GEOHAB

Global Ecology and Oceanography of Harmful Algal Blooms

BOOK OF ABSTRACTS

OPEN SCIENCE MEETING
on the
CORE RESEARCH PROJECT:
HABs IN UPWELLING SYSTEMS

INIAP
Instituto Nacional de Investigação Agrária e das Pescas

IPIMAR, Lisbon, PORTUGAL
17-20 November 2003

SCOR
SCIENTIFIC COMMITTEE ON OCEANIC RESEARCH

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION
COMMISSION OCÉANOGRAPHIQUE INTERGOUVERNEMENTALE
COMISIÓN OCEANOGRÁFICA INTERGUBERNAMENTAL
МЕЖПРАВИТЕЛЬСТВЕННАЯ ОКЕАНОГРАФИЧЕСКАЯ КОМИССИЯ
اللجنة الدولية الحكومية لعلوم المحيطات
政府间海洋学委员会

GEOHAB

Global Ecology and Oceanography of Harmful Algal Blooms

OPEN SCIENCE MEETING ON HABS IN UPWELLING SYSTEMS
LISBON, PORTUGAL
17-20 NOVEMBER 2003

PROGRAMME AND ABSTRACTS

The GEOHAB Scientific Steering Committee (SSC) is grateful for the support for this meeting supplied by the Intergovernmental Oceanographic Commission (IOC), U.S. National Science Foundation (Division of Ocean Sciences), Luso-American Foundation, the Portuguese Science and Technology Foundation, and British Council. The SSC also thanks the Instituto Nacional de Investigação Agrária e das Pescas (INIAP-IPIMAR) for hosting the Open Science Meeting, supporting some of the local costs, and providing excellent staff support. Other organizations that provided in-kind support for the meeting are shown on the following page.

International Council for Science
Scientific Committee on Oceanic Research

Intergovernmental Oceanographic Commission

FUNDAÇÃO LUSO-AMERICANA

NSF

BRITISH COUNCIL

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA E DO ENSINO SUPERIOR Portugal


lisboa
CÂMARA MUNICIPAL


ÁGUA
SERRA
DA
ESTRELA
Do Que a Serra Tem de Melhor


SUMOL


ESTORIL
SINTRA


Caixa Geral
de Depositos

GEOHAB OPEN SCIENCE MEETING ON HABS IN UPWELLING SYSTEMS

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GEOHAB OPEN SCIENCE MEETING ON HABS IN UPWELLING SYSTEMS

ORGANIZATION OF THE OPEN SCIENCE MEETING

Conveners

Teresa Moita, Portugal
Grant Pitcher, South Africa

Co-ordinating Committee

Francisco G. Figueiras, Spain
Raphe Kudela, USA
Trevor Probyn, South Africa
Vera Trainer, USA

Assistance with Meeting Preparation:

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

GEOHAB Open Science Meeting on HABs in Upwelling Systems

AN INTRODUCTION TO THE MEETING

Welcome to the GEOHAB Open Science Meeting on HABs in Upwelling Systems.

The GEOHAB Programme, sponsored by the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO, is an international programme aimed at fostering and promoting co-operative research directed toward improving the prediction of harmful algal bloom events.

Core Research Project: HABs in Upwelling Systems
The GEOHAB Implementation Plan describes plans for four Open Science Meetings designed to stimulate international input to focused research projects. This first Open Science Meeting will focus on the topic of harmful algal blooms (HABs) in Upwelling Systems.

The GEOHAB Core Research Project on HABs in Upwelling Systems must be comparative, interdisciplinary, and international. It will directly address the goal of GEOHAB of improved prediction of HABs by determining the ecological and oceanographic mechanisms underlying their population dynamics, integrating biological, chemical, and physical studies supported by enhanced observation and modelling techniques.

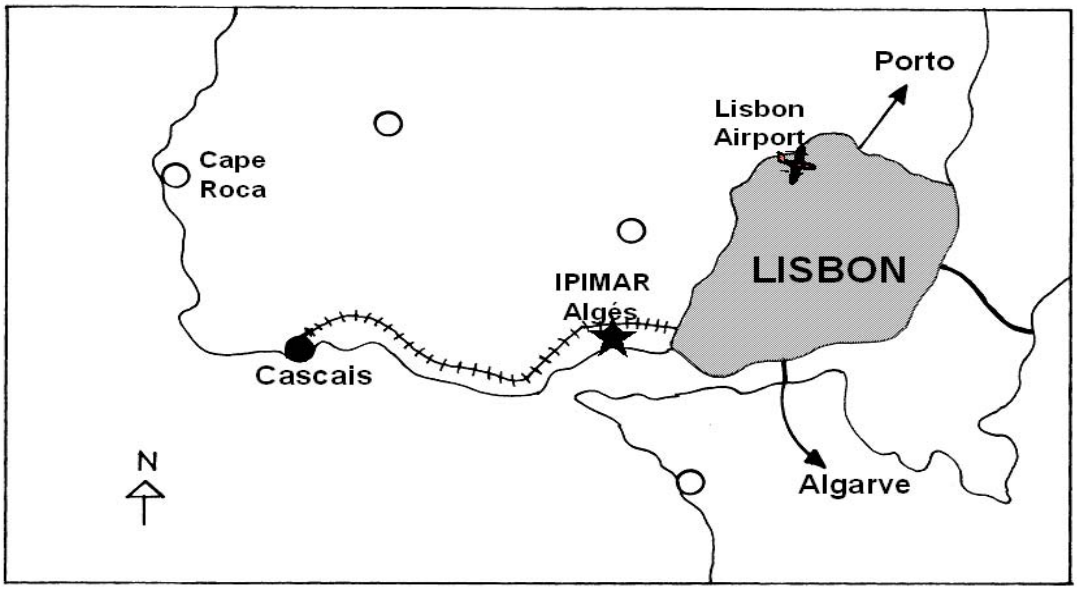
Upwelling systems can be classified according to their physical, chemical and biological characteristics. Development of a Core Research Programme on HABs in Upwelling Systems is built on the premise that understanding the ecology and oceanography of HABs in upwelling systems will benefit from a comparative approach. The comparative method is the method of choice when controlled experimentation is not practical. To the extent that experimental control in the study of marine ecosystems is problematic, comparison presents an alternative for drawing scientific inference. Comparisons will allow the grouping of harmful species from similar habitat types. The extent to which HAB species respond in a similar way, in systems that share similar characteristics, will assist in establishing the oceanographic processes that influence HAB population dynamics and community interactions. Equally important will be identification of similar systems that do not have the same functional HAB species or groupings. The purpose of this meeting is to obtain community input for the development of a detailed research plan for the GEOHAB Core Research Project on HABs in Upwelling Systems. The first draft of this plan will be brought together on Friday, November 21, by the meeting co-ordinating committee. The plan will be posted on the GEOHAB Web site for comment and will be augmented as additional planning occurs. Each GEOHAB Core Research Project is envisioned to last for about 5 years.

The GEOHAB SSC and OSM Planning Committee thank you for your participation in developing and implementing GEOHAB research.

Patrick Gentien	Grant Pitcher	Teresa Moita
GEOHAB SSC Chair	Co-Convenor	Co-Convenor

ABOUT THIS BOOK

We hope you will find this book to be helpful, both as a reference during the Open Science Meeting and afterward. The list of participants includes all those who completed registration for the meeting before this book went to print on 31 October 2003. Similarly, the abstracts, both for speakers and the poster sessions, reflect the status of the program for the conference on that date. Changes to the program will be announced and posted at the conference and you are advised to look for these.



LOGISTICAL INFORMATION

Transportation

From Airport to Cascais: Cascais can be reached from the Portela Airport in Lisbon by taxi or bus.
Taxi: A taxi from the airport to Cascais will cost the equivalent of around US$45.
Bus: A timetable of hourly Express Bus 498 can be obtained from www.scotturb.com. The Minibus stop is in front of Lisbon Airport-International Arrivals, in front of the taxi stop. The bus runs at different hours on Saturdays and Sundays than on weekdays. The price of the bus should be around the equivalent of US$7. Passengers can ask the driver to drop them off in front of the hotels: Hotel Baia and Cascais Villa (at the Cascais Bay), Pergola House (in front of SANTINI, a well-known ice cream house, close to the railway station). For information about the bus, call +(351) 214699127

From Cascais to IPIMAR: The hotels in Cascais are located about 25 minutes by train from the meeting location at IPIMAR in Alges. A ticket for 10 trips on the train can be purchased at a cost equivalent to US$9.45. The train ticket can be purchased on your first trip from Cascais to IPIMAR and validated on each subsequent trip. IPIMAR is located across from the train station, on the ocean side. There are signs in the station indicating the way to IPIMAR.

TRAIN TIMETABLE- Monday to Friday - see site www.cp.pt (Linha de Cascais)
Meeting hours:

Departure Cascais	8:03	8:18	8:33	8:48	9:03	9:18	9:33				
Arrival Alges	8:25	8:40	8:55	9:10	9:25	9:40	9:55				
Departure Alges	17:09	17:24	17:39	17:54	18:09	18:24	18:39	18:54	19:09	19:24	19:39
Arrival Cascais	17:32	17:47	18:02	18:17	18:32	18:47	19:02	19:17	19:32	19:47	20:02

Hotels

Estalagem Cascais Villa
Rua Fernandes Tomás, 1
Cascais, Portugal
Tel : +351-214-863-410
Fax: +351-214-844-680
Web site: www.villa-cascais.pt
E-mail: estalagem@villa-cascais.pt

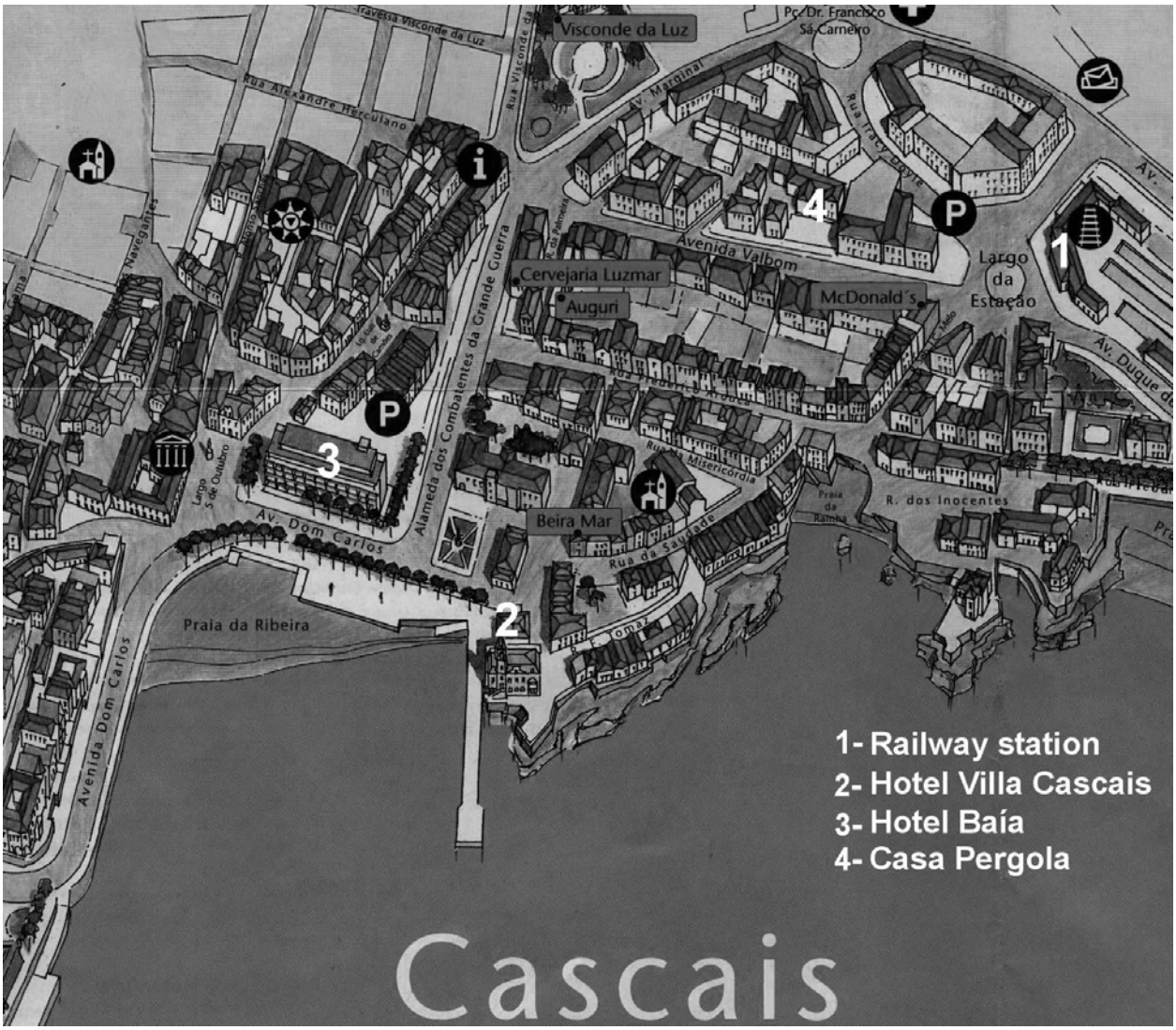
Guest House "Casa da Pergola"
Avenida Valbom, 13
Cascais, Portugal
Tel : +351-21 484-0040
Fax: +351-21-483-4791
Web site: www.ciberguia.pt/casa-da-pergola
E-mail: pergolahouse@vizzavi.pt

Casa da Pergola does not accept credit cards, but does accept checks.

Hotel Baía
Av. Marginal
Cascais, Portugal
Tel: +351-214-831-033
Fax: +351-214831095
Web site: www.hotelbaia.com
E-mail: reservas@hotelbaia.com

Meals

Breakfasts are included in the cost of some of the hotels. Lunches at IPIMAR will cost around US$4-5. Dinners will be on your own, except that we have arranged a special dinner in Lisbon on Thursday night, November 20. The cost is US$35 per person. Transportation to and from Lisbon will be provided. Restuarant recommendations for Cascais will be provided at the meeting.



GEOHAB OPEN SCIENCE MEETING ON HABS IN UPWELLING SYSTEMS

PROGRAMME SUMMARY

Monday 17 November	Tuesday 18 November	Wednesday 19 November	Thursday 20 November	Friday 21 November
Registration Poster Set-up 8:00 – 9:3am				SESSION 11 Planning Committee Meets in Closed Session to Write Meeting Report
9:30 Opening Remarks SESSION 1	9:00 SESSION 4	9:00 SESSION 6	9:00 SESSION 9	
11:00 COFFEE	10:20 COFFEE	10:30 COFFEE	10:30 COFFEE	
11:30 SESSION 1 (cont.)	10:50 SESSION 4 (cont.)	11:00 SESSION 7	11:00 SESSION 9 (cont.)	
12:10 LUNCH	12:10 LUNCH	12:15 LUNCH	12:15 LUNCH	
13:30 SESSION 2	13:40 SESSION 4 (cont.) 14:20 SESSION 5	13:45 SESSION 7 (cont.)	13:45 SESSION 10	
16:10 COFFEE	15:40 COFFEE	15:45 COFFEE	15:45 COFFEE	
16:30 SESSION 3 Posters	16:10 SESSION 5 (cont.)	16:15 SESSION 8	16:15 SESSION 10 (cont.)	
Porto Icebeaker IPIMAR 18:00 p.m.			17:30 Bus leaves from IPIMAR for Lisbon	

DETAILED PROGRAMME

Notes for Participants

Talks: Invited speakers will be expected to adhere to the allocated times for their talks. The chairs of the plenary sessions will be strict about the timing, in order to keep the conference running smoothly.

Posters: Posters can be set up from 8:00 to 9:30 a.m. and at lunch time on Monday, November 17. All poster authors are expected to be present at their posters during the poster session on Monday at 16:00. Posters may also be viewed during all coffee and lunch breaks. Supplies will be provided for mounting the posters. Posters will be left up for the entire meeting to make it possible for participants to view them during coffee breaks and lunch times. Posters should be taken down during the day on Thursday, November 20.

GEOHAB Open Science Meeting on HABS in Upwelling Systems

17-20 November 2003
Lisbon, Portugal

PROGRAMME

Monday, 17 November

9:30-9:50 Welcomes
Director, Instituto Nacional de Investigação Agrária e das Pescas, Lisbon, Portugal
Teresa Moita, Instituto Nacional de Investigação Agrária e das Pescas, Lisbon, Portugal
Ed Urban. Scientific Committee on Oceanic Research (SCOR)
Henrik Enevoldsen, Intergovernmental Oceanographic Commission (IOC)

9:50-10:10 GEOHAB Programme – *Patrick Gentien*, GEOHAB Chair

10:10-10:20 GEOHAB Core Research Project: HABs in Upwelling Systems – *Grant Pitcher*, Marine & Coastal Management, Cape Town, South Africa

SESSION 1: Overview of HABs in Californian, Iberian and Benguela upwelling systems
Session Chair: *Patrick Gentien*, Institut français de recherche pour l'exploitation de la mer, La Rochelle, France

10:20-11:00 Overview of the ecology of HABs in upwelling systems on the U.S. West Coast – *Vera Trainer*, U.S. National Oceanic and Atmospheric Administration, Seattle, Washington, USA

11:00-11:30 COFFEE

11:30-12:10 ***Ecology and oceanography of HABs in the Portuguese Iberian Upwelling waters –****Teresa Moita*

12:10-13:30 LUNCH

13:30-14:10 **Ecology and oceanography of harmful algal blooms in the southern Benguela** *– Grant Pitcher*

14:10-14:30 Conclusion of Session 1: Discussion

SESSION 2: Identification of the HAB species in given upwelling systems
Session Chair: *Allan Cembella*, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

14:30-14:50 Molecular approaches to the ecology of algal blooms – *Carlos Pedros Alio*, Institut de Ciències del Mar, Barcelona, Spain

14:50-15:10 HABs in upwelling systems: A view from the dinoflagellate cyst record **–** *Barrie Dale*, University of Oslo, Oslo, Norway

15:10-15:30 Phylogenetic analysis of toxic *Alexandrium* (Dinophyceae) isolates from South Africa: Implications for the global phylogeography of the *Alexandrium tamarense* species complex – *Carlos Ruiz Sebastian*, University of Cape Town, South Africa

15:30-15:50 Distribution of *Dinophysis* spp. in Western Iberian Shelf waters during an unusual Spring poleward current event – *Beatriz Reguera*, Instituto Español de Oceanografía, Centro Oceanográfico de Vigo, Spain

15:50-16:10 Conclusion of Session 2: Discussion

16:10-16:30 COFFEE

SESSION 3: POSTERS

16:30-18:00 Posters

18:00 PORTO ICEBREAKER at IPIMAR

Tuesday, 18 November

SESSION 4: Identification of the physical, chemical and biological processes that define or characterise upwelling systems and quantification of the response of HAB species to these processes

Session Chair: *Marta Estrada*, Institut de Ciències del Mar-CMIMA (SCIC), Barcelona, Spain

9:00-9:20 Some aspects of the upwelling dynamics along the western coast of Portugal – *João Vitorino*, Instituto Hidrográfico, Lisboa, Portugal

9:20-9:40 Coastal retention and nearshore algal blooms in upwelling **systems** – *John Largier*, Scripps Institution of Oceanography, La Jolla, USA

9:40-10:00 Physical oceanography and HABs in the California Current System – *Barbara Hickey*, University of Washington, Seattle, Washington, USA

10:00-10:20 Downwelling and HABs in the NW of the Iberian Peninsula: The Rias Baixas of Galicia – *Francisco Figueiras*, Instituto de Investigaciones Marinas, Consejo Superior de Investigaciones Científica (CSIC), Vigo, Spain

10:20-10:50 COFFEE

10:50-11:10 Upwelling relaxation – the ecological importance of transient coastal countercurrents – *E.D. Barton*, University of Wales, Bangor, UK

11:10-11:30 Discussion of physical influences on HABs

11:30-11:50 **Carbon and nutrient cycles in the NW Iberian upwelling system: Seasonal and event-scale variability** – *Xose Anton Alvarez Salgado*, Instituto de Investigacións Mariñas Consejo Superior de Investigaciones Científica (CSIC), Vigo, Spain

11:50-12:10 Nitrogen utilization by a novel dinoflagellate bloom off the west coast of South Africa – *Trevor Probyn*, Marine & Coastal Management, Cape Town, South Africa

12:10-13:40 LUNCH

13:40-14:00 From the laboratory to the field: Can we apply knowledge of *Pseudo-nitzschia* physiology in the real world? – *Raphael Kudela*, University of California Santa Cruz, USA

14:00-14:20 Discussion of chemical and biological influences on HABs

SESSION 5: Development of observation systems and models of HABs in upwelling systems to support fundamental research and predictive capabilities

Session Chair: *Paulo Relvas,* CIMA - Universidade do Algarve (F.C.M.A.), Faro, Portugal

14:20-14:40 The coastal monitoring applications of a bio-optical reflectance model to derive algal size and biomass – *Stuart Bernard*, University of Cape Town, South Africa

14:40-15:00 Satellite remote sensing in eastern boundary currents: Multiple programmatic roles – *Andy Thomas,* University of Maine, Orono, Maine, USA

15:00-15:20 Remote sensing and monitoring of harmful algal blooms in different upwelling conditions: Gulf of Mexico and Washington, USA – *Richard P. Stumpf,* NOAA National Ocean Service, Silver Spring, Maryland, USA

15:20-15:40 Discussion of remote sensing in HAB research

15:40-16:10 COFFEE

16:10-16:30 Hydrodynamic models as a basis to understand HAB bloom accumulation and advection in upwelling systems – *Pedro Monteiro*, Coast Programme, CSIR, Stellenbosch, South Africa

16:30-16:50 Integrated modelling of physical and biological processes in the Iberian upwelling system – *Ramiro Neves*, Instituto Superior Técnico, Lisbon, Portugal

16:50-17:10 Discussion of modeling in HAB research

17:10 Adjourn for the Day

<u>Wednesday 19 November</u>

9:00

SESSION 6: Identification of interested participants and designated regions for comparative research

SESSION 7: Review of current national and regional projects/programmes in order to identify elements of research that could contribute to the core research

SESSION 8: Identification of gaps in national and regional research projects/programmes

18:00 Adjourn for the day

Thursday, 20 November

9:00

SESSION 9: Formulation and design of a plan to guide core research in upwelling systems

SESSION 10: Identification of framework activities to support the research plan

17:30 Adjourn for the day
BUS TOUR OF LISBON AND DINNER – Bus will leave from IPIMAR and return to hotels in Cascais

Friday 21 November

SESSION 11 – CLOSED SESSION: The Core Research Project Planning Committee will meet to finalise a report of the Open Science Meeting comprising an implementation plan to guide core research

INVITED SPEAKERS' ABSTRACTS

Overview of the ecology of HABs in upwelling systems on the U.S. West Coast

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The food web transfer of the toxin, domoic acid, to shellfish, crustaceans, seabirds, finfish and marine mammals has been recently documented on the U.S. West coast. Data collected during West coast cruises in the years 1997-2001 indicate that often the highest toxin levels and greatest numbers of toxic cells are positioned in water masses associated with offshore eddies, such as the Juan de Fuca eddy or in upwelling zones near coastal promontories, such as Heceta Bank, Oregon, and Point Conception, California. Beach samples collected in 1998 indicated that a *Pseudo-nitzschia pseudodelicatissim*a bloom was responsible for razor clam toxicity on the Washington coast, whereas toxin produced by *P. australis* resulted in sea lion mortalities in central California. The detection of toxin in urine, feces, and stomach contents of several sea lions represents the first proven occurrence of domoic acid transfer through the food chain to a marine mammal. The pennate diatoms, *P. multiseries* and *P. australis*, were the dominant, toxin-producing phytoplankton constituting algal blooms in California near Monterey Bay, Half Moon Bay, and Oceano Dunes, areas where sea lions with neurological symptoms stranded. Toxic *Pseudo-nitzschia* were also found near Morro Bay, Point Conception, Point Arguello, and Santa Barbara, demonstrating that these species were widespread along the central California coast in June 1998. Measurements of particulate domoic acid during three cruises during the summers of 1997 and 1998 showed the highest toxin levels in *P. multiseries* near Point Año Nuevo at 6 pg cell^{-1}, in *P. australis* from Morro Bay at 78 pg cell^{-1}, and in *P. pseudodelicatissima* from the Juan de Fuca eddy region at 4 pg cell^{-1}. Maximum cellular domoic acid levels were often observed between 0 and 10 m depth, although toxin was also measured to depths of 40 m.

Ecology and oceanography of HABs in the Portuguese Iberian Upwelling waters

Maria Teresa Moita*, Ana Sofia Palma, Ana Amorim and Graça Vilarinho
*Instituto de Investigação Agrária e Pescas
Av. Brasília 1449-006 Lisboa, Portugal
E-mail: tmoita@ipimar.pt

Off the Iberian coast of Portugal, circulation and hydrology have a marked seasonality and upwelling appears as the major source of temporal and spatial phytoplankton variability. The

upwelling season starts in Spring and persists until Autumn with upwelling patterns being largely determined by coastal morphology, bathymetry and local winds. Stratification is enhanced to the north of Lisbon due to the existence of a wider and flatter continental shelf and a higher river runoff.

Outbreaks of HAB species are recurrent phenomena along the Portuguese coast. The most problematic species are *Dinophysis acuminata* and *Dinophysis acuta* (DSP), *Gymnodinium catenatum* (PSP), and more recently *Pseudo-nitzschia australis* (ASP). The potentially toxic species *Lingulodinium polyedra* (yessotoxin) also blooms occasionally.

Since the beginning of HAB monitoring in 1985, the species with the worst economic impact on shellfish catches have been *D. acuminata* and *D. acuta* due to their persistence in the system. Both species contaminate bivalves even when they are present in low numbers in the water column. They occur during the upwelling season but higher concentrations are associated with an increase in stratification. These two species often coexist but blooms do not coincide in space or in time. *D. acuminata* seems to bloom in waters with lower temperatures and salinities than *D. acuta*.

Between 1985 and 1995, the major toxic events arose from the outbreaks of the chain forming dinoflagellate *G. catenatum* at the end of the upwelling season. This species seems to have spread along the Iberian coast along the years. Data on SST satellite images and on the distribution of planktonic and benthic stages of *G. catenatum* and *L. polyedrum*, both considered as "upwelling relaxation taxa", suggest that these two species may explore different hydrodynamic conditions associated with upwelling plumes, in particular those formed to the south of the major capes.

Pseudo-nitszchia spp. belong to the phytoplankton assemblage associated with an increase in biomass during the intensification of upwelling episodes and blooms are normally multispecific. *P. australis* outbreaks can occur from spring to late summer and are characterised by short episodes.

Ecology and oceanography of harmful algal blooms in the southern Benguela

Grant C. Pitcher
Marine & Coastal Management
Private Bag X2, Rogge Bay, 8012, Cape Town, South Africa
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The South African coastline is influenced by two major boundary current systems – the warm Agulhas on the east and the cool Benguela upwelling system on the west where a disproportionately high incidence of harmful blooms is observed. Here the harmful effects of high biomass dinoflagellate blooms result typically from anoxia following the decay of blooms, while public health is impacted by the high incidence of Paralytic (PSP) and Diarrhetic Shellfish Poisoning (DSP). Within the upwelling regime Cape Point forms the natural divide for species that dominate blooms of the west coast as opposed to those that dominate the south coast, owing to changes in the orientation of the coastline and changes in the wind field. PSP is attributed to the dinoflagellate *Alexandrium catenella* which appears confined to the west coast. Despite

recent identification of *Alexandrium tamiyavanichii* on the South Coast, PSP remains undetected in this region owing to the observed low concentrations of *A. tamiyavanichii* and to the low cellular toxicity of this isolate. DSP is associated with either *Dinophysis acuminata* or *Dinophysis fortii* which are prevalent on the west and south coasts. A newly described fish-killing dinoflagellate *Karenia cristata* is found on the south coast and produces aerosol toxins similar to those produced by *Karenia brevis*. Amnesic Shellfish Poisoning has not been reported, although extensive blooms of *Pseudo-nitzschia australis* have been recorded particularly on the west coast. The distribution and the incidence of west coast blooms is influenced by longshore variation in upwelling. The region between the Namaqua and Cape Columbine upwelling cells is particularly susceptible to red tide. The shelf is broad in this region, favouring stratification and stability of the water column, features of the surface boundary layer important in determining species selection and development. A variety of bloom-forming dinoflagellate species representing a range of life-form types tends to indicate a high degree of overlapping and intergrading of species traits and/or a diversity of habitats in terms of their nutrient-mixing characteristics. Zones of convergence and fronts are important in bloom accumulation and transport. Wind reversals cause frontal systems and associated dinoflagellate blooms to move shoreward and the development of an inshore counter current results in the southward advection of blooms.

Molecular approaches to the ecology of algal blooms

Carlos Pedrós-Alió
Institut de Ciències del Mar, CMIMA, CSIC
Passeig Marítim de la Barceloneta 37-49, 08003 Barcelona, Spain
E-mail: cpedros@cmima.csic.es

The formation of blooms by harmful algae is a particular case of bloom formation by microorganisms in general. Many blooms tend to be dominated by a particular taxon, to the detriment of the remaining populations. The factors that lead to this disequilibrium in the taxonomic structure of the assemblage are poorly known in the case of harmful algae. Indeed just the detection of the blooming population is problematic. Traditionally this has been done by collecting samples and examining them under the microscope. While rather sensitive and informative, this technique is laborious. It also suffers from the difficulties to distinguish certain species or subspecies morphologically and the inability to determine toxicity. Molecular techniques offer an attractive alternative, with their own set of advantages and problems. I will examine the range of techniques available and the problems that can be addressed with each one of them, including cloning and sequencing, fingerprinting techniques such as DGGE and T-RFLP, and hybridization with specific probes. A promising alternative is to look for genes responsible for toxin production instead of the commonly used 18S rDNA gene. However, the questions of sensitivity and specificity are still problematic. Thus, when deciding whether a molecular or a microscopy technique is more appropriate, the researcher must be extremely careful in evaluating the advantages of each for the stated purpose.

HABs in upwelling systems: A view from the dinoflagellate cyst record

Barrie Dale
Geosciences Department
University of Oslo, PB 1047 Blindern
N-0316 Oslo, Norway

It is more difficult to investigate HABs in upwelling systems than in many of the coastal systems, since HABs may be episodic, and the upwelling sites are generally more remotely situated offshore, making adequate sampling more difficult. Many of the common HAB-species of dinoflagellates produce resting cysts. In coastal systems, dinoflagellate cyst assemblages in bottom sediments provide an integrated sample representing several years of accumulated information for at least the cyst-forming species (useful to supplement otherwise inadequate plankton records), and this approach has an obvious application in studies of upwelling systems.

We have studied fossilizable cysts in surface sediments from some of the major upwelling systems (NW Africa, SW Africa, Peru, California), as part of a global distribution study to increase our ability to use fossil cysts as paleoenvironmental indicators. We have identified ecological signals for upwelling, based on more dominance of heterotrophic species compared with adjacent waters (mostly within the genus *Protoperidinium* - especially *P. conicum* and *P. americanum*). HABs associated with a species of *Protoperidinium* are recorded from Ireland, suggesting the possibility for toxicity in other species of this extensive genus. Also of interest to HAB research is large amounts of cysts of *Protoceratium reticulatum* and *Lingulodinium polyedrum* (bloom species that produce toxins)sometimes associated with waters adjacent to strong upwelling (or waters from relaxed upwelling).

The results from this more paleontologically directed research thus show distinctive features of phytoplankton composition in upwelling systems reflected in the cyst record, and of interest to HAB research. They also suggest a potential for utilizing the cysts more in future work: 1) in other systems not yet covered (e.g. upwelling in offshore Portugal where the main HAB species *Gymnodinium catenatum* produces a fossilizable cyst); 2) by examining the chemically untreated cyst assemblages in upwelling systems such as those reported here to include the less resistant cyst types produced by other HAB species; and 3) to use fossilizable cysts in cored sediments from upwelling systems to add the time dimention to present-day studies of these system to investigate how both upwelling and bloom species have responded to global change (one such example is shown to illustrate variations in the Angola-Benguela Front over the past 200 000 years).

Phylogenetic analysis of toxic *Alexandrium* (Dinophyceae) isolates from South Africa: Implications for the global phylogeography of the *Alexandrium tamarense* species complex

Carlos Ruiz Sebastián [1*], Stacey M. Etheridge [2], Colleen O'Ryan [3], Peter A. Cook [1] and Grant C. Pitcher [2]
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Current knowledge on global phylogeographic patterns and dispersal routes of dinoflagellates in the *Alexandrium tamarense* species complex is primarily based on isolates from the northern hemisphere. The paucity of molecular data available from southern hemisphere isolates has limited the development of evolutionary hypotheses for southern *Alexandrium* populations. To address this shortcoming, we present the first molecular and toxin data from *Alexandrium* isolates from African waters. Two isolates from the west coast and one isolate from the south coast of South Africa were examined microscopically and toxin profiles were obtained. Nuclear ribosomal large subunit (LSU) sequences were generated for the three isolates and used in neighbour-joining, maximum-parsimony and Bayesian inference phylogenetic analyses together with 200 other *Alexandrium* sequences from around the world. Morphological analysis indicates that the west coast isolates are *A. catenella*, while the south coast isolate is *A. tamiyavanichii*. All three South African isolates are toxic and have a similar toxin profile, but the toxicity of the west coast isolates is almost fifty-fold that of the south coast isolate. Phylogenetic analysis placed all three South African isolates in the *A. tamarense* complex, but with different phylogenetic affinities. The west coast *A. catenella* isolates fall in the North American clade, a ribotype with a cosmopolitan distribution, while the south coast *A. tamiyavanichii* falls into the Tropical Asian clade. The presence of *A. tamiyavanichii* in South Africa expands the known geographic range of this dinoflagellate in the Indo-Pacific region and suggests a West Pacific-East-South African dispersal route. The increasing predominance of *A. tamiyavanichii* isolates in the Tropical Asian clade of the *A. tamarense* species complex challenges the validity of this clade as part of the complex. The west coast *A. catenella* population is closely related to multiple congeners and could be a relatively recent human-mediated introduction of uncertain origin and timing. The D1-D2 LSU ribosomal DNA (rDNA) genetic marker used was insufficient to resolve intracladal phylogenetic relationships within the *A. tamarense* species complex, and other markers with higher resolution should be evaluated to improve phylogenetic resolution and assess dispersal hypotheses.

Distribution of *Dinophysis* spp. in Western Iberian Shelf waters during an unusual Spring poleward current event

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Chronic occurrences of dinoflagellates of the genus *Dinophysis* Ehrenberg that produce lipophilic toxins (okadaic acid and derivatives and pectenotoxins) constitute one of the main threats for Galician shellfish growers. In the Galician Rías Baixas, *Dinophysis acuminata*, the most abundant species of the genus, is very persistent and can exhibit several peaks between spring and autumn. *Dinophysis acuta*, *D. caudata* and *D. tripos* proliferations show a more neritic distribution and a marked seasonality (late summer to autumn). When *D. acuminata* and the other two species co-occur, their maximum cell concentrations occupy different water masses. An autumn maximum of *D. acuta* usually precedes *Gymnodinium catenatum* during downwelling pulses. A key issue of *Dinophysis* proliferations in the Galician Rías is to establish the origin of the *inoculum*: is it the result of aggregation of disperse winter residual populations or the injection of allochtonous populations? During the *MORENA 93* cruise (11-26 May 1993), opportunistic sampling of phytoplankton was carried out at different depths on 45 stations from 10 transects of the grid (between off Ría de Vigo and south of Figueira da Foz) to explore the distribution of *Dinophysis* spp on the upper half of the western Iberian shelf. Lugol-fixed samples of 250 ml were pre-concentrated and further sedimented (Utermöhl method) to be able to detect very low concentrations (detection level, 4 cell $\cdot$ l^{-1}) that escape from routine monitoring counts. Downwelling driven by southerly winds, during the whole cruise, led to instrusions of high-salinity oceanic water over the shelf similar to those commonly observed at the end of the upwelling season (October). *D. acuminata*, present in moderate concentrations ($10 - 10^2$ cell $\cdot$ l^{-1}) in most stations of the middle to inner shelf, showed maximum values between transects 4 and 9 (between Ría de Vigo and Oporto) at stations with a phytoplankton community dominated by diatoms. *D. acuta* and *D.* tripos were detected in very low concentrations (< 10 cell $\cdot$ l^{-1}) at stations between transects 10 and 13 (between Aveiro and Figueira da Foz) where *Gymnodinium catenatum* was the dominant species. The relations between *Dinophysis* spp. and other accompanying species with the different water masses are discussed. Observations on the shelf agreed with the species-specific spatio-temporal distribution of the species of *Dinophysis* in the Galician Rías Baixas.

Some aspects of the upwelling dynamics along the western coast of Portugal

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The occurrence of seasonal (summer) upwelling along the western Iberian coast is well known. It involves energetic manifestations in the form of cold filaments, extending offshore hundreds of kilometer, and strong jets. These aspects are well documented through satellite imagery or by situ measurements. Upwelling, however, is also observed during other periods of the year or can be promoted in specific areas of the Iberian margin where particular bottom topography and/or coastline orientation occurs.

In this contribution we discuss several contrasting manifestations of upwelling that are observed along the western Portuguese coast, such as: (a) the summer upwelling regime off the northern Portuguese coast, an area characterized by a rather regular shelf topography, (b) the strong upwelling events observed during winter, along the northern Portuguese coast, (c) the upwelling filament of Cape S. Vicent, in the southwestern tip of Portugal, an area characterized by abrupt changes in coastline orientation and complex topography and (d) the response of Nazare Canyon (the largest European canyon system, located off the NW Portuguese coast) to local wind forcing and to interactions with shelf and slope dynamics.

These aspects are explored using data (hydrographic casts, moorings, etc) collected by Instituto Hidrográfico in the framework of both national or European funded research projects, conducted during the last decade. Insight on the dominant physics characterizing the upwelling dynamics, in each case, is obtained through the combination of observations and numerical models. Finally, we address the subject of operational forecasting and monitoring of upwelling conditions off the Portuguese, based on ongoing work conducted at Instituto Hidrográfico.

Coastal retention and nearshore algal blooms in upwelling systems

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In the WEST study of the role of wind-driven transport in shelf productivity, we have obtained a two-year mooring record of nitrate and chlorophyll fluorescence off northern California, in addition to detailed shipboard surveys of specific phytoplankton blooms. These data confirm the importance of wind relaxation events for dense algal blooms nearshore and also point to the importance of embayments and alongshore transport of blooms. During relaxation events, poleward flow may link plankton populations in “upwelling shadow” regions to open-coast regions poleward of the embayments. For example, in the WEST study, water from the Gulf of the Farallons was observed to intrude along the northern California coast. The observed blooms off Bodega Bay are understood as a combination of production and advection, requiring careful

work to distinguish the effects of *in situ* primary production from imported production. The relative importance of these two terms varies with the nature of the relaxation event and the preceding upwelling conditions.

While the densest algal blooms along the northern California coast are non-toxic diatom blooms, the themes of retention and relaxation are likely to be common to the nearshore occurrence of diverse harmful algal blooms in upwelling systems. To explore this assertion, WEST data are compared with observations from other upwelling regions – elsewhere in California as well as in Chile, South Africa, and Namibia. Further, the interaction of shelf waters with enclosed bays is discussed with a view to the possible import of algal blooms into these bays (e.g., Tomales Bay).

Physical oceanography and HABs in the California Current System

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The California Current System is an Eastern Boundary System of currents, including the equatorward flowing California Current and the poleward flowing California Undercurrent. The Undercurrent, which hugs the upper continental slope, is the primary source of the nutrient rich water upwelling to the coastal marine ecosystem. In this system in the summer and early fall growing season physical processes are large scale—upwelling events occur over distances exceeding several hundred kilometers along the coast. Nevertheless, mesoscale features are important to the plankton and to the occurrence of HABs along the U.S. west coast. Within the California Current System, at least three types of physical environments can be identified; we speculate that these environments have a first order role in the occurrence or non occurrence of HABs. In the first environment, upwelling occurs on a nearly straight coastline—plankton are swept primarily downstream and slightly offshore as they grow, returning to the coast during periods of downwelling or relaxation. In the second environment, where promontories and headlands occur, upwelling jets break free of the shelf, delivering plankton to regions up to a few hundred kilometers offshore, rarely returning plankton to the coast. In the third environment, local topographic irregularities such as banks or canyons alter the flow in such a way as to retain plankton longer in the coastal environment than in either of the other environments, often providing as well a higher or more continuous source of nutrients. In ECOHAB PNW, two of these environments are being contrasted; namely straight coast upwelling and a mesoscale bank. Results to date suggest that macro nutrients are indeed provided more continuously to the bank, by virtue of estuarine-driven upwelling into the nearby Strait of Juan de Fuca. Moreover, our results suggest that a nearby river plume (in this case the Columbia) may provide mitigating effects on HABs events, effectively preventing them from impacting the beach at some locations and times. Plumes from rivers may play a role in HABs incidence by this physical mechanism as well as by controlling the supply of micronutrients such as iron to both the sediment and the water column.

Downwelling and HABs in the NW of the Iberian Peninsula: The Rias Baixas of Galicia

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The Rías Baixas of Galicia, on the Northwest Iberian Peninsula, suffer from frequent HAB episodes mainly caused by *Pseudo-nitzschia australis*, *Dinophysis* spp. and in the recent past by *Gymnodinium catanutum*. As mussel production is an important activity in the region, research on oceanographic processes underlying HAB development has been worthy of continuous interest. This effort has delivered an understanding on correspondences between oceanography and HABs, specifically for those of *G. catenatum*, from which downwelling reveals as the key process for HAB formation.

The NW Iberian margin is in the northern limit of the NW Africa upwelling system and, therefore, is influenced by along-shore winds that interact with the coastline to generate seasonal upwelling-downwelling dynamics. Upwelling occurs between March and October, while downwelling predominates the rest of the year when a surface poleward current develops and maintains on the shelf. The first upwelling events coincide with the spring bloom when large diatoms are dominant. Later, during summer, dinoflagellates, ciliates and diatoms compose the phytoplankton community, with diatoms prevalent during upwelling episodes and dinoflagellates during relaxation periods. The dynamics on the shelf interacts with circulation in the Rias basically in two ways. Coastal upwelling forces a density-induced circulation inside the Rías with outflow of surface waters and a compensating inflow of upwelled waters at the bottom. Downwelling causes a reversal of this circulation pattern with intrusion of coastal waters at the surface, which accumulate in the Ria interior and finally flows oceanwards through the bottom. This affects plankton in the Rias. Under upwelling, plankton growing in the Rías interior is exported to the shelf, whereas plankton from the shelf is accumulated in the interior of the Rías under downwelling conditions. HABs of swimming species often develop in the interior of the Rías during downwelling events, especially at the upwelling-downwelling autumn transition. This prevalence of dinoflagellates vs. diatoms under reversal circulation conditions is due to their swimming capability, which allows them to remain in the water column.

Upwelling relaxation – the ecological importance of transient coastal countercurrents

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Blooms of *Gymnodinium catenatum* and *Dinophysis acuminata* have been reported in the Ria de Vigo in the early autumn of different years. Various possible explanations for these outbreaks, which have considerable economic and social consequences, were put forward. One was that cysts were reintroduced from the ocean by convergence towards the coast following relaxation of upwelling. Another was that dormant cysts resting in the bed of the Ria were triggered into growth and reproduction by the onset of appropriate conditions. However, little evidence was

found of cysts in offshore surface waters and blooms have been recognized in coastal waters south of the Rias immediately prior to outbreaks. Analysis of AVHRR images showed the sudden onset of significant blooms was preceded by the development of a previously unrecognized narrow coastal poleward flow. This extended from northern Portugal in a band ~10 km wide, often difficult to observe because of cloud cover in the images associated with the relaxation of the Trade winds. The populations of toxic dinoflagellates are likely transported in the inshore northward current into the outer Rias, from where they are available to spread throughout the ria system. Similar narrow countercurrents, distinct from the general winter slope poleward flow, occur elsewhere around the Iberian coasts. Observations around Cabo Sao Vicente and the Algarve coast show that relaxation of upwelling favourable winds permit the rapid development of a narrow coastally trapped flow extending from the Gulf of Cadiz as far as Sines. The counterflow is associated with a persistent downward slope of the sea surface towards the north. This probably extends around the peninsula, giving rise to localised near-shore poleward flows arising whenever upwelling conditions relax. Rapid advection in these nearshore currents provides a means of inducing sudden toxic outbreaks or introduction of contaminants into sheltered areas.

Carbon and nutrient cycles in the NW Iberian upwelling system: Seasonal and event-scale variability

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Intensive oceanographic research has been conducted over the last decade in Galician shelf waters, particularly off the Rías Baixas, where the culture of mussels on hanging ropes, about 250,000 tonnes/year, is disturbed by the incidence of harmful algal blooms (HABs). Coastal winds—which vary on decadal (positive and negative NAO periods), seasonal (dominant upwelling- and downwelling-favourable seasons) and event (1-3 wk wind stress/relaxation cycles) time-scales—are the main reason behind both the productivity and the occurrence of HABs in these waters. This presentation will be specifically focused on the effect of coastal wind forcing on the carbon and nutrient biogeochemistry of the area, which affects and, in turns, it is affected by HABs. It will assess the control of coastal winds on (1) the flux of nutrient salts into the shelf and the rías; (2) the flushing rate of coastal waters; (3) the metabolism of the pelagic ecosystem, which switches from net autotrophy to net heterotrophy in response to the wind stress/relaxation cycles; and (4) the fate of coastal production: off-shelf export *versus* deposition on the sediments of the shelf and the rías, with subsequent benthic mineralization processes and reinjection of nutrients into the water column.

Nitrogen utilization by a novel dinoflagellate bloom off the west coast of South Africa

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Field measurements of nitrogen uptake, as ^{15}N labelled NO_3, NH_4 and urea, were conducted during Feb-Mar of 2000 and 2001 at an inshore location off the west coast of South Africa (Lambert's Bay). During both studies, netplankton diatoms and mixed diatom-*Ceratium* spp. assemblages dominated initially to be replaced by blooms of a small Gymnodinioid species (G. sp). These changes in assemblages were brought about by the advection of different water bodies towards the sampling station in response to changes in the upwelling/relaxation cycle. These studies provided the first recorded occurrence of G.sp blooms along the South African coastline. Near-surface concentrations reached 1.3 x 10^8 cells.l^{-1} and chlorophyll levels in excess of 120 mg.m^{-3}.

During the 2000 study, depth profiles of N uptake during the day indicated netplankton diatoms utilised relatively more oxidised N as NO_3 than reduced N as NH_4 and urea. Measured f-ratios (NO_3 uptake/ reduced N uptake) integrated over the water column during the day ranged between 0.61 and 0.69 for netplankton assemblages including those containing significant numbers of *Ceratium lineatum*. Night-time f-ratios were somewhat depressed (0.17 0 0.52), a likely result of the energetic cost of NO_3 assimilation. Water column integrals of the f-ratio for G. sp assemblages were considerably reduced (0.09 – 0.37) with urea contributing some 3 – 30% of the total N uptake. Carbon uptake of upper water column netplankton assemblages was often considerably in excess of the Redfield requirements suggesting storage of C and energy for night-time N assimilation. On the other hand, G. sp assemblages displayed N and C dynamics roughly in accordance with the Redfield ratio, similar to the deeper netplankton populations.

The 2001 studies tended to confirm the findings from the previous year. Intense surface blooms of G. sp were maintained almost exclusively by reduced N utilization, predominantly as NH_4. Direct measurements of NH_4 regeneration indicate an important role for the microbial loop in water column N recyling processes. Based on near-surface f-ratios two contrasting patterns are proposed for bloom development that are broadly indicative of a growth versus maintenance strategy.

From the laboratory to the field: Can we apply knowledge of *Pseudo-nitzschia* physiology in the real world?

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Coastal California is typically viewed as upwelling-dominated, with strong equatorward and Ekman-dominated offshore flows, bounded to the west by the broad, meandering California Current. This implies that biological and physical processes propagate predominantly southward, that coastal runoff has negligible impacts on the near-shore oceanographic conditions and that much of biological interest is driven by seasonally intense spring upwelling. Recent observations suggest that this view is misleading, and that the occurrence of infrequent but high-impact events such as precipitation-driven coastal runoff and poleward surface flow may dominate the biological signal over large spatial and temporal scales. These events can "fertilize" the coastal ocean with anthropogenically derived nutrients, and may catalyze or exacerbate HAB conditions in the coastal ocean. One such HAB genus, *Pseudo-nitzschia*, has become increasingly important throughout the world's upwelling systems.

Pseudo-nitzschia spp. are known to vary domoic acid (DA) production as a function of multiple nutrients, including nitrogen, phosphorous, silicate, iron, copper, and possibly lithium. Recent evidence from laboratory and field experiments also demonstrates that nutrient stress impacts photosynthetic performance as diagnosed by physiological parameters such as variable fluorescence. The detection of *Pseudo-nitzschia* in the field has also been greatly improved by the application of molecular methods such as rRNA probes. Despite the large body of information on DA production and the occurrence of DA poisoning events, we still have a very poor understanding of event-specific triggers for DA production in the field, or the ecological basis for its production; this has thus far hampered our ability to predict or detect early onset of toxin production.

This contribution will evaluate the oceanographic conditions associated with HAB events in California and attempt to define common features across years, which makes central California a "hot spot" for HABs. Specific emphasis will be placed on reviewing the applicability of lab studies (ecology, physiology, and molecular genetics) to prediction and detection of toxic *Pseudo-nitzschia* blooms in upwelling systems.

The coastal monitoring applications of a bio-optical reflectance model to derive algal size and biomass

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An inverse reflectance algorithm designed to calculate the chlorophyll a concentration and effective diameter of surface phytoplankton assemblages is presented. The algorithm is suitable for application with both *in situ* hyperspectral and space-based multispectral sensors. Algorithm performance with regard to the derivation of algal bio-mass and size descriptors is assessed using measured *in situ* reflectance data. The utility of such algorithms in monitoring algal dynamics are discussed with regard to application with both moorings and synoptic ocean colour data, using examples of moored times series and satellite imagery. Algorithm structure results from a study of the optical properties of algal populations in the southern Benguela, which establishes a predictive formulation between size descriptors of the algal assemblage, algal absorption and ocean colour data. Measurements of phytoplankton absorption and particle size distributions are used in conjunction with anomalous diffraction models to assess the relationship between the size and absorption of regionally occurring harmful algal blooms. A simple and robust inverse phytoplankton absorption model employing the package effect is used to return size from algal absorption data. Size related variations in algal backscattering coefficients are analysed by combining measured phytoplankton optical data with particle scattering models based on the Aden-Kerker formulations for heterogeneous spheres. Phytoplankton absorption and backscattering models, together with parameterisations for non-algal constituents, are then incorporated into the non-linear inverse reflectance algorithm.

Satellite remote sensing in eastern boundary currents: Multiple programmatic roles

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Strong latitudinal variability in seasonal cycles coupled with interannual variability that often exceeds seasonal variability in magnitude make eastern boundary current systems highly dynamic and temporally/spatially heterogeneous. Satellite data provide both real-time and archived synoptic insight into variability patterns allowing informed decisions to be made at multiple stages of a research program. These include retrospective analyses of archived time series during the initial stages of a project for both statistical analysis of variability and model implementation, ongoing analyses during the project supported by, and in support of, field programs and modeling, realtime data delivery to support cruise activities, analyses coupled with the field results and modeling during project synthesis, and lastly, the opportunity for delivering

a monitoring system to coastal management agencies. Examples of each of these aspects will be shown, focused on chlorophyll, SST and wind variability. These examples will be drawn from the US GLOBEC program in the California Current and Gulf of Alaska, the US ECOHAB program and NASA-funded research on eastern boundary current variability in the Humboldt, Canary, Benguela and Canary Current systems. Finally, examples from a recent real-time, multi-sensor monitoring system set up in U.S. coastal waters will be shown.

Remote sensing and monitoring of harmful algal blooms in different upwelling conditions: Gulf of Mexico and Washington, USA

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Harmful algal blooms of the toxic dinoflagellate, *Karenia brevis,* along the Gulf of Mexico coast of Florida have been monitored for nearly four years using a combination of remote sensing and rudimentary models. While spectral detection methods have been considered optimal, they are problematic because dinoflagellates and diatoms have similar pigment suites. *Karenia*, however, often dominates biomass, allowing for other options. Detection of these blooms has been found to be effective with short-term chlorophyll anomalies. Even when *Karenia* is not the dominant species, it has co-occurred with other phytoplankton blooms, so that the anomaly technique can provide detection by surrogate. This method allows observation of development of new blooms, which can have broader application. Additionally, an optical technique based on backscatter differences provides further identification of these blooms under certain conditions. Monitoring of blooms draws on other oceanographic characteristics. In particular, upwelling-favorable winds are a driving factor for the appearance of the blooms at the coast, and also appear to cause re-intensification of existing blooms. This upwelling association appears to be due to transport of the organism from an offshore zone of initiation. The use of the anomalies provides information on transport patterns, which aids in addressing the problematic detection and monitoring of *Pseudo-nitzschia*/domoic acids events in the classical upwelling area of the Washington (USA west coast).

Hydrodynamic models as a basis to understand HAB bloom accumulation and advection in upwelling systems

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This study is based on the hypothesis that the observed HAB blooms in the late summer season in the southern Benguela (St Helena Bay System) are the result of advective responses to atmospheric forcing rather than new production activity. This study sets out to test the validity of this view as a first step in assessing the feasibility of numerical hydrodynamic models to understand and later to predict the incidence of HAB blooms.

The approach is to deliberately exclude any explicit phytoplankton physiological activity in the model and treat the cells either as passive tracers or Lagrangian particles. The focus is to better understand the space-time characteristics of atmospheric forcing (seasonal and event scales) and coastal ocean response in respect of both vertical turbulence dissipation (mixing and stratification) as well as horizontal advection of surface and bottom layer waters.

The model used was the finite difference -layer Delft3d-FLOW, which is well suited to the sub-regional scale of the study (~100km length scales) as well as for the high-resolution space-time requirements of the key underlying processes. The domain was set up with a variable grid resolution and eight layers distributed to provide adequate resolution of thermocline dynamics. The model runs are free and not constrained by any relaxation needs to regional ocean climatology. The time domain of the model runs was July 2001 to June 2002 but the verification period in respect of advection, bloom development and bloom collapse concentrated on the January-February 2002 window. Verification was undertaken using time series of AVHRR thermal data as well as SeaWiFS ocean colour images.

Preliminary results are encouraging not only in respect of understanding the bloom concentration mechanisms but also in respect of the timing of the low oxygen events that follow the collapse of those blooms.

Integrated modelling of physical and biological processes in the Iberian upwelling system

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Harmful Algal Blooms (HAB) develop in very specific physical and biogeochemical conditions which must be simulated prior to any HAB model development with forecasting skills. As a consequence HAB modelling has to be seen as a specific chapter of a more general integrated

ecosystem model. In this talk an integrated ecosystem model will be described and demonstration results will be presented for Iberian upwelling in a typical situation.
The aim of the talk is to raise questions, proposing assessing methods and solutions for some of them and stimulating the discussion of others. Methods will be proposed for discipline integration based on a modular strategy, in order to permit combining of a model for an ecosystem compartment with many models for physics and/or other ecosystem compartments. This approach is essential for assessing the real quality of that module.

Integration of scales will also be discussed. This issue is particularly important for assessing the role of river runoff and loads for the development of HAB, for which contradictory opinions coexist.

POSTER ABSTRACTS

Seven years of dinoflagellates from a Portuguese upwelling system

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An offshore, commercial "long-line" system for bivalve aquaculture has been set up at Sagres on the SW coast of Portugal., based on the exceptional growth rates of bivalves in these waters. This productivity is attributed to the natural eutrophication of surface waters by the upwelling of nutrient rich waters from the sea bottom during the summer months. However, blooms of harmful algae occur in these waters with the consequent negative affects on the commercial viability of the bivalve culture.

As part of a programme to understand the pattern of dinoflagellate succession at the aquaculture, net samples were taken from the surface waters on approximately a fortnightly basis between 1994-2001. 204 species were identified over this period, of which only a few are known to be toxic. The pattern of succession was irregular over the eight years , but Principle Components Analysis restricted to the thirty most numerous species showed up a more consistent seasonal pattern A specific analysis of the seasonal variation of known toxic species throughout the eight years is also presented and related to the commercial cycle for the bivalve culture at Sagres.

A preliminary study of DOC distribution in the NW Iberian upwelling system: Seasonal and spatial variability along the four coastal embayments of Rias Baixas

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This study analyse the Dissolved Organic Carbon (DOC) data from the all four embayments of Rías Baixas (Ria de Vigo, Pontevedra, Arousa and Muros) weekly sampled during 2002 with a. This is the first time that DOC data were studied in the all four embayments recurrently affected by HABs.

The coastal ecosystems affected by wind-driven upwelling reacts to the increased nutrients by enhancing organic matter production. Bioreactive fractions of dissolved organic matter (DOM, labile and semilabile pools) that accounts for the ~30% of total DOM will contribute to the regenerated and export production and seasonal accumulation of organic matter in surface waters. The uptake of this phytogenic material is mainly due to bacteria although other

heterothophic organisms, as some HABs species can use preferentially organic sources and ammonium over inorganic sources.
Recent work in the NW Iberian upwelling system has confirmed the seasonal accumulation of DOM in the Ria de Vigo and the importance of horizontal export of DOM to the shelf and oceanic waters. This study assesses the summer accumulation of DOC in surface waters in all four embayments.

The spatial heterogeneity within the same Ria: estuarine and oceanic situations, and comparing different Rias, characterised by hydrographical, biological and chemical differences will be related with DOC distribution.

Hybrid neuro-symbolic artificial intelligence system for forecasting red tides caused by *Pseudo-Nitzschia* spp.

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Pseudo-nitzschia spp. may produce domoic acid, the toxin responsible for amnesic shellfish poisoning (ASP). Periodic blooms in Galician coastal areas have caused virtual collapse of ecosystems with accompanying serious economic impacts. Harmful Algal Blooms (HABs) result in mass ecosystem dysfunction, risks to public health, and enormous economic losses. This is a very important reason for the development of a system that allows to understand the causes of blooms. Therefore, field research and model development is essential to determine and predict the conditions under which diatoms blooms form. This paper presents an artificial intelligence mechanism developed for forecasting the *Pseudo-nitzschia* spp. that appear in the coastal waters of the north west of the Iberian Peninsula.

The developed prototype is able to forecast the *Pseudo-nitzschia* spp with an acceptable degree of accuracy. The results obtained may be extrapolated to provide forecasts further ahead using the same technique, and it is believed that successful results may be obtained.

In conclusion, the hybrid reasoning problem solving approach may be used to forecast in complex situations where the problem is characterized by a lack of knowledge and where there is a high degree of dynamism.

Harmful algal blooms -indicators for local DOWNwelling

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Mass occurence of toxin producing algae have been observed worldwide. The environmental circumstances leading to their appearance, however, are not well understood. Often, for example, algal blooms have been related to upwelling processes.
Bloom forming HAB species belong to different taxonomic groups and thus differ significantly in their nutrient demand. A common growth requirement for most species, however, are relatively high water temperatures. The maximum growth rate of many species is recorded at temperatures above 20°C and the occurence of most of the harmful algal blooms is also restricted to temperature above 20°C. Oceanic upwelling regions, however are characterized by typical temperatures between 10 and 16°C. This apparent contradiction can be resolved, if it is taken into account that the conditions within these upwelling regions are not uniform, but rather are characterized also by the presence of downwelling locations (due to curved coastlines and rough bottom-topography) or downwelling events (due to meandering currents and fronts as well as the mesoscale eddy field).

A literature review of worldwide occurence of harmful algae suggests that HABs develop preferentially in downwelling locations or during downwelling events, where the sea surface temperature is significantly larger than in the surrounding areas.

Upwelling regime at Sagres (SW Portugal): Microplankton composition and production during Summer 2001

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Microplankton community dynamics, production and respiration were studied during an upwelling season, from May to September, at Sagres, alongside physical and chemical parameters. The Sagres sampling station was situated 5km east of the upwelling center off Cape São Vicente, Europe's southwestern tip, and 3km west from an offshore oyster-farm. The detection of phytotoxins in the bivalves, usually during autumn, has led to the closure of commercialization, at times for several months. The occurrence of potentially toxic species has also been monitored. Three major periods were distinguished according to sea surface temperature (SST) data: period 1 (P1), characterized by high temperature values (17.0±1.8 ºC), period 2 (P2) which corresponded to a lower temperature (14.6±0.3 ºC) stage identified as an upwelling-blooming phase, and period 3 (P3) that again presented a higher temperature pattern (16.25±1.14 ºC). PRIMER© software was used to assess changes in microplankton assemblage by means of multi-dimensional scaling (MDS) ordination and SIMPER routine. Major taxa contributing to the dissimilarities between P2 upwelling-blooming and the other periods were: *Chaetoceros* spp, *Thalassiosira* spp, *Lauderia* spp., *Detonula* spp. and *Pseudo-nitzschia* spp.

During P2 the average rate of gross primary production (GP; 52.5±12.3 µM O_2 d^{-1}) and net community production (NCP; 46.9±15.3 µM O_2 d^{-1}) reached its maximum. Rates of dark community respiration (DCR) remained low and more constant throughout (4.6±3.6 µM O_2 d^{-1}). SST were significantly correlated with the weekly average of the offshore Ekman transport for both the west and south coasts reflecting the influence of the two coasts circulation patterns on this geographical transition zone. Hydrographic events were the main factor determining the microplankton structure community at this location.

Pseudo-nitzschia australis along the west coast of South Africa

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The marine planktonic diatom genus *Pseudo-nitzschia* has been in the spotlight over the last 16 years because of its role in Amnesic Shellfish Poisoning (ASP). The responsible toxin is domoic acid which is transferred via the food chain from *Pseudo-nitzschia* via various shellfish and fish to humans and marine mammals. *Pseudo-nitzschia australis* was a dominant component of a bloom at Lambert's Bay, along the west coast of South Africa. Three distinct communities were observed in samples taken in an offshore and an alongshore transect off Lambert's Bay during February 2000. These were: an inshore, cold water community dominated by *P. australis*, an offshore community in warmer water dominated by a *Chaetoceros* species and a community north of Lambert's Bay, also in warm water, dominated by a *Gymnodinium* species. This *P. australis*-dominant bloom persisted inshore close to Lambert's Bay in 13^0C water for 7 days in concentrations of up to 2 million cells.L^{-1}. Despite the high numbers of *P. australis* cells, no case of ASP was reported and no isolates of *P. australis* from these waters has tested positive for the presence of domoic acid.

Intraspecific genetic variability of *Alexandrium tamarense* and *A. minutum* studied by RAPD-PCR

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Toxic dinoflagellates of the genus *Alexandrium* are known to cause serious episodes of PSP. Genetic characterization by different methods (i.e. rDNA sequences, allozymes) fail to reveal variation among strains from different global populations of several dinoflagellate species. RAPD-PCR is a method that reveals intraspecific genetic variability, and has been used to

elucidate differences at the poblational level in dinoflagellates and other microalgae. We have performed RAPD-PCR analysis of 5 clones of *Alexandrium tamarense* and 9 clones of *Alexandrium minutum*. Arbitrary 10-mer oligonucleotides were used as primers for the reaction. Electrophoresis on polyacrilamide gels showed that 8 from the 20 primers assayed gave reproducible results and the banding profiles generated by them were used for constructing matrices of similarity indices . Analyses were performed independently for each of the two species. Each strain showed a unique band profile. Results for *A. tamarense* showed the highest similarity for two distinct clones isolated from the same sample of water in the Baltic Sea (KAC01 and KAC02). The highest similarity among *A. minutum* clones was found for three of them (AL1V, AL2V and AL3V) isolated from the Ria de Vigo in NW Spain. The invader strain *A. minutum* A89BM from the Atlantic coast of France showed greater ressemblance to Australian than other European strains. The results show a high genetic variability within each single species and confirms the adequacy of the technique for distinguishing among co-specific *Alexandrium* populations.

Toxicity of marine cyanobacterial strains on embryogenesis and early larval growth of *Paracentrotus lividus* and *Mytilus galloprovincialis*

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Numerous cyanobacterial species are capable of producing potent toxins which have been the cause of wildlife intoxications. Since reproductive success is a determining factor for species survival, toxic effects can be particularly important in the most sensitive stages of development such as embryonic and larval stages. Acute toxicity of marine cyanobacterial strains were tested using a sea-urchin and a bivalve embryo-larval toxicity test. *Paracentrotus lividus* and *Mytilus galloprovincialis* were the chosen species. Cyanobacterial strains were isolated from water samples and solid material on the Portuguese coast and cultivated under laboratory conditions. Fertilized eggs of the sea urchin and mussel were exposed to crude extracts and partially purified extracts of the cyanobacterial strains at a concentration of 50 mg freeze-dried material/ml for a 48 hour period at 20 C. Assessment of embryogenesis success, early larval growth and some larval abnormalities were recorded. Toxicity tests displayed an evident toxicity, higher in the crude extracts. It was registered a retarded embryonic development and a significant higher percentage of abnormal larvae than of the control with the sea urchin assay. With the mussel bioassay, a retarded embryonic development was registered and different abnormalities in D-larvae were also observed.

HABs in Culebra Bay, Gulf of Papagayo, a small upwelling region in the Pacific coast of Costa Rica: What we know and what we need to know

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Golfo of Papagayo is a small upwelling region in the northern of the Pacific coast of Costa Rica, localized between 10°37´N & 85°40´W. The intensification of the north trade winds during December until May, originate a horizontal water transport away of the coast and a rich nutrients water raises to the surface, this phenomenon enhances the primary biological production. This bay is characterized by coral reef communities, by the entrance of many marine species of economical importance and its utilization as a nursery place of a major part of molluscs, crustacean and coastal fishes.

In Culebra Bay there are very few studies on morphodynamic processes and sedimentology. It is considerate in the last 15 years an important zone for international and local tourism, that has increased the anthropogenic processes and the environmental impact and motivated the research of the coral reef and coralline communities, plankton (nano and microphytoplank-ton, micro and mesozooplankton) and marine mammals.

Some harmful algal bloom events has been observed in Culebra Bay, but only one reported. It was produced by *Lingulodinium polyedrum* in April 2000, which induced a red discoloration of the water and a peculiar strong odor. This species produces spherical hypnocysts that may remain for decades when dark or anoxic conditions are present. In those time were found seven puffer fish (Diadontidae) and two lobsters dead in the sand. This species had been associated with the production of paralysing toxins such as saxitoxins and yessotoxins.

Culebra Bay presents large seasonal temperature changes. There is little information about the physical and chemical factors controlling the development of HAB's phenomena and its consequent prediction. The relationship between the HAB's and oceanic- atmospheric parameters like precipitation, run off, wind intensity, strong tide and include sea whirlwinds trombes, had been not studied in our region. During 2002 and 2001, north trade winds blow an unusual intensity, along of all the year. Frequent HABs were reported those years, with significant spatial distributions, which remain in some places of our Pacific coast many months. It is important to develop a monitoring program to identify seasonal behaviour of toxic dinoflagellates in Culebra Bay, specially the recognition of the cysts nursery place, and so ameliorate its impact on coastal human communities.

Bakun's triad principle as a basis for dinoflagellate algal bloom analysis in upwelling regions

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The ecosystem approach in the study of biological processes is a research field which is receiving an increasing attention by a number of harmful algal blooms researchers. Several methods and approaches have been proposed until now, but basically all of them try to integrate bio-geophysical and atmospheric parameters as a way to clarify the triggering conditions under which the dinoflagellate blooms develop.

The Bakun's triad (Bakun, 1996, 1998) is a three-step process (enrichment, concentration and retention) initially proposed by the author for the identification of suitable fish recruitment areas. This method is especially well adapted in upwelling regions.

After several years of observations and analysis of dinoflagellate blooms along the Huelva's coast (SW, Spain) and according to recent bibliography which consider the integration of bio-geophysical and atmospheric favourable conditions as a "need" for the development of dinoflagellate blooms (toxic and benign), we have adapted the principle of the Bakun's triad to the analysis of phytoplankton blooms.

This paper shows the environmental (water circulation patterns, nutrient concentration, atmospheric and meteorological parameters, etc.) and biological conditions (phytoplankton population) existing during extensive dinoflagellate blooms recorded in the coastal waters of the Huelva during 6 years (1998-2003). A combination of *in situ* measurements, laboratory determinations, remote sensing data and model outputs are used in the analysis.

A close interaction among a large variety of biological parameters (dinoflagellate population), chemical (nutrient concentrations), atmospheric conditions (wind direction and speed, irradiance conditions), and physical oceanography (water circulation patterns, turbulence, fronts, etc.) is shown. According to those results, the future capabilities of this approach, as a potential predicting tool, are discussed.

Development of an assemblage of harmful dinoflagellate associated to an oceanic front in the Galician Rías

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A dinoflagellate assemblage dominated by harmful species *Karenia mikimotoi, Prorocentrum minimum* and *Dinophysis acuta* was detected in autumn 2001 by the official HAB monitoring program in the Galician Rías Baixas (NW Spain). The bloom started with the detection of a

concentration of more than 10^4 cells L^{-1} of *K. mikimotoi* and 2.4 10^3 L^{-1} of *Dinophysis acuta* in the southwestern monitoring station of the Galician coast. The positive estuarine circulation of the Rías was blocked by a strong downwelling coinciding with the development of the bloom. This downwelling was observed by satellite images and CTD *in situ* data. The thermohaline properties were homogeneous in the water column and corresponded with oceanic superficial water: temperature 16.0-17.5 ºC and salinity 34.0 to 35.1 and water was completely exhausted of nitrates (< 0.1 μmol Kg^{-1}). In one week of southerly winds, the dinoflagellate assemblage was extended northeastwards reaching all the Rías Baixas and then a population of *Prorocentrum minimum* (>5.10^6 $celL^{-1}$) was developed into this community. An area of 680 Km^2 dedicated to extensive culture of mussels (*Mitylus galloprovincialis* > 240,000 Tonnes year) was affected by the bloom during six weeks but no massive mortality was observed. The end of the harmful episode and the re-establishment of the estuarine positive circulation in the Galician Rías Baixas caused an exportation of the dinoflagellate assemblage toward deep sea as could be observed by SeaWiFS images.

Objectionable odor associated with algal bloom at Wadi Al-Arab Dam Reservoir, Jordan

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This study concentrates on the biological parameters prevailed in the Wadi Al-Arab Dam Reservoir in Northern Jordan during the period between February-July, 2001. Dinophyceae was by far the most important group with *Peridinuim sp*. as the most significant species thriving in the reservoir. *Peridinium sp*. was recorded in high numbers and showed a peak in March and April and constituted 54 % and 75% of the total cell count, respectively. The cucumber smell of *Peridinuim sp*. was very clear in April along with a change in water color to brownish green. Cyanophyceae dominated the phytoplankton population in late Spring and early Summer (May-July) with development of a surface water bloom by *Microcystis aeroginosa* and *Anabaena wisconsinese*. Fluctuation in species succession and cell count at Wadi Al-Arab Dam Reservoir seems to be influenced by factors other than nutrients since these are available in high concentrations all over the year.

Physical-biological interactions in the ocean: Two case studies in the Western Iberia Upwelling Ecosystem

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Two cases of different interactions between physical processes and phytoplankton biomass off the western Iberia Peninsula are presented. The studies are based on distributions of

temperature, chl-a, and sea surface height derived from satellite data (NOAA/AVHRR; OrbView/SeaWiFS; TOPEX/POSEIDON), and also using in situ data from an oceanographic survey.

In the first case, a winter upwelling event off northwestern Iberia shelf/slope in the area of influence of the Western Iberia Buoyant Plume (WIBP) in February 2000 is described. Due to the WIBP, a shallow Ekman layer developed nearly coincident with the stratified upper meters. The transport comprises a westward advection and stretching of the plume, with little entrainment with the offshore deep mixed layer waters. Spatial patterns and time evolution of chlorophyll *a* (chl-a) biomass distribution (*in situ* and satellite) are analysed. A mechanism for concentration of phytoplankton is proposed.

The second case is a situation of phytoplankton biomass exchange from the coast to the open ocean, observed with satellite data, during February 2001. Off the southwestern coast two counter-rotating eddies interact in the vicinity of the slope. An anticyclone to the north and a cyclone to the south generate a cross slope jet, which promotes a strong offshore transport of shelf water to deep ocean The event lasted for about two weeks. The consequence is an enrichment of the phytoplankton biomass at the surface. The observed concentrations were two orders of magnitude higher than the usual.

Photoadaptation of harmful algal bloom-forming species in the southern Benguela upwelling system

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Photoadaptive responses of phytoplankton were investigated over 12 days in February/March 2003 during the southern Benguela upwelling season. Our aim was to establish how phytoplankton species respond to variable irradiance which might influence HAB development. The 50m water-column was well stratified with 16-17°C surface temperatures, a sharp thermocline at 5-10m and bottom waters of ~10°C. Chlorophyll profiles had mean surface values of ~2 mg m^{-3} and a subsurface chlorophyll maximum (SCM) averaging ~17 mg m^{-3} between 5 to 18m, just above the 1% light depth. Initially, dinoflagellates (*Prorocentrum*, *Dinophysis*, *Ceratium*) dominated surface waters while diatoms (*Chaetoceros*, *Pseudonitzschia*) dominated the SCM. Later, *Chaetoceros* appeared at the surface while dinoflagellates (mostly *Ceratium*) characterised the SCM. Photosynthesis versus irradiance (PE) relationships were established using standard ^{14}C methods. Surface and SCM values of E_k (light saturation parameter) and α^* (initial slope, the maximum light utilization coefficient) were significantly different (Wilcoxon signed ranks test; $p<0.05$). Surface E_k (mean 489 µE m^{-2} s^{-1}) values were higher relative to the SCM (mean 296). Surface α^* (mean 0.025 mgC $mgChl^{-1}$ [µE m^{-2}]$^{-1}$) was lower than within the SCM (mean 0.032). Mean surface P^*_m (max. photosynthetic rate normalised to Chl-a) was higher (11.78 mgC [$mgChl^{-1}$]h^{-1}) than at the SCM (mean 8.68) although these were not statistically different. E_k at the SCM correlated positively with the dinoflagellate: diatom

(DNF/D) ratio (r^2=0.70, $p<0.05$). The DNF/D ratio was also positively correlated with PAR in the SCM (r^2=0.98, $p<0.05$). These findings indicate that a lower Ek was associated with diatom dominance while a higher Ek was associated with dinoflagellate dominance. Meanwhile, diurnal variations of P^*_m and E_k at the surface exhibited early morning and evening minima, but midday maxima, implying photoadaptation to changing underwater irradiance. Coincidentally, surface dinoflagellate biomass exhibited morning and evening maxima, but minima during the day, suggesting vertical migration and isolume tracking. We conclude that PE responses have photoadaptive significance in pulsed upwelling regimes of alternate stability and vertical mixing characterised by a variable light environment. This may regulate shifts in phytoplankton community structure and vertical distribution patterns.

Evaluation of the Ensemble Kalman Filter in ecosystem state forecasting

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A complex Hydrodynamic-Ecosystem coupled 1-D model has been used to evaluate the usability of a sequential data assimilation method, the Ensemble Kalman Filter, in the modelling and prediction of Algal Blooms. The ERSEM-GOTM 1-D model is capable of reproducing the seasonal phytoplankton succession as well as Harmful Algal Bloom events of motile dinoflagellates. The complexity of the model allows us to investigate the triggering factors of the blooms and the community structure leading to HAB events. A module describing *Gymnodinium catenatum* included characteristics like diel migration, toxicity and its ability to form chains. The main factors involved in bloom formation are heterotrophic nutrient recycling, predation and absence of competitors, while motility alone favours bloom in nutrient stressed conditions. Data assimilation of model-generated data show that the Ensemble Kalman Filter is able to constrain the model evolution, particularly during bloom events when the nonlinearity is strongest. We show that biomass-related variables are better at constraining the model evolution than nutrients at different times of the year and explore the minimum sampling frequency and temporal distribution of measurements required for reliable prediction of algal blooms.

Study of *Pseudo-Nitzschia* spp. toxic blooms in Galician coastal areas using a correlation between MERIS and in-situ data

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Periodic blooms of *Pseudonitzschia* spp. in Galician coastal areas have caused virtual collapse of ecosystems with accompanying serious economic impacts. The aim of this work is the study of the physical environment of a coastal system correlating different bands of MERIS data with *in*

situ chlorophyll data provided by the Marine Environment Quality Control Centre during a study period associated to *Pseudo-nitzschia* spp. toxic blooms related to coastal upwelling events (May-June 2003). This work tries to establish the foundations for the future development of algorithms for the study of the primary production and the identification of *Pseudo-nitzshia* spp toxic blooms in coastal waters type II making use of the great potential of the FR MERIS products, with high spatial and spectral resolution. The study is a part of the ESA project AO623, which is intended to study changing shorelines-beaches seasonally and annually, together with suspended matter discharged into coastal waters and pigments related to algae blooms.

GEOHAB OPEN SCIENCE MEETING ON HABS IN UPWELLING SYSTEMS

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