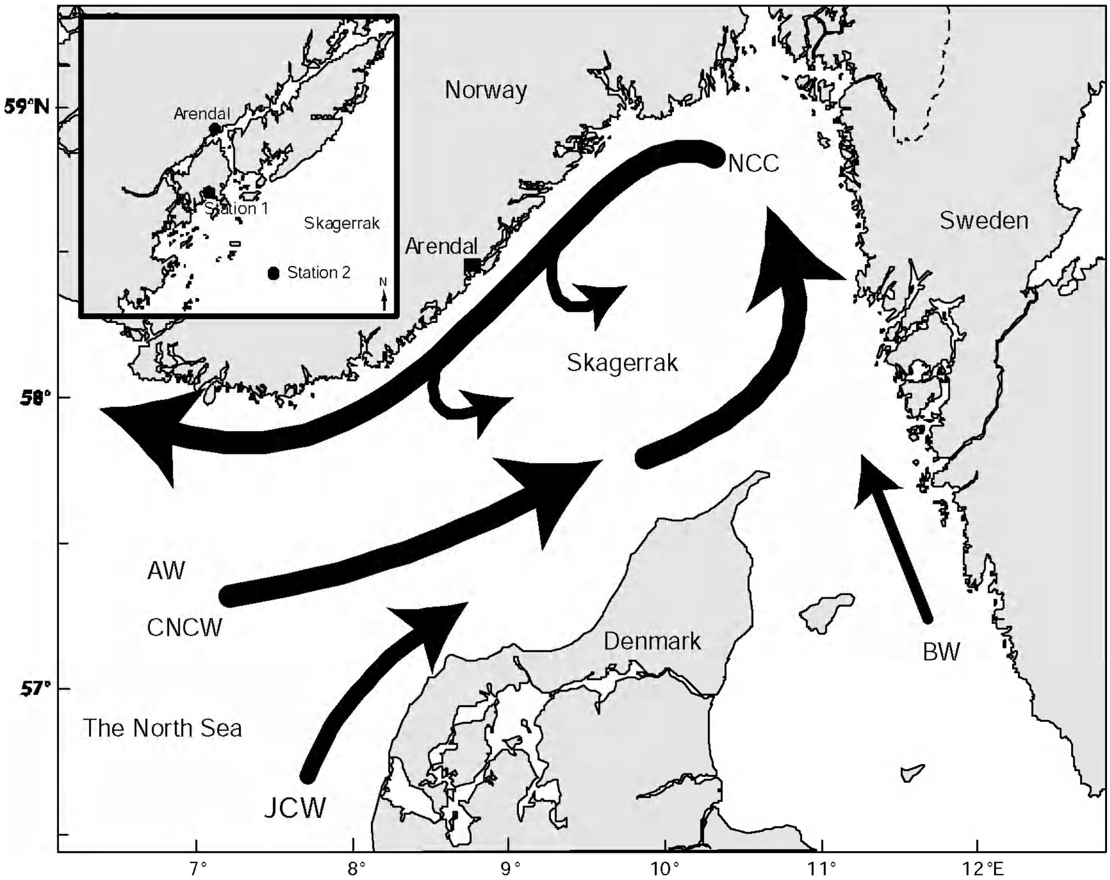


Fig. 13. Simplified picture of the general circulation in the Skagerrak (Aure et al.*, 1998). Flødevigen Bay indicated as Station 1 in the inset is located along the southern coast of Norway in Arendal municipality. AW = Atlantic Water. CNSW = Central North Sea Water. JCW = Jutland Coastal Water. BW = Baltic Water. NCC = Norwegian Coastal Current (map from E. Dahl, unpublished).*

bivalve shellfish. Toxins associated with DSP and PSP, accumulated in mussels above quarantine levels, are major recurrent problems along the Norwegian coast. Occasionally, pectenotoxins, yessotoxins, azaspiracids and domoic acid have also been found in mussels at levels above the quarantine limit.

Common harmful algal taxa found in Flødevigen Bay are *Alexandrium* spp. (*A. tamarense* and *A. ostenfeldii*), *Dinophysis* spp. (*D. acuminata*, *D. acuta* and *D. norvegica*), *Protoceratium reticulatum*, *Karenia mikimotoi*, *Chrysochromulina* spp., *Pseudochatonella farcimen* and *Pseudo-nitzschia* spp. In Figure 14, the «normal» seasonal occurrence for *Dinophysis* spp. is shown as an example of data available.

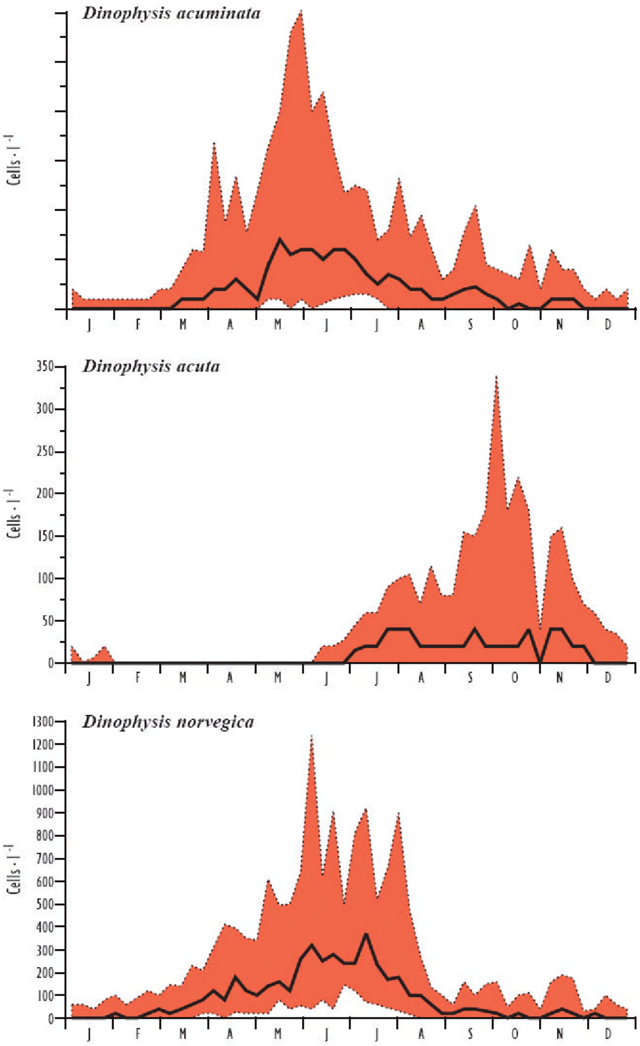


Fig. 14. Temporal succession of three Dinophysis *species in Flødevigen Bay (Skagerrak) based on data for the period 1989-2008. The thick lines are weekly medians, the dotted lines are the first and third quartiles and the red areas show the «normal» annual variation of the three* Dinophysis *species. Reproduced from Cembella* et al.*, 2005, Oceanography, vol. 18, no. 2, page 163, url: www.tos.org/oceanography/issues/issue_archive/18_2.html.*

4.2. Coastal Embayments of the Swedish Skagerrak

The Swedish west coast consists of open coast, embayments, fjords and archipelagos along the eastern boundaries of the Kattegat and the Skagerrak in the northeast Atlantic Ocean (Fig. 15). Characteristics of the area are that the tidal amplitude is less than 30 cm and the water mass is strongly stratified. The Kattegat surface water is strongly influenced by the outflow of brackish water from the Baltic Sea, which forms a surface layer with a salinity of about 15 psu in the southern part. Surface salinity increases northward along the coast to about 25 psu in the northeastern Skagerrak. Water originating from the North Sea is found below a pronounced halocline at a depth of about 15 m. The salinity in the deep water ranges from 32 to 34 psu. The Kattegat and the Skagerrak have mean depths of 23 m and 210 m, respectively. In the fjords, local conditions such as sills and freshwater input from rivers change the general pattern. Anthropogenic input of nutrients has resulted in eutrophication in several areas. Oxygen depletion in the Kattegat is a common event in autumn and some of the fjords have more or less permanent oxygen-depleted deep water. In contrast, in the Byfjorden (Fig. 15), reduction of input of inorganic nitrogen through water treatment has resulted in reduced biomass of phytoplankton and bottom-water oxygen concentrations have increased.

Algal blooms are common and, in general, natural phenomena in the area. The diatom spring bloom usually occurs at the end of February or in March. The biomass

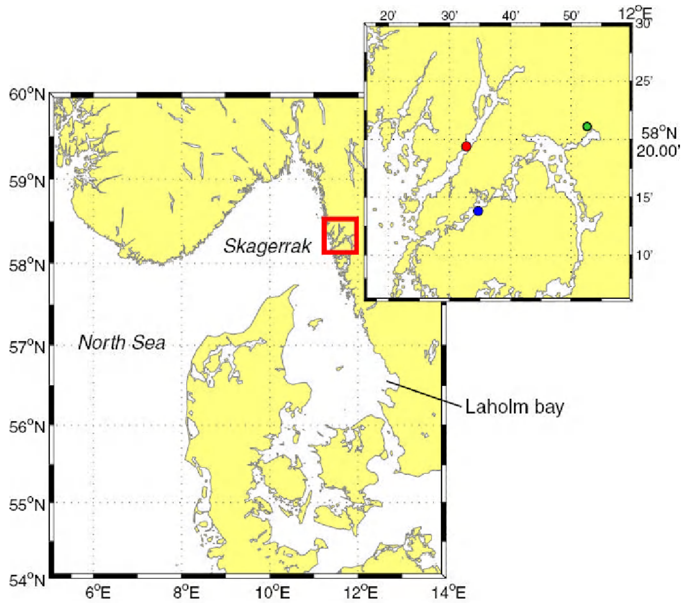


Fig. 15. Map from B. Karlson (unpublished) showing the Skagerrak (between Denmark and Norway) and the Kattegatt (between Denmark and Sweden), adjacent to the North Sea. Inset: Bohus coast. Red dot – the Gullmar fjord, green dot – the Byfjorden, blue dot – the Koljö fjord.

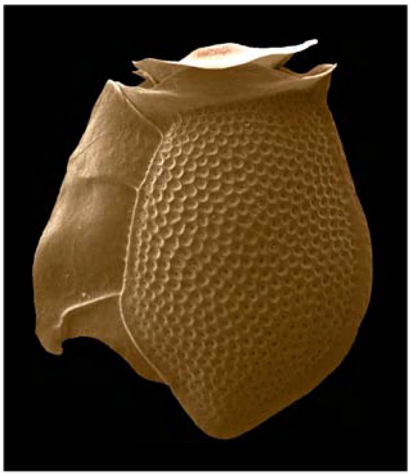


Fig. 16. The dinoflagellate Dinophysis acuta*, probably the major contributor to diarrhetic shellfish toxins in blue mussels (*Mytilus edulis*) in the Skagerrak area. Scanning electron micrograph with artificial colour. Photo by Bengt Karlson.*

of phytoplankton usually reaches the yearly peak during the spring bloom, and since zooplankton such as copepods grow slower than the diatoms, a large part of the spring bloom ends up on the seafloor where filter feeders and other benthic animals utilize this resource. Diatoms, dinoflagellates and other flagellates often form blooms during the rest of the growing season, but biomass is in general lower since zooplankton feed on the blooms. In May-June blooms of flagellates harmful to fish and other organisms have occurred in several years. In 1988, *Chrysochromulina polylepis* formed a devastating bloom. *Chattonella* cf. *verruculosa* (possibly conspecific or identical to *Pseudochattonella farcimen*) caused fish kills in 1998 and also bloomed in 2000, 2001 and 2006. The coccolithophorid *Emiliania huxleyi* formed spectacular blooms in the North Sea-Skagerrak area in May-June for several years, but this alga is harmless. In 2004 the bloom reached the Bohus coast and the water was discoloured turquoise from the calcite plates covering the algal cells. During summer, small cyanobacteria (1 µm in diameter) dominate production but in general biomass is low. In autumn cyanobacteria commonly occur along with another diatom bloom.

Blooms of the diatom genus *Pseudo-nitzschia* frequently occur in the Skagerrak and the Kattegat. Several species from this genus produce domoic acid and cause Amnesic Shellfish Poisoning (ASP). The toxin has been detected in shellfish in Denmark and Norway. In Denmark, levels above the regulatory limit were detected in 2004. The dataset on amnesic shellfish toxins in blue mussels in Sweden is very small. The most important harmful algae for mussel harvesting occur in low cell numbers and do not form high-biomass blooms. Along the Swedish west coast the most potent toxins are produced by *Alexandrium* species, some of which produce PSP toxins. *Alexandrium* spp. are regularly found along the Bohus coast, most often in late spring. Other toxin-producing dinoflagellates include *Lingulodinium polyedrum* and *Protoceratium reticulatum*. These two species are known to produce yessotoxins, which are toxic to mice following intraperitoneal injection of lipophilic extracts containing yessotoxins, but are not considered a serious health risk for humans after ingestion of yessotoxin-contaminated shellfish (Blanco *et al.*, 2005).

DSP is the predominant threat to mussel farmers and consumers in Sweden. The phytoplankton species in Sweden that have been linked to DSP belong to the genus *Dinophysis*, namely, *D. acuminata*, *D. acuta*, and to a minor extent *D. norvegica* and *D. rotundata*. *Dinophysis* spp. are relatively large planktonic organisms that occur year-round in the area. Cell numbers are most often below 1000 cells l^{-1}. In the Skagerrak, *D. acuta* is a potent producer of both okadaic acid (OA) and DTX1 (Fig. 16). *D. acuminata* from the region usually produces only OA even if this species has been shown to be a producer of DTX1 in other regions. *D. norvegica* has never been shown to produce DSP toxins in the Skagerrak region and *D. rotundata* usually occurs at numbers too low to contribute to the problem. Most

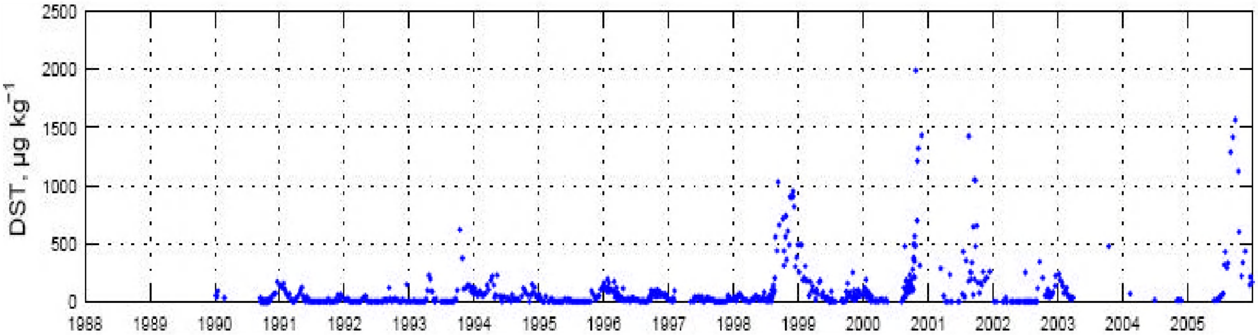


*Fig. 17. Long-term data on diarrhetic shellfish toxins in blue mussels (*Mytilus edulis*) in the Koljö Fjord indicating substantial year-to-year variation (Karlson* et al.*, 2007) (used with permission from the Swedish Meteorological and Hydrological Institute).*

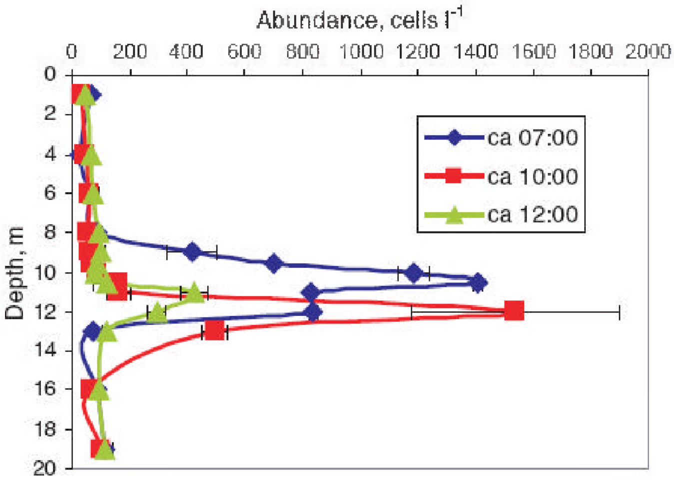


Fig. 18. Vertical distribution of Dinophysis *spp.* (D. acuta *and* D. acuminata*) in the Koljö Fjord sampled on October 15 with a hose and a pump. Data produced by Odd Lindahl, Marie Johansen, Bengt Lundve and Joakim Strickner (used with permission).*

attempts to correlate the occurrence of *Dinophysis* abundance and the concentration of diarrhetic shellfish toxins in mussels (Fig. 17) have failed, except on short time scales and for specific sites (e.g. Godhe *et al.*, 2002). One explanation might be the considerable variation of toxin content per *Dinophysis* cell. Lindahl *et al.* (2007) reported an inverse relationship between the population density of *D. acuminata* and the toxin content per cell. Another is the characteristic feature of *Dinophysis* blooms, that is, the formation of dense patchy populations in thermoclines or pycnoclines.

Other planktonic organisms that may cause shellfish toxicity also occur along the Bohus coast. The area has been extensively studied in research projects and long-term monitoring programmes are run by local organisations. Physical and biogeochemical models also exist for the area. A physical model is run operationally by the Swedish Meteorological and Hydrological Institute.

Three more areas lend themselves to GEOHAB studies in different ways: 1) the fjordal system north of the island of Orust, 2) the Gullmar fjord, and 3) Laholm Bay. In the fjordal system north of the island of Orust, high abundances of different *Dinophysis* species are very common and have been shown to occur in thin layers (Fig. 18). The system is of special interest because anoxia events occur regularly. This may influence cyst-producing dinoflagellates. Furthermore, the phytoplankton community in part of the fjord system may be controlled by benthic suspension feeders, such as bivalves. Thus, changes in feeding activity among these benthic organisms may cause changes in the frequency of HABs. Finally, physical oceanographic characteristics in the area have been modelled in different ways, thereby providing a context for modelling the development of HABs.

The Gullmar fjord has a true sill partly controlled by the conditions in the Baltic current, where high-resolution monitoring is performed from a mooring with a profiling instrument platform (Fig. 19). Input from the River Öreskilsälven influences the fjord. The freshwater contains high concentrations of humic substances and may dramatically affect the light regime in the fjord (Lindahl and Hernroth, 1983). The Kristineberg Marine Biological Research Station is situated at the mouth of the fjord and the Bornö oceanographic station is located in the inner part. Both are about 100 years old, indicating that the area is well investigated and that a lot of background data are available. Automatic profiling devices are now used to collect measurements enabling the detection and follow-up of harmful algal species. High-resolution data from such a profiling mooring system (with sensors mounted on a vertical profiling device; Karlson, 2006) deployed in the fjord are illustrated in Figure 20.

The large embayment of Laholm Bay in the Kattegat is prone to oxygen-depleted deep water. This phenomenon partly results from the hydrographic conditions since a pycnocline is often present only a few meters above the seafloor. High-biomass algal blooms of non-toxic genera such as the dinoflagellate *Ceratium* spp. fall to the seafloor in this small volume of water and bacterial decomposition of the algae results in anoxia. This phenomenon may be exacerbated by nutrient enrichment (Granéli, 1992).

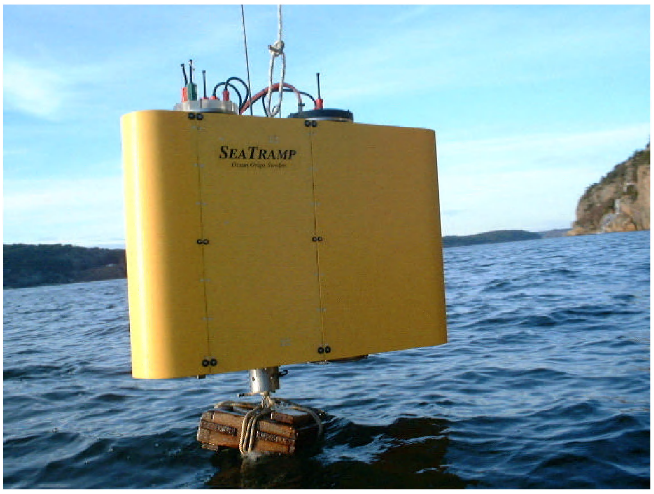


Fig. 19. A profiling device (older version) for automatic measurements of salinity, temperature, and chlorophyll a *fluorescence, turbidity, oxygen and nitrate concentrations deployed in the coastal current of the Gullmar fjord (photo by Sverker Skoglund, OceanOrigo AB, used with permission).*

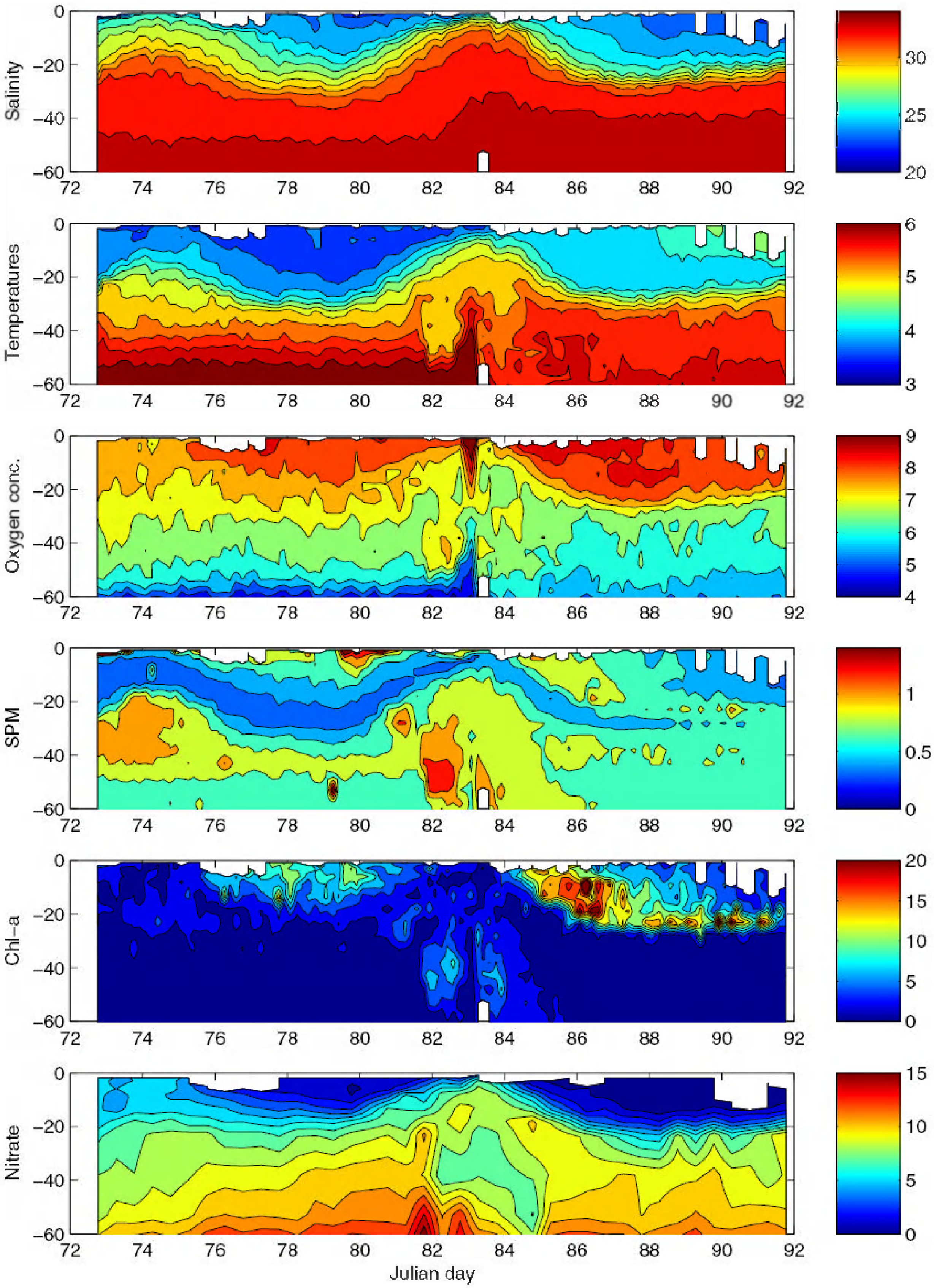


Fig. 20. Salinity (psu), temperature (°C), oxygen concentration (ml l^{-1}), suspended particulate material (SPM, mg l^{-1}), chlorophyll a *fluorescence (relative units) and nitrate concentration (mmol l^{-1}) in Gullmar Fjord (2002), investigated with high vertical and temporal resolution using a profiling mooring. The data illustrate the short-term dynamics and show that an algal bloom occurred after nitrate was introduced to surface water. Data from the EU project OAERRE by Arneborg and co-workers. See Arneborg (2004) and Final OAERRE Report no. EVK3-CT1999-0002 (url: www.lifesciences.napier.ac.uk/ OAERRE/Report.htm).*

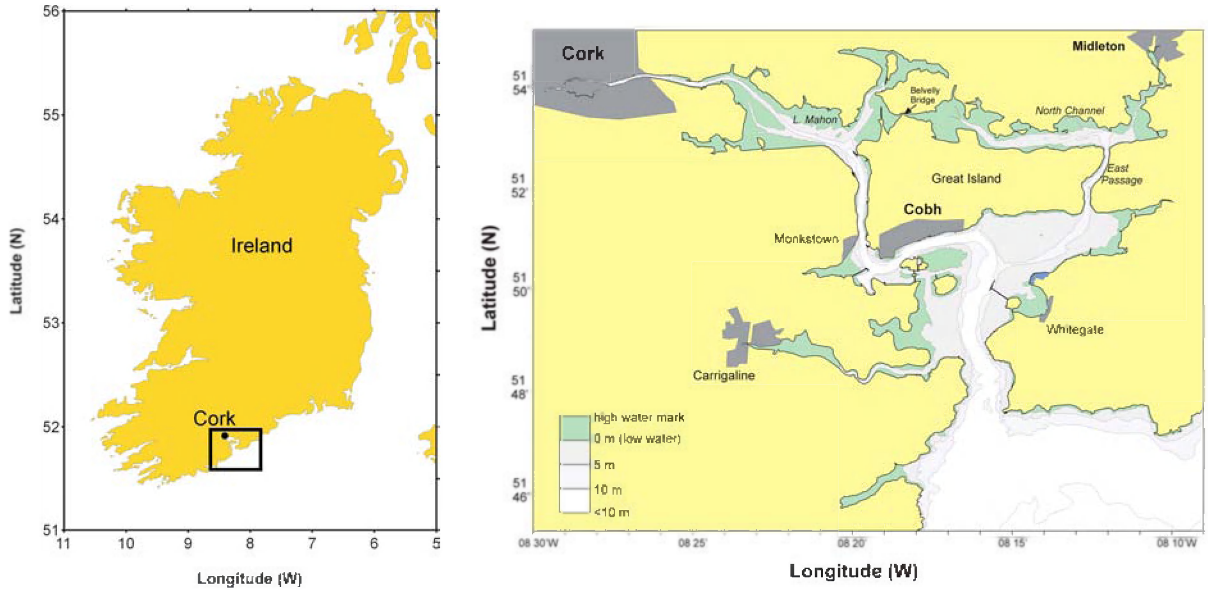


Fig. 21. Maps of Cork Harbour, Ireland (R. Raine, unpublished). The River Lee flows through Cork Harbour (see bottom map, top left corner).

5. Estuaries of Southern Ireland (Celtic Sea)

Cork Harbour is situated on the southern coast of Ireland (Fig. 21). It is a mussel and Pacific oyster (*Crassostrea gigas*) production region. At the inner end of the estuary is the city of Cork (pop. 250000) sited on the River Lee, a designated salmonid river, which is the main freshwater input to the estuary.

The estuary is a major port, both for container traffic and with a car ferry terminal to France and the United Kingdom, and also harbours the naval base and headquarters of the Irish navy at Haulbowline. The level of industrialisation in Cork Harbour, although not as high as 20 years ago, is still amongst the highest in estuarine areas in Ireland, and includes a number of large chemical and pharmaceutical plants around the upper and lower harbour. Ireland's only oil refinery is situated at Whitegate in the lower harbour. At low water, extensive areas of mud and sand-flats are exposed, particularly around Lough Mahon, near Monkstown and Whitegate, and in the North Channel.

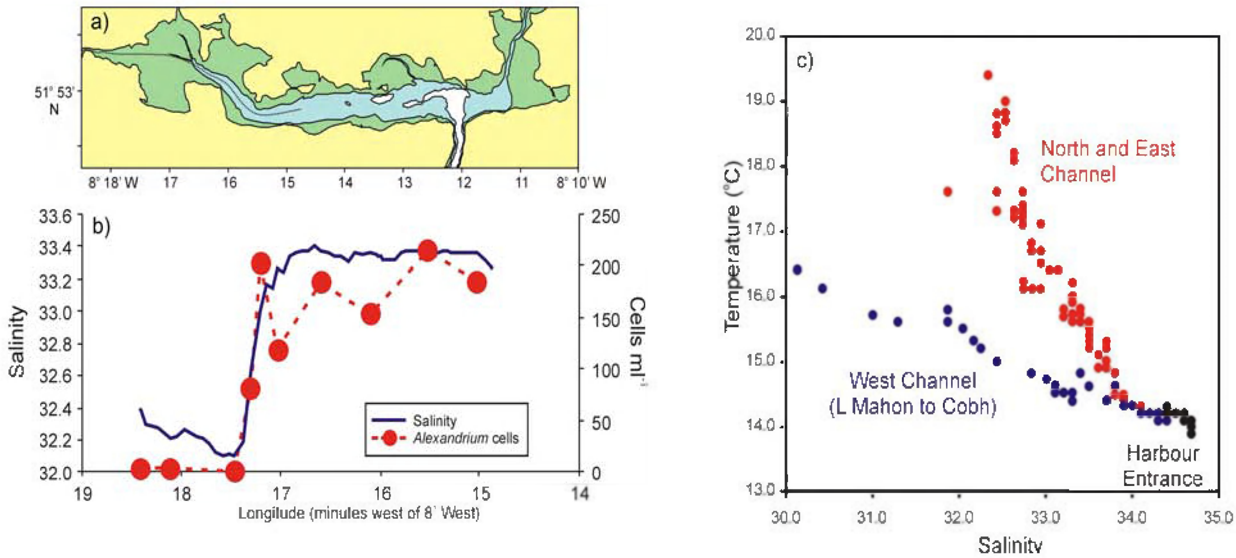


Fig. 22. The North Channel of Cork Harbour. a) Hydrographic features indicating its retentive nature; b) the salinity front present at the western end of the channel at high tide together with Alexandrium *cell densities during a toxic bloom; and c) a temperature-salinity plot of data from the whole of Cork Harbour showing the separation of the western and eastern channels (map from R. Raine, unpublished, and data courtesy of Ní Rathaille, 2007).*

Hydrographically, the estuary can be split into western and eastern sections. On a flood tide, water coming in from the sea splits into two; one branch flows west along the main channel through the west passage and on towards Cork. A second branch flows towards the east, through the East passage and into the North Channel. There is a slack tidal circulation in the region to the south east of Cobh. A physical model exists which mimics the circulation in Cork Harbour. This is a two-dimensional depth integrated model and is a modified form of the model DIVAST (Depth Integrated Velocities and Solute Transport) which is run by Marcon Computations Ltd., Galway.

The main HAB problem in Cork Harbour is from *Alexandrium* and contamination with PSP toxins. *Alexandrium* blooms are localized in the North Channel due to its retentive nature, which is evident from several hydrographic features, including temperature-salinity characteristics and a marked front at the western end of the North Channel at high tide; at low tide this entrance is dry (Fig. 22). Three species of *Alexandrium* occur in the North Channel, a non-toxic *A. tamarense*, *A. minutum* which produces GTX2 and GTX3, and a spirolide-producing *A. ostenfeldii*.

The dynamics of *Alexandrium* blooms are closely linked to physical forcing, principally tidal dilution. Dilution rates vary considerably and are relatively high at spring tides when the tidal range is large when compared with mean water depth (Fig. 23). Values are compatible with the maximum *Alexandrium* specific growth rate of 0.5 d^{-1}, derived from laboratory measurements using strains isolated from the area. The maximum achievable *in situ* growth rate is less than this due to high light attenuation of the water and, prior to June, cool water temperatures experienced in the North Channel. It has been calculated that, in the absence of tidal flushing, in excess of 10 days would be required to form a toxic bloom of around $<10^4$ cells l^{-1} of *A. minutum*. Thus, blooms do not materialise with average or equinoctial

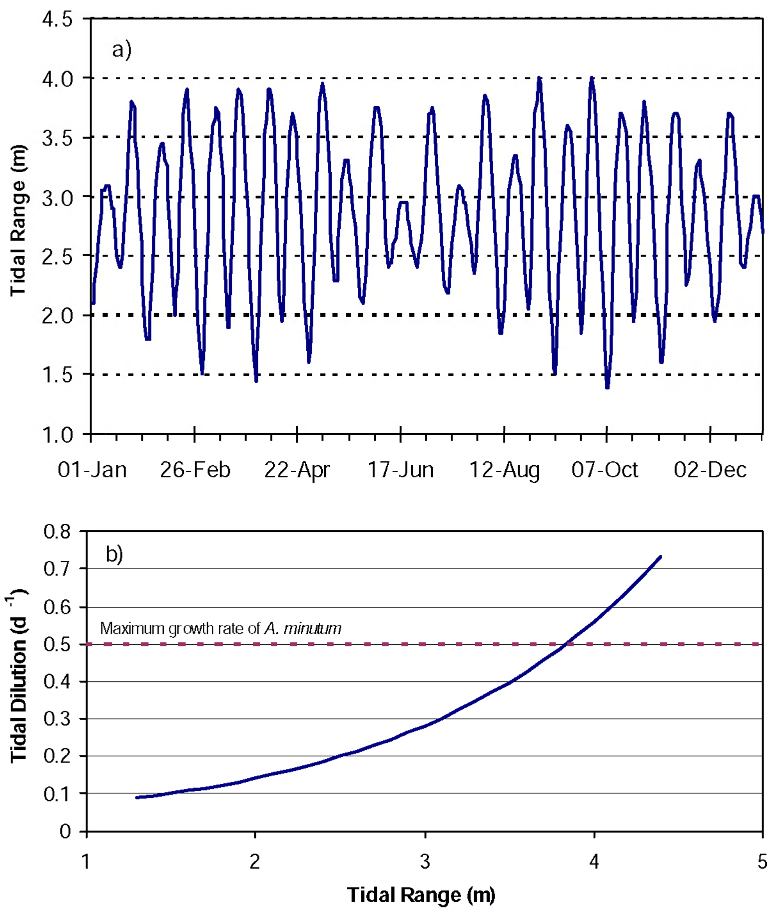


Fig. 23. Tidal dilution in the North channel, Cork Harbour, Ireland. a) Spring-neap tidal variation in tidal range throughout the year. The example given is for 2004. Note the low spring tides (maxima) in June (source: United Kingdom Hydrographic Office); and b) net tidal dilution in the western section of the North Channel, Cork Harbour as a function of tidal range. The data, courtesy of Ní Rathaille (2007), are derived from 2D hydrodynamic model runs for Cork Harbour, and observing the depletion in concentration of neutrally buoyant passive particles from the North Channel. The model applied is a depth-integrated vertically averaged solute transport model and details can be found in Ní Rathaille (2007). The maximum growth rate of Alexandrium minutum *is shown in comparable units.*

spring tides, and it is only in June, when smaller spring tides and correspondingly smaller tidal flushing rates occur, that blooms can develop. Coupled with an observed seasonal *in situ* excystment which is maximum in late spring and minimal in autumn (Ní Rathaille, 2007), *Alexandrium* blooms always initiate after the first spring tide in June (Fig. 24). The degree of physical forcing is also reflected in the dynamics of all three *Alexandrium* species, which are virtually identical to each other through summer (Touzet and Raine, 2009).

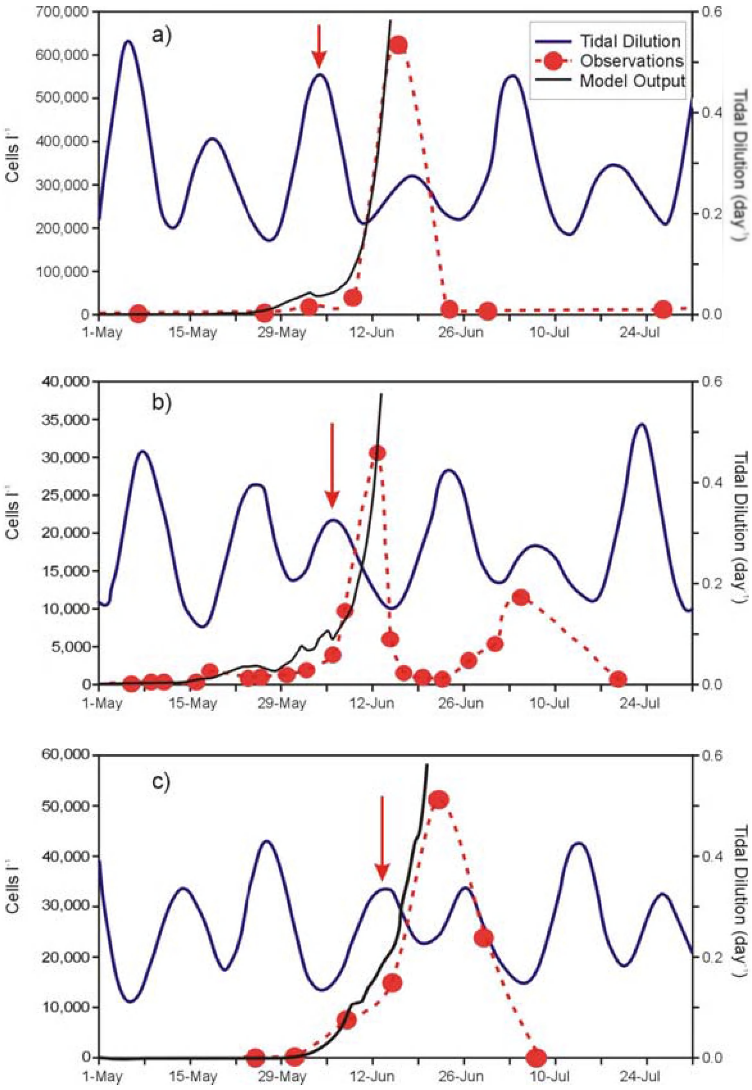


Fig. 24. Observations of Alexandrium *cell densities in the North Channel, Cork Harbour, Ireland in a) 2004, b) 2005 and c) 2006. Data are average values derived from a minimum of seven sampling stations and are plotted with tidal range. Note that blooms always arise after the first spring tide in June (arrowed). Also included are outputs from a simple growth model showing changes in cell biomass calculated as the balance between growth (as a function of temperature and irradiance) and export (tidal dilution) (Raine* et al.*, 2009). Details of the model can be found in Ní Rathaille (2007).*

IV. Research Priorities for Understanding HAB Dynamics in Fjords and Coastal Embayments

The highest priority research activities for understanding HAB dynamics in fjords and coastal embayments were discussed at the CRP workshop and have been subsequently refined. The following list of key questions was established:

A. *Are there definable adaptive strategies that characterize HAB species in confined and semi-confined systems?* An ecologically based classification of the different species found in fjords and coastal embayments should be carried out based on their adaptation to the multiple sub-habitats characteristic of such ecosystems. This should be done with consideration of the type of connection that dominates the confined or semi-confined system: oceanic, land or sediment, and depending on morphology, depth and circulation. The functional role of morphological, physiological, behavioural and life-history characteristics, at the cellular level, should be included in this classification of HAB species in coastal embayments.

B. *What is the importance of life history transitions and cyst distribution in bloom initiation and maintenance – endogenous seed beds versus exogenous introduction?* The seeding strategies employed by HAB species within coastal systems should be identified. Transitions between the vegetative cycle and sexual cycle and a cycle involving the formation of short term temporary (pellicular) cysts, small-sized cells or aggregates (often in response to short-term environmental fluctuations) need to be identified and understood for each study site. Establishment of the sites of HAB initiation and characterisation of environmental influences on the life history stages of HAB species is a priority in developing a predictive capability.

C. *How do physical dispersion and aggregation processes within a semi-confined basin affect HAB growth and distribution?* The influence of small-scale physical processes on the growth and dispersion of HAB species should be determined. Thin layers of phytoplankton (and often also of their grazers) frequently occur under calm conditions that may be encountered in fjords and coastal embayments (e.g. Bjørnsen and Nielsen, 1991; McManus *et al.*, 2003). This vertical structure needs to be taken into account for field sampling. Turbulent mixing determines much high-frequency environmental fluctuation and in so doing can control nutrient, irradiance, and phytoplankton patchiness, and is also known to affect plankton growth rates and other physiological aspects. Varying responses in terms of the succession of species within and between embayment systems will allow inferences of the properties regulating species succession and the development of HABs.

D. *What is the relative contribution of nutrient flux and supply ratios to HAB dynamics in eutrophic versus non-eutrophic coastal embayments?* The nutritional physiology of target species should be investigated as related to the natural variation in nutrient signals. Although time-series field measurements of nutrient concentrations can provide valuable insight to nutrient dynamics, provided that trans-boundary fluxes are quantified, direct measurements of regeneration and assimilation rates also need to be performed using isotope tracer methods. These measurements will serve to provide meaningful input to biogeochemical models that can be employed in a predictive manner when coupled with the primary hydrodynamic forcing typical of fjords and coastal embayments. Organic forms of nitrogen and phosphorus should also be considered, since they can play an important role in the dynamics of particular species, as exemplified by the growth-promoting role of humic acids for *Alexandrium* spp. (Gagnon *et al.*, 2005).

E. *What is the importance of spatial scale and retention time in the expression and effects of allelochemicals/toxins in semi-confined systems?* The production of allelochemicals — biologically active components eliciting specific responses in target organisms — may be an important mediator of intra- and inter-specific interactions and may play a role in chemical defence of cells. Other hypothetical functions of allelochemicals include a critical role in cell-to-cell communication, involving processes such as sexuality and life history transitions (Wyatt and Jenkinson, 1997), chemotaxis and apoptosis («programmed cell death»). The role of phycotoxins in chemical defence against predators or algal and bacterial competitors remains largely unresolved, and their function as allelochemicals is increasingly under scrutiny (Cembella, 2003). Concentration of toxin-producing cells of a HAB population into a thin layer would facilitate the development of an effective concentration against target organisms, via creation of a «toxic cloud». In partially enclosed embayments and fjords that can act as retention zones for allelochemical-producing microalgae, the opportunity for enhanced concentration and hence intensified allelochemical activity may be offered via «quorum sensing» as observed in bacterial populations. In any case, a potential disadvantage or «trade-off» associated with the formation and maintenance of HAB populations in thin layers or other retention zones is the problem of auto-inhibition or auto-toxicity resulting from excretion or leakage of the allelochemical into the surrounding medium (e.g. Gentien *et al.*, 2007). At the termination of the bloom, larger quantities of these endogenous metabolites would be released via cell lysis and decay. Nevertheless, it is expected that the deleterious consequences of this bulk release may be more dramatic upon grazers and competitors within the retention zone than upon the producing organisms.

F. *How do embayment morphology, bathymetry and hydrodynamics affect HAB dynamics?* The fjords, inlets, estuaries, and coastal areas where HABs often occur are frequently characterized by complex geometry and bathymetry which can include islands, barriers, creeks and intertidal wetlands. These geometric features can create multi-scale physical processes such as vertical mixing, lateral dispersion, complex tidal currents and internal tides, high-frequency internal waves, eddies, and estuarine-shelf interaction. There is a clear need to better understand and model these complex multi-scale water transport and mixing processes. In addition, the resolution of the hydrodynamic models should match the spatial and temporal variation scales at which HABs occur. Altogether, this will definitively contribute to the understanding and modeling of HABs (see also section V.E. Co-ordination of Modelling Activities).

G. *Are the effects of human activities (e.g. aquaculture) and global climate change on HAB dynamics magnified in enclosed and semi-enclosed embayments?* More specifically, does the increased reliance on coastal aquaculture for proteins from the sea increase the risk of HAB events? Do these activities directly or indirectly affect the distribution of harmful microalgae? Is grazing on HAB species altered in aquaculture sites due to the presence of farmed organisms or epibenthos fixed on these? All these questions can best be addressed by careful local investigation of site-specific consequences of introduction of new aquaculture stock and the risk of human transfer of alien species (including those of HABs) into coastal regimes, for example, via ballast water discharge. Ports and harbours are particularly vulnerable and can act to seed HAB events in adjacent confined waters of embayments. Efforts must also be made to determine whether or not climate indicators can be identified as predictors of HAB events in coastal embayments. Research is required to relate the effects of climate change, and associated variation in the predominant physical and chemical forcing mechanisms, on HAB species and communities that typify coastal environments. Action could be taken to accurately define the specific data and samples to take in upcoming years, in order to «optimize» the tools for analysis to be conducted by future generations on the impact climate change may have on HAB events in coastal ecosystems, on a large-scale basis.

V. Framework Activities

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

A. Scientific Networking and Coordination of Resources

GEOHAB CRPs are coordinated by the GEOHAB SSC through the establishment of separate sub-committees for each CRP composed of SSC members and leaders of CRP activities. The sub-committees will primarily work by correspondence, but may also meet on an opportunistic basis and when identified resources allow for meetings to address major planning and co-ordination issues. The subcommittee for each CRP will work with the GEOHAB SSC to encourage scientific networking and co-ordinate research activities and resources.

An important aspect of international activities like GEOHAB is the sharing of scarce resources among participating nations. Such sharing makes possible research activities of a scale and breadth that are not otherwise feasible, and thereby enable the comparison of ecosystems of a similar type in different parts of the world. The CRP on **HABs in Fjords and Coastal Embayments** will promote the application of national resources, in terms of scientific expertise, sampling platforms and equipment to the key research questions identified in this document. GEOHAB has already initiated the sharing of expertise and development of an international research community on the CRP topic by supporting the OSM. GEOHAB will continue to promote sharing of expertise by creating a CRP Subcommittee to help implement this research plan. Presently, international GEOHAB activities are sponsored primarily by funding from IOC, SCOR (through grants from the U.S. National Science Foundation), and National Oceanic and Atmospheric Administration. Development of the CRP will depend on increased funding from other national and international organizations.

GEOHAB will identify, and draw the attention of responsible bodies to opportunities for co-ordination of resources that will add value to ongoing and planned research. Individuals involved in studying each key question will be responsible for developing plans relating to the sharing of expertise and equipment and how they will contribute to the continued coordination of the CRP. Collaboration among CRPs is encouraged. In the case of the CRP on HABs in Fjords and Coastal Embayments, there will be coordination with the research underway in the other CRPs, notably on Eutrophication and on Stratification, as the work involved in these CRPs is frequently in coastal regions.

GEOHAB and the CRP Subcommittee will encourage the publication of results from the CRP in relevant peer-reviewed scientific journals, with appropriate reference to the relation of the research to GEOHAB. In addition to this publication in the primary scientific literature, GEOHAB will seek to disseminate both current developments within the programme and research results more broadly to the worldwide community of managers and scientists interested in HABs. *Harmful Algae News* is distributed regularly by the IOC and is available as a forum to communicate news of GEOHAB activities and research results. It is the responsibility of each CRP sub-committee to announce events, calls for proposal contributions, availability of core research working documents and results, and summaries of these, in *Harmful Algae News* and through the GEOHAB Web site.

The CRP Subcommittee will promote the involvement of individuals from the major targeted ecosystems described in this report but also will assist in building upon this nucleus of key study sites by adding new project elements, comparative locations and scientific teams and expertise. The CRP will also assist the scientific teams working on the different questions and technologies to work together. Successful conduct of research on this topic will require the pooling, coordination, and joint use of several different types of measurement platforms such as ships, moorings for *in situ* observations and satellite or aircraft-based remote data, when applicable to small embayments and fjords.

B. Data Management and Data Sharing

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 has worked with other international marine research projects to develop basic guidelines for data management and sharing (see www.scor-int.org/DataMgmtActivity.htm). Each CRP will need to develop its own specific plan, conforming to the principles adopted by GEOHAB.

GEOHAB applies a decentralised data management and distribution system with a centralised index. The components 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. 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. Each GEOHAB CRP should address the long-term archival of observational data and data products to ensure a lasting contribution to marine science. Data will be shared with the Harmful Algal Information System (HAIS, www.iode.org/haedat/), which will, when fully established, consist of access to information on harmful algal events, harmful algae monitoring and management systems worldwide, current use of taxonomic names of harmful algae, and information on biogeography of harmful algal species. Supplementary components include an expert directory and a bibliography. The HAIS is being built in cooperation with the World Register of Marine Species (WoRMS, www.marinespecies.org), the International Council for the Exploration of the Seas (ICES, www.ices.dk), the North Pacific Marine Sciences Organization (PICES, www.pices.int) and the International Society for the Study of Harmful Algae (ISSHA, www.issha.org). The Harmful Algae Events Database (HAEDAT, www.iode.org/haedat/) is a meta-database containing records of harmful algal events. HAEDAT contains records from the ICES area (North Atlantic) since 1985 and from the PICES area (North Pacific) since 2000. IOC Regional networks in South America and North Africa are prepared to contribute.

C. Protocols and Quality Control

Specification of protocols within elements of the CRP will ensure that data generated are reliable and compatible, thereby facilitating synthesis and modelling. Each key question will require measurement of somewhat different parameters, although for each question, a set of parameters should be measured in each region. Likewise, the CRP will include a set of core parameters (along with standard measurement protocols) that will be measured in each location. This information will make it possible to draw inferences across systems, to construct models of HABs in fjords and coastal embayments, and to contribute information that will be useful for other CRPs.

Recommendations on methods and measurements will be disseminated through the GEOHAB Web site. The methods adopted to ensure quality control and the protocols used for data collection will be fully documented in information files (meta-data) accompanying data sets. Well-defined, internationally agreed descriptions of methods will be adopted where possible. Where required, the GEOHAB SSC will initiate Framework Activities that lead to the development of appropriate protocols and methods to ensure data collection in a uniform manner for comparative studies. GEOHAB investigators retain the primary responsibility for quality control and assurance.

D. Capacity Building

GEOHAB encourages a «training through research» approach that offers opportunities for student participation in field work and instruction in marine research disciplines relevant to HABs. Exchange of post-doctoral fellows and senior scientists are equally important for the CRPs. Training activities that would benefit GEOHAB research will be organised by the GEOHAB SSC and proposals for specific training activities can be submitted to the SSC for endorsement as GEOHAB activities.

E. Co-ordination of Modelling Activities

Models based on frequent monitoring have already been developed for a number of the sites identified as key field sites for the CRP on Fjords and Coastal Embayments. These need to be compared and tested for other sites or for different years. These models need to take into account import and export of material from the embayments or fjords, as this often influences nutrient supply and growth of HAB species or their retention inside the embayments. Models should also incorporate various functional groups in an ecosystem-type approach. This requires a good knowledge of the relationships between HAB species and biotic (e.g. vertical migration, grazing) and abiotic (e.g. stratification, mixing, advection) factors controlling their growth and population dynamics. Models also need to couple a benthic sub-model (see life–history transitions) and a pelagic sub-model (bloom in the water column) to a physical circulation model. Functional-based models should be compared to individual-based models to identify the best predictors of HAB events. As stated earlier (Section IV.F.), hydrodynamic models should resolve complex multi-scale water transport and mixing processes with a similar resolution of the spatial and temporal scales at which HABs occur. A state-of-the-art model will require (1) grid flexibility to resolve complex coastline and bathymetry, (2) mass conservation to accurately simulate volume and mass transports, (3) both hydrostatic and non-hydrostatic dynamics to capture large- to small-scale physics, (4) proper parameterization of vertical and lateral mixing to produce realistic stratification, (5) modular design to allow easy selection of the essential model components needed in different applications and multi-domain nesting, and (6) ability to use a wide variety of input data, especially as real-time atmospheric and coastal ocean measurements become more available.

The hydrodynamics in this model also requires coupling fully with surface wave and sediment processes to resolve the realistic embayment morphology and morphology-induced change of the water movement. A good candidate for such a model is an unstructured-grid finite-volume coastal ocean model (Fig. 25). There are many open-source code unstructured-grid hydrodynamics models available for HAB studies. Examples include FVCOM (finite-volume) (fvcom.smast.umassd.edu), ADCIRC (finite-element) (www.adcirc.org), ICOM (finite-element) (amcg.ese.ic.ac.uk/index.php?title=ICOM). FVCOM (Finite-Volume Coastal Ocean Model) is a prognostic, unstructured-grid, finite-volume, free-surface, 3-D primitive equation ocean model (Chen *et al.*, 2003, 2006a,b, 2007), which is particularly interesting in the context of HAB studies in coastal regions. A Smagorinsky (1963) formulation is used to parameterize the horizontal diffusion and turbulent vertical mixing is calculated with the General Ocean Turbulence Model (GOTM) libraries (Burchard, 2002). FVCOM features a number of options and components, including (1) non-hydrostatic dynamics (NH-FVCOM), (2) a 3-D sediment transport module (called FVCOM-SED), (3) 4-D nudging and Kalman Filters for data assimilation, (4) an unstructured-grid version of the Simulating Waves Nearshore (SWAN) surface wave model (called FVCOM-SWAVE), (5) the Generalized Biological Module (GBM) that allow users to select either a pre-built biological model (such as NPZ, NPZD, etc.) or construct their own biological model using the pre-defined pool of biological variables and parameterization functions, and (6) a set of water quality models. FVCOM-SWAVE and FVCOM-SED have been coupled into

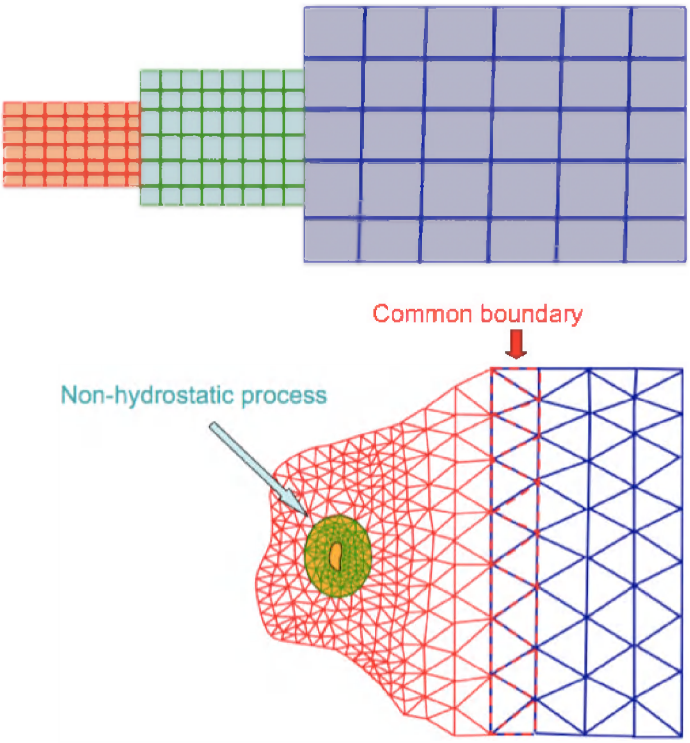


Fig. 25. Illustration of multi-domain nesting approached in structured grid (finite-difference) models (upper panel) and unstructured grid (finite-volume or finite-element) models (lower panel; both panels from C. Chen, unpublished). The structured grid model requires an interpolation at nesting boundary to match two domains, while with common cells at the boundary, an unstructured grid model can ensure the mass conservation and also avoid numerical energy accumulation due to grid mismatching at nesting meshes. The unstructured grid nesting allows the model to be run under different physics for large- to small-scale processes in various subdomains. For more information, see the website: http//fvcom.smast.umassd.edu/research_projects/NECOFS/index.html

FVCOM to simulate the impact of wave-current interactions on sediment transport and water currents (with eventual inclusion of dinoflagellate cysts). A nesting software module is built into FVCOM that allows it to run simultaneously multi-sub-regional FVCOM domains through nesting with the regional FVCOM (Fig. 26). The modular approach used in FVCOM will facilitate the addition of HAB dynamics and the development of a forecast model system for the spatial and temporal evolution of a HAB.

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. It may also be necessary to initiate new modelling activities. The CRP Steering Committee will interact closely with the GEOHAB Modelling Subcommittee, to ensure that the results of the CRP are included in GEOHAB models and that the CRP collects data needed to parameterize GEOHAB models and create appropriate equations for the models. An upcoming Report of the GEOHAB Modelling Workshop developed in Galway (Ireland) on June 2009 will be soon available on the GEOHAB webpage.

F. Interaction With Other International Programmes and Projects

GEOHAB exists in the context of several other large international programmes and projects that study aspects of global change that could be relevant to the CRP. Of special strategic importance to the development of the CRP on HABs in Fjords and Coastal Embayments will be the linkages with the Land-Ocean Interactions in the Coastal Zone (LOICZ) project (www.loicz.org). Key questions must be addressed in relation to other international efforts on the study of coastal processes, particularly in relation to seeding strategies, nutrient supply, and climate indicators:

- Seeding Strategies—Some HAB species, specifically those that form cysts, are seeded from one HAB event to another. Cysts typically fall to the seafloor and stay there until they are resuspended or excysted, sometimes for several years. Sampling of cysts in sediments provides opportunities to study bloom initiation, and possibly to correlate blooms with other ocean conditions through known paleoceanographic indicators. IMAGES (International Marine Aspects of Global Change Study, www.images-pages.org) is a sub-project of the Past Global Changes (PAGES) project, and was initiated to respond to the challenge of understanding the mechanisms and consequences of climatic changes using oceanic sedimentary records. IMAGES collects large-diameter cores in many coastal areas of the world, specifically to examine paleoceanographic conditions of the past 0 to 40000 years. The CRP will seek opportunities to work with IMAGES to analyze previously collected samples and to relate cyst information with other paleoceanographic variables.
- Nutrient Supply—LOICZ has compiled information about the supply of macro-nutrients from the land to the ocean, information that could be useful to the CRP in studying the relationship between nutrient supply (amount, rate, timing, and sequence), type (inorganic versus organic), and ratios, and HABs. The IOC-affiliated Global Nutrient Export from Watersheds (Global *NEWS*, marine.rutgers.edu/globalnews/mission.htm) is developing nutrient export models, from river loads to quantitative assessments of coastal ecosystem health. The planned Global Nutrient Export from Watersheds 2, User Scenario Evaluation (NEWS2USE) will focus on quantitative analysis of impacts of nutrient loading and changing nutrient stoichiometry in coastal ecosystems. This is of great interest to several of GEOHAB's CRPs, including this one. The SCOR-IGBP Integrated Marine Biogeochemistry and Ecosystem Research (IMBER, www.imber.info) project develops a predictive understanding of how marine biogeochemical cycles and ecosystems respond to complex forcings, such as large-scale climatic variations, changing physical dynamics, carbon cycle chemistry and nutrient fluxes, and the impacts of marine harvesting. Some of IMBER's activities might provide useful input to the CRP and in integration of activities among other GEOHAB CRPs. The International Nitrogen Initiative (INI, www.initrogen.org) is another global effort to examine the flows of nitrogen and related problems in several targeted regions of the world. A follow-up of these various initiatives will be facilitated by consultation with the CRP on HABs in Eutrophic Systems, which focuses on the role of increased eutrophication on the occurrence of HABs and their harmful effects.
- Climate Indicators—A programme of the World Climate Research Programme called Climate Variability and Prediction (CLIVAR, www.clivar.org) is studying how climate oscillations, such as ENSO and NAO, operate and are expressed in the ocean and atmosphere. The influence of climate change on HAB dynamics in fjords and coastal embayments is of special interest to this CRP, hence collaboration with CLIVAR or other climate-related programmes such as the Global Energy and Water Cycle Experiment (GEWEX, www.gewex.org) would be beneficial.

- Monitoring and Observation Systems—The Global Ocean Observing System (GOOS, www.ioc-goos.org) could provide important information for this CRP, insofar as GOOS provides long-term continuous monitoring in coastal areas. GEOHAB has linkage with GOOS through IOC, which sponsors both programmes.
- Invasive Species—Following several aquatic invasion events with severe negative influences and important economic costs, the International Maritime Organization (IMO) set up a series of guidelines to reduce this world-wide threat to coastal waters. Several national programmes now examine the types and abundance of organisms that travel through ballast water or sediment, or attached to ship hulls. These programmes, such as the Canadian Aquatic Invasive Species Network (CAISN, www.caisn.ca) or the international GloBallast programme (globallast.imo.org) can provide information on potentially harmful invasive microalgae being brought in through marine transportation. This influx of non-indigenous species can affect the local dynamics of harmful algae in several ways and will need to be considered in future efforts to understand coastal responses of harmful algae.

VI. Next Steps

This document presents the basis for a comparative research project of GEOHAB, with each of the seven key questions being addressed by one or more teams of scientists funded through national or international funding mechanisms.

Several steps need to be taken following publication of this plan, to ensure that the research is funded and coordinated appropriately:

1. The plan must be disseminated to the interested research community and to the national agencies that fund HAB research. National GEOHAB committees should help in this effort. This step will be most effective if carried out by national scientists, but SCOR and IOC will also help distribute the plan to their member nations.
2. National and international teams of scientists must propose research related to the key questions, and affiliate their research to international GEOHAB, to ensure that the CRP is coordinated.

The GEOHAB SSC provides international coordination for the CRP through the following actions:

1. Establishment and operation of a GEOHAB CRP Subcommittee on Fjords and Coastal Embayments. This subcommittee is responsible to work with scientists involved in the CRP to ensure that they coordinate their research, using the same measurement protocols, sharing data, and contributing to model development. One or two members of the CRP Subcommittee will be members of the international GEOHAB SSC, to ensure a strong linkage between the subcommittee and the SSC. The work of the subcommittee will be conducted primarily by email.
2. Assistance from the GEOHAB Modelling Subcommittee. The GEOHAB Modelling Subcommittee will assist CRP scientists in locating and applying appropriate physical-biological models that can be applied in the coastal systems to HAB research questions.
3. Work with the CRP Subcommittee to identify priority targeted research.
4. Work with the Global Ocean Observing System (GOOS) to ensure that GOOS observations are available and useful to the CRP scientists.
5. Provide access to *Harmful Algae News* and the GEOHAB Web site to promote communication among CRP scientists.
6. Provide assistance in tracking research planned, funded, ongoing, and completed, including maintaining metadata records of data holdings by individual scientists and scientific teams.
7. Communicate with national and international funding agencies about the need for funding for general and targeted research.

Finally, several priority Targeted Research activities need to be undertaken to enable scientific advances of our understanding of HABs in fjords and coastal embayments. The GEOHAB *Implementation Plan* defines Targeted Research as research that «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:

- *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*
- *Development and comparison of specific models and observational systems*

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 focused 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 inter-calibration are targeted activities, valuable in their own right, yet are also essential to conduct comprehensive field studies and modelling in Core Research Projects.

Targeted research activities particularly needed for the CRP on Fjords and Coastal Embayments include:

- Development of molecular probes for the detection of toxigenic species and genes responsible for toxin production
- Development of molecular techniques to identify HAB life-cycle stages and the status/viability of cysts and over-wintering stages
- Development of biochemical indicators of non-cyst-forming HABs
- Development of methods to trace encystment/excystment events in the field

- Development of HAB models that include encystment/ excystment
- Laboratory research on triggers of encystment and excystment
- Laboratory/mesocosm studies of the behaviour and toxin production of HAB species in simulated natural conditions (including a variety of physical and nutrient conditions)
- Improvement of methods for satellite, aircraft or weather balloon detection of HABs, and expanded development of *in situ* sensor systems (moorings, profilers, drifters, and autonomous vehicles, etc.) particularly for the often small spatial scale of fjords and coastal embayments
- Establishment of a collection of isolates of HAB species from the target regions linked to a Framework Activity
- Documentation of the biogeography of target species in coastal embayments over time
- Creation of a database of HAB events over time in relation to climate cycles

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Appendix I
Open Science Meeting Programme

HABS in Fjords and Coastal Embayments
Viña del Mar, Chile
26-29 April 2004

Conveners

Allan Cembella, Germany
Leonardo Guzmán, Chile

Co-ordinating Committee

Jorge Diogène, Spain
Bengt Karlson, Sweden
John Largier, USA
Suzanne Roy, Canada

Assistance with Meeting Preparation

Henrik Envoldsen, IOC
Elizabeth Gross, SCOR
Phyllis Steiner, SCOR
Ed Urban, SCOR

Assistance with Meeting Preparation (Chilean group)

Alejandro Cabezas (CONA)
Karim Kaiser (SHOA)
Miriam Seguel (Universidad Austral)
Alejandro Clément (Plancton Andino Ltda.)

PROGRAMME SUMMARY

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30 April</th></tr>
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Poster Set-up
8:00 – 9:30am</td><td></td><td></td><td></td><td rowspan="11">SESSION 10

Planning Committee Meets in Closed Session to Write Meeting Report</td></tr>
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Opening Remarks

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SESSION 3</td><td>9:00
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Reception Hosted by CONA</td><td>16:20
Posters</td><td>20:30
Group Dinner</td><td></td></tr>
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DETAILED PROGRAMME

Monday, 26 April

9:30 – 10:15 ***Welcome and Introductory Addresses***

Roberto Garnham, Presidente del Comité Oceanográfico Nacional
Leonardo Guzmán, Co-convenor of the Open Science Meeting
Ed Urban, Executive Director, Scientific Committee on Oceanic Research (SCOR)
Henrik Enevoldsen, Intergovernmental Oceanographic Commission (IOC)

10:15 – 10:35 *The GEOHAB Mission and Comparative Approach: Core Research and Relevant Activities* – Grant Pitcher, *GEOHAB Scientific Steering Committee Chairman*

SESSION 1: Bloom characteristics in fjords and coastal embayments

10:45 – 11:30 *Unique features and processes that characterize HAB dynamics in enclosed and semi-enclosed coastal basins* – Allan Cembella, *Alfred Wegener Institute, Bremerhaven, Germany*

11:35 – 11:55 COFFEE BREAK

11:55 – 12:40 *Harmful algal blooms in the Chilean fjords* – Alejandro Clément, *Plancton Andino, Puerto Varas, Chile*

12:45 – 14:00 LUNCH

14:00 – 14:45 *HABs in Mediterranean coastal embayments: comparisons with high temperate latitudes* – Jorge Diogène, *IRTA, Sant Carles de la Ràpita, Spain*

14:50 – 15:20 Session 1: General Discussion and Questions

15:20 – 15:40 COFFEE BREAK

15:40 – 17:00 Rotating Presentations of the Posters (Session 1)

17:00 – 17:30 General Discussion and Questions from Poster Session

17:30 Adjourn for the Day

20:30 Reception

Tuesday, 27 April

SESSION 2: Biological-chemical processes and bloom dynamics in fjords and coastal embayments

09:00 – 09:45 *In situ determination of extracellular biotoxins and other potential allelochemicals in seawater* – Lincoln MacKenzie, *Cawthron Institute, Nelson, New Zealand*

09:50 – 10:35 *Cyst dynamics in coastal embayments* – Suzanne Roy, *ISMER, Université du Québec à Rimouski, Rimouski, Canada*

10:40 – 11:00 COFFEE BREAK

11:00 – 11:45 *Life cycle strategies and in situ growth rate of HAB species in semi-enclosed systems* – Beatriz Reguera, *Instituto Español de Oceanographía, Vigo, Spain*

11:50 – 12:20 Session 2: General Discussion and Questions

12:20 – 13:45 LUNCH

SESSION 3: Development and implementation of observational and monitoring systems for bloom dynamics in coastal areas

13:45 – 14:30 *The Magellan Region Monitoring Programme: Integration and use of monitoring data on toxicity and HABs for scientific studies* – Leonardo Guzmán, *Instituto de Fomento Pesquero, Puerto Montt, Chile*

14:35 – 15:10 *Korean monitoring for the initiation and subsequent development of ichthyotoxic Cochlodinium polykrikoides blooms and fuzzy prediction* – Hak-Gyoon Kim, *Department of Oceanography and Marine Environment, National Fisheries Research & Development Institute, Pusan, Korea*

15:15 – 15:30 COFFEE BREAK

15:30 – 16:15 *Optical monitoring and moorages for bloom surveillance in coastal embayments* – Bengt Karlson, *Swedish Meteorological and Hydrological Institute, Västra Frölunda, Sweden*

16:20 – 17:30 Rotating Presentations of the Posters (Session 2)

17:30 – 18:00 General Discussion and Questions from Poster Session

18:00 Adjourn for the Day

Wednesday, 28 April

SESSION 3 (*continued*): Development and implementation of observational and monitoring systems for bloom dynamics in coastal areas

09:00 – 09:45 *Fine-scale measurements and vertical stratification of plankton in thin-layers in embayments* – Percy Donahay, *GSO, University of Rhode Island, Narragansett, USA*

09:50 – 10:20 Session 3: General Discussion and Questions

10:20 – 10:40 COFFEE BREAK

SESSION 4: Integrated modelling of HAB dynamics with specific attention to fjords and coastal embayments

10:40 – 11:25 *Circulation in bays: Stratification, retention, and exchange processes* – John Largier, *Scripps Institution of Oceanography, San Diego, USA*

11:30 – 12:15 *Multi-parameter ecosystem models as tools for process modelling and prediction of HABs in fjords and coastal embayments* - J. Icarus Allen, *Plymouth Marine Laboratory, Plymouth, UK*

12:20 – 14:00 LUNCH

14:00 – 14:45 *Numerical modelling: Physical/biological coupling in coastal ecosystems* – Wolfgang Fennel, *Baltic Sea Research Institute, Rostock, Germany*

14:50 – 15:20 Session 4: General Discussion and Questions

15:20 – 15:40 COFFEE BREAK

15:40 – 17:30 Group photograph and Afternoon Excursion Activity

20:30 GROUP DINNER

Thursday, 29 April

9:00 – 10:00

SESSION 5: Identification of interested participants and designated regions for comparative research

10:00 – 10:20 COFFEE BREAK

10:20 – 11:30 Rotating Presentations of the Posters (Session 3)

11:30 – 12:00 General Discussion and Questions from Poster Session

12:00 – 13:30 LUNCH

13:30 – 15:00

SESSION 6: Review of current national and regional projects/programmes in order to identify elements of research that could contribute to the core research

SESSION 7: Identification of gaps in national and regional research projects/programmes

15:00 – 15:20 COFFEE BREAK

15:20 – 16:30

SESSION 8: Formulation and design of a plan to guide core research in fjords and coastal embayments (Session Theme groups; plenary discussion)

16:30 – 17:30

SESSION 9: Identification of framework activities to support the research plan (Session Theme groups; plenary discussion)

17:30 – 18:00 Wrap-up plenary discussion

18:00 Adjourn

Friday 30 April

SESSION 10—CLOSED SESSION: Meeting of the Core Research Project Co-ordinating Committee to prepare a report of the Open Science Meeting comprising an implementation plan to guide core research

Appendix II – Meeting Participants

GEOHAB Open Science Meeting on HABs in Fjords and Coastal Embayments

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Appendix III
List of OSM Poster Presentations

The extended abstracts of all OSM poster presentations have been posted on the GEOHAB Web site, and can be found at the following Web address:

http://www.geohab.info/index.php?option=com_content&task=view&id=37&Itemid=66

List of Poster Presentations

(alphabetical list, based on first author's name)

Distribution of toxic algae blooms of *Alexandrium catenella* and their impact upon the Chiloé Archipelago

Aguilera, A.,[1] Arriagada, G.,[3] Caniggia, M.,[2] Clément, A.,[1] Contreras, V.,[2] Córdova, M.,[2] Dressmann, S.,[1] Fonseca, M.,[2] Fuentes, C.,[1] Gárate, C.G.,[2] López, A.,[2] Silva, L.,[2] Suárez, B.[2]

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[2]Laboratorio de Toxinas Marinas, Facultad de Medicina, ICBM, Universidad de Chile

[3]Facultad de Ciencias Vet. y Pecuarias, Universidad de Chile, Chile

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Circulation patterns in fjords of Southern Chile

Cáceres, M.

Hydrographic and Oceanographic Service of Chilean Navy, Valparaíso, Chile

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Studies on the role of UV radiation in harmful algae blooms dynamic: The adaptive strategies of *Alexandrium catenella*

Carreto, J.I., Carignan, M.O., Montoya, N.G.

Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP).Paseo Ocampo N° 1-B7602HSA-7600 Mar del Plata, Argentina

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Temperature and harmful algae in Aysen Fjord (45°26´S 73°00´W), Chile, between 1993 and 1999

Cassis, D.,[1] Avaria, S.,[2] Muñoz, P.[2]

[1]Department of Earth and Ocean Sciences, University of British Columbia, Rm. 1461, 6270 University Blvd., Vancouver, British Columbia, Canada.

[2]Facultad de Ciencias del Mar, Universidad de Valparaíso, Casilla 13-D, Viña del Mar, Chile.

***Pfiesteria*-like dinoflagellates, the misunderstood phantoms**

Cassis, D., Taylor, F.J.R.

Department of Earth and Ocean Sciences, University of British Columbia, Rm. 1461, 6270 University Blvd., Vancouver, British Columbia, Canada

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First approximation to a multidisciplinary study in a fjord system associated with PSP outbreaks and *Alexandrium catenella* blooms

Frangópulos, M.,[1] Pizarro, G.,[2] Guzmán, L.,[2] Blanco, J.L.,[3] Valle-Levinson, A.,[3] Torres, R.[4]

[1]Centro de Estudios del Cuaternario Fuego – Patagonia (CEQUA), Chile

[2]Instituto de Fomento Pesquero, IFOP, Chile

[3]Old Dominion University, Norfolk, USA

[4]Universidad de Concepción, Chile

Gene global expression of toxic dinoflagellate *Alexandrium catenella* in nitrate depletion conditions

Fuentes, S.,[1] Amaro, A.M.,[2] Suárez, B.[2]

[1]University of Louisiana at Lafayette, Biology Department, LA, USA

[2]Universidad de Chile, Facultad de Medicina, ICBM, Laboratorio de Toxinas Marinas, Santiago, Chile

Distribution patterns of *Alexandrium tamarense* (Lebour) Balech populations in the Golfo Nuevo (Patagonia, Argentina)

Gayoso, A.M., Fulco, V.K.

Fulco Centro Nacional Patagónico. Bv. Brown s/n, 9120 Puerto Madryn, Argentina

Kin selection in phytoplankton endotoxin producers?

Guisande, C.,[1] Frangópulos, M.,[2] Barreiro, A.,[1] Maneiro, I.,[1] Riveiro, I.,[1] Iglesias, P.,[1] Turner, J.T.[3]

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[3]Department of Biology, University of Massachusetts, Darmouth, 285 Old Westport Road, N. Dartmouth, MA 02747-2300, USA

The Red Tide Programme of the Magellan Region

Guzmán, L.,[1] Pizarro, G.,[1] Alarcón, C.,[1] García, F.,[2] Banciella, M.I.,[2] Pacheco, H.[1]

[1]Instituto de Fomento Pesquero, Chile

[2]Servicio de Salud Magallanes, Chile

Distribution of harmful species *Alexandrium ostenfeldii* and *Dinophysis acuta* in the Magellan Region

Guzmán, L.,[1] Pizarro, G.,[1] Frangópulos, M.,[2] Alarcón, C.[1]

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[2]Centro de Estudios del Cuaternario Fuego – Patagonia (CEQUA), Chile

Probable effects of El Niño-La Niña cycle on phytoplankton responses in fjords and channels of the Magellan Region

Guzmán, L.,[1] Pizarro, G.,[1] Frangópulos, M.,[2] Alarcón, C.[1]

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[2]Centro de Estudios del Cuaternario Fuego- Patagonia (CEQUA), Chile

Spatial and temporal dynamics of *Alexandrium catenella* abundance and «Toxicity Geographic Nuclei» in the Magellan region

Guzmán, L.,[1] Pizarro, G.,[1] Alarcón, C.,[1] Frangópulos, M.[2]

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Phosphate uptake behaviour of cyanobacteria: Numerical experiments

Hense, I., Kaitala, S., Stipa, T.

Finnish Institute of Marine Research, Lyypekinkuja 3 A, P.O. Box 33, FIN-00931 Helsinki, Finland

Glutamine synthetase and Nitrate reductase activities of a bloom-forming dinoflagellate (Dinophyceae) in Southern Chile (41ºS): A field approach

Iriarte, J.L.,[1,2] Quiñones, R.A.,[3] González, R.R.,[3] Valenzuela, C.P.[1]

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[3]Departamento de Oceanografía, Universidad de Concepción, P. O. Box 160-C, Concepción, Chile

Improved high-performance liquid chromatographic method for determination of domoic acid: pH effect

López-Rivera, A.,[1] Suárez, B.,[1] Eilers, P.P.,[2] Beaudry, C.G.,[2] Hall, S.,[2] Fernández, M.,[3] Furey, A.,[3] James, K.J.[3]

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[2]Division of Science Applied Technology, U.S. Food and Drug Administration, Washington DC, USA

[3]PROTEOBIO, Mass Spectrometry Center for Proteomics and Biotoxin Research, Department of Chemistry, Cork Institute of Technology, Cork, Ireland

Effects of domoic acid (Amnesic Shellfish Toxin) on pharmacokinetics of antipirine: Preliminary results

López Rivera, A., Martínez, O.J., Suárez Isla, B.

Marine Toxins Laboratory, Biomedical Sciences Institute, Faculty of Medicine, University of Chile, Santiago, Chile

HABs in Golfo Dulce, Costa Rica: A unique fjord-like embayment on the Eastern Tropical Pacific

Morales, A.,[1] Vargas, M.,[2] Freer, E.,[2] Vargas, J.A.[1]

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[2]Centro de Investigaciones en Estructuras Microscópicas, Universidad de Costa Rica, 2060 San Pedro, Costa Rica

Monitoring algal blooms in the Valparaíso Bay, Chile, using satellite imagery

Muñoz, P.

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Growth and toxin production by the dinoflagellate *Alexandrium catenella* under controlled temperature conditions

Navarro, J.M., Muñoz, M., Urrutia, G., Maturana, M., Contreras, A.

Instituto de Biología Marina «Dr. Jürgen Winter», Universidad Austral de Chile, Valdivia, Chile

Dynamics of *Pseudo-nitzschia* group in Todos Santos Bay, Baja California, México

Orellana-Cepeda, E.,[1] Ávalos-Borja, M.,[2] Granados Machuca, C.,[1] Morales-Zamorano, L.A.,[3] Santamaría del Angel, E.,[1] Serrano-Esquer, J.[1]

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[3]FCAS, Universidad Autónoma de Baja California, México. PMB 1378, 4492 Camino de la Plaza, San Ysidro, CA 92173-3097, USA

Phytoplankton size composition in austral fjords and channels in Chile: Association with environmental factors

Paredes, M.A.,[1] Montecino, V.,[1] Astoreca, R.,[1] Uribe, P.,[1] Pizarro, G.[2]

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[2]IFOP- Punta Arenas, Chile

Distribution of *Pseudo-nitzscha australis* and *P. pseudodelicatissima* in the Magellan Region

Pizarro, G., Guzmán, L., Alarcón, C.

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Prediction of harmful algal events in coastal bays which derive from wind-forced advection

Raine, R.

The Martin Ryan Institute, National University of Ireland, Galway, Ireland

Phytoplankton and HAB Monitoring Program in South Chiloé associated to salmonid farming

Silva Coronado, M., Vivanco Tapia, X., Calfuleo, G.

SIAQ Ltda. Pedro Aguirre Cerda 347-B Quellón, Chiloé, Chile

Mortality of seabirds from Falkland Islands by Paralytic Shellfish Poison

Uhart, M.,[1] Karesh, W.,[2] Cook, R.,[2] Huin, N.,[3] Lawrence, K.,[4] Guzman, L.,[5] Pacheco, H.,[5] Pizarro, G.,[5] Mattsson, R.,[6] Mörner, T.[6]

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Development of immunological tools for the rapid detection and quantification of *Alexandrium catenella*

Varela, D.,[1] Stead, R.,[1] Seguel, M.[1,2] Osuna, A.[3]

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[2]CERAM, Universidad Austral de Chile, Chile

[3]Instituto de Biotecnología, Universidad de Granada, Spain

Investigation and monitoring of marine toxins and harmful phytoplankton in the inner sea of Chiloé Island and adjacent fiords, Chile

Vidal, G.,[1] Seguel, M.,[1,2] Guzmán, L.,[1] Lara, A.M.,[1] Sfeir, A.,[2] Calderón, J.[1]

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