Welcome to the conference

Dear Delegate

Welcome to Plymouth, and to this IMBER (Integrated Marine Biogeochemistry and Ecosystem Research) UK meeting.

The IMBER vision is "to provide a comprehensive understanding of, and accurate predictive capacity for, ocean responses to accelerating global change and the consequent effects on the Earth System and human society". Using five high priority research topics selected from the IMBER Science Plan (www.imber.info/SPIS.html) :

- ***Interactions between biogeochemical cycles and marine food webs : Transfers of matter across ocean interfaces***
- ***Sensitivity to Global Change : Effects of increasing anthropogenic CO_2 and temperature***
- ***Sensitivity to Global Change : Changing supplies of macro- and micronutrients***
- ***Sensitivity to Global Change : End-to-end food webs and biogeochemical cycles***
- ***Responses of society***

which also map onto the new NERC Theme Action plans (Earth System, Climate System, Technologies, Natural Resources and Biodiversity), this meeting aims to provide a forum to facilitate interaction between UK marine researchers studying IMBER topics, and to create a suitable environment through which new collaborative research ventures may be fostered.

An important output from the meeting will be the five science topic reports detailing potential areas for future UK / EU IMBER related marine science research initiatives .

We would like to take this opportunity to thank the sponsors of the meeting – The Royal Society, the NERC Strategic Oceanographic Funding Initiative (SOFI) and the Plymouth Marine Sciences Partnership. We hope you find this meeting engaging, interesting and most of all constructive in forging new scientific collaborations.

Carol Robinson, Andy Rees and Richard Sanders

Programme

Thursday 8 January 2009
08:30 Coffee, registration and poster set up
09:00 IMBER: Integrated Marine Biogeochemistry and Ecosystem Research, Julie Hall

Interactions between biogeochemical cycles and marine food webs: Transfers of matter across ocean interfaces
Remineralisation in the mesopelagic layer and exchange between the seafloor and water column
Chair Richard Lampitt
09:30 Mineralization of organic matter in the dark ocean, Christian Tamburini
09:50 Balancing the carbon budget of the mesopelagic zone, Tom Anderson
10:10 The benthic response to natural iron fertilisation in the Southern Indian Ocean – The Crozet Islands, George Wolff

Sensitivity to Global Change : Effects of increasing anthropogenic CO_2 and temperature
Effects of speciation of carbon, nutrients and trace metals and susceptibility/adaptability of organisms
Chair Steve Widdicombe
10:30 Unifying principles in ecosystem effects of ocean warming and acidification, Hans-Otto Portner
10:50 Effects of High CO_2 and Acidification on the Plankton, Toby Tyrrell
11:10 Multi-species coccolithophore response to an anthropogenically-modified ocean, Ros Rickaby
1130 Coffee

Sensitivity to Global Change : Changing supplies of macro- and micronutrients
Effects of change in inputs, distribution and stoichiometry of nutrients, increases in hypoxia & anoxia
Chair Gideon Henderson
12:00 Atmospheric inputs to the oceans, Tim Jickells
12:20 Combined effects of hypoxia and high pCO_2 on iron speciation, Maeve Lohan
12:40 Molecular underpinnings of adaptation to different nutrient limitations in the marine diatom *Thalassiosira pseudonana*, Thomas Mock

13:00 Lunch & posters

Sensitivity to Global Change : End-to-end food webs and biogeochemical cycles
Impacts of harvesting marine resources
Chair Simon Jennings
14:30 Ecosystems End to End: A BASIN scale perspective, Mike St John
14:50 An impending need for scientific advice on the impact of fishing on marine food webs, Mike Heath
15:10 Predicting the impacts and socio-economic consequences of climate change on global marine ecosystems and fisheries: the QUEST_Fish framework, Manuel Barange

15:30 Coffee & posters

Responses of society
Relationships between marine biogeochemical cycles, ecosystems and human society
Chair Laurence Mee
16:00 Multiple-pathways for impacts of climate change on fisheries social-ecological systems, Tim Daw
16:20 Science and Policy Integration: Rusty Gate or Revolving Door ? Tavis Potts

16:40 Governance mechanisms which respond to marine and coastal change: the evolving UK framework and opportunities for scientific input, Tim Stojanovic

17:30 Wine and nibbles reception sponsored by the Plymouth Marine Sciences Partnership

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Friday 9 January 2009

09:00 – 11:30 Parallel structured discussion sessions – to propose the key questions to be addressed in the future

Interactions between biogeochemical cycles and marine food webs : Transfers of matter across ocean interfaces
Remineralisation in the mesopelagic layer and exchange between seafloor and water column
Chair Richard Lampitt

Sensitivity to Global Change : Effects of increasing anthropogenic CO_2 and temperature
Effects of speciation of carbon, nutrients and trace metals and susceptibility/adaptability of organisms
Chair Steve Widdicombe

Responses of society
Relationships between marine biogeochemical cycles, ecosystems and human society
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11:30 Coffee & posters

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Sensitivity to Global Change : Changing supplies of nutrients
Change in inputs, distribution and stoichiometry of nutrients, increases in hypoxia and anoxia
Chair Gideon Henderson

Sensitivity to Global Change : End-to-end food webs and biogeochemical cycles
Impacts of harvesting marine resources
Chair Simon Jennings

13:30 Lunch & posters

Session chairs report to plenary
14:30 Richard Lampitt
14:50 Steve Widdicombe
15:10 Laurence Mee

15:30 coffee

Session chairs report to plenary
16:00 Gideon Henderson
16:20 Simon Jennings

Summing up and way forward
16:40 Carol Robinson (UEA, Norwich)
17:00 End

ORAL PRESENTATIONS

IMBER: Integrated Marine Biogeochemistry and Ecosystem Research

Julie Hall[1], Sylvie Roy[2]

[1]*National Institute of Water and Atmospheric Research Ltd, Hamilton, New Zealand.*
E-mail: j.hall@niwa.co.nz
[2] *IMBER IPO, European Institute for Marine Studies, France.*
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Human activities are rapidly altering Earth System processes that directly and indirectly influence society. Informed decisions require an understanding of which parts of the Earth System are most sensitive to change, and the nature and extent of anticipated impacts of global change. In response to this need, the new IGBP-SCOR Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) project has been formed, to focusing on ocean biogeochemical cycles, ecosystems and there interactions. The IMBER vision is to; "*provide a comprehensive understanding of, and accurate predictive capacity for, ocean responses to accelerating global change and the consequent effects on the Earth System and human society*". To achieve this, the IMBER Science Plan and Implementation Strategy is structured around four major research themes. Theme 1 focuses on identifying and characterising interactions of the key biogeochemical and ecosystem processes that will be impacted by global change. Central to IMBER goal, Theme 2 will develop 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 harvesting. Theme 3 investigates the roles of ocean biogeochemistry and ecosystems in impacting the larger Earth System through direct and indirect feedbacks. Finally, Theme 4 integrates natural and social sciences, drawing on information from the previous three themes to investigate key interactions with the human system and the options for mitigating or adapting to the impacts of global change on marine biogeochemical cycles and ecosystems. An update on IMBER activities and working groups will be presented.

Mineralization of organic matter in the dark ocean

Christian Tamburini, Javier Arístegui, Dominique Lefèvre

Centre d'Océanologie de Marseille and University of Las Palmas

The dark ocean is the major reservoir of active carbon of the biosphere, and thus a key player in the sequestration of excess CO_2 -resulting from human activities- and amelioration of global warming. Nevertheless, the mechanisms of transport, transformation and mineralization of organic carbon from the surface ocean to the ocean interior are still uncertain. This has led modelers to predict carbon fluxes to the deep ocean based on processes occurring at the illuminated euphotic zone. A part of this surface production (between 20 to 50%, according the estimation of the f ratio) is exported to the dark ocean as dissolved and particulate organic material (POM). During sedimentation, most of the particulate organic carbon (POC) is mineralized and only a small fraction reaches the sediments. Substrate quality influences the energetic yield, and thus the dynamic response of microbial communities to particles. However, despite the crucial importance of the organic material composition, there are only a few studies addressing the link between diversity and function on deep-water prokaryotes. Here we present a brief overview of the processes concerning the role of prokaryotes into POM degradation and biogenic remineralization through the water column, including pressure effects. We also review the different approaches to estimate mineralization rates in the ocean, as well as new methodologies to help reconciling biogeochemical and ecological estimates. Finally we discuss the discrepancy obtained between carbon export, prokaryotic carbon demand and oxygen utilization rates, and give recommendations to advance in knowledge through the understanding of the biogenic processes occurring in the dark ocean.

Balancing the carbon budget of the mesopelagic zone

Thomas R. Anderson

National Oceanography Centre, Southampton

Most of the particulate and dissolved organic matter that is exported from the upper ocean is remineralised in the mesopelagic zone by a diverse biota which as yet we have little understanding of. There is great uncertainty, for example, in the relative roles of zooplankton and microbes in consuming particles as they sink through the water column. Attempts to budget carbon by comparing the attenuation of particulate organic carbon (POC) with depth to the sum of respiration by zooplankton and bacteria have been inconclusive. One problem is that various processes, such as the active flux from migrating zooplankton, may not be represented. At a more fundamental level, existing estimates of zooplankton and bacterial respiration, and/or POC flux could be erroneous. Looking forward, future progress will require recognition of the extent of the current problem in reconciling C budgets, further observational/experimental work on the complex biology (and physics) of the mesopelagic zone, and modelling studies to help focus our understanding and suggest quantitative bounds for different processes.

The benthic response to natural iron fertilisation in the Southern Indian Ocean – The Crozet Islands

George A. Wolff, Jens Holtvoeth, Ian Salter[1], David Billett[1], Richard Lampitt[1]

Department of Earth and Ocean Sciences, University of Liverpool
[1]National Oceanography Centre, Southampton

An established paradigm in the open ocean is that the biological pump fuels export of carbon to the deep sea by the vertical flux of particulate organic matter (POM[1]) from the base of the photic zone to the interior of the ocean. The chemistry of the sinking particles is modified through reworking in the water column. Zooplankton produce faecal pellets and release dissolved organic matter (DOM; Gordon, 2001; Lampitt et al., 1993; Watanabe et al., 2002) and together with the microbial community, remineralise organic compounds and lead to the diminution of POM flux with depth. Nevertheless, the material that escapes the TZ and reaches the sea floor fuels the non-chemosynthetic benthic community and the timing and quality of the POM arriving at the sea floor, as well as its quantity, appear to have a very strong influence on the benthic ecology. Dramatic changes in species dominance in the abyssal North Atlantic (Billett et al., 2001) do not appear to be related to changes in total export flux (Lampitt et al., 2001), but instead to changes in the "quality" or organic chemical composition of the OM arriving at the seafloor (Wigham et al., 2003, Neto et al., 2006). A similar change in the community structure of the dominant megafauna was observed at 4100 meters depth in the northeast Pacific and was synchronous to a major El Nino/ La Nina event that occurred between 1997 and 1999 (Ruhl and Smith, 2006).

We speculate that the chemical signature of material arriving at the sea floor is crucial and potentially impacts the benthic community. To test this idea, we have compared a seasonally iron-fertilised abyssal location northeast and a non-fertilised HNLC region to the south of the Crozet plateau in the Southern Indian Ocean. We show significant differences in POM fluxes to the sea floor at the two sites, which are also distinct in their benthic faunal assemblages. We find differences in POM quality between the two sites that can be ascribed to the productivity differences in overlying waters and particularly phytoplankton dominance and to processing in the water column.

Billett, D. S. M. et al. (2001). Progr. Oceanogr. 50: 325-348

Gordon, J. D. M. (2001). Cont. Shelf Res. 21: 987-1003;

Lampitt R. et al. (2001). Progress in Oceanography, 50, 27-63.

Ruhl HA and Smith KL (2006) Science, 305-513.

Neto R. R., et al. (2006). Deep-Sea Res I, 53, 516-527.

Watanabe, H. et al. (2002). Mar. Ecol. Prog. Ser. 236: 263-272

Wigham, B. D. et al. (2003). Progress in Oceanography, 59, 409-441

[1] POM is separated into two pools: Suspended POM defined as <20µm, sinking velocity < 1 m d^{-1}; sinking POM defined as >20µm, sinking velocity(ies) >1 to 100s m d^{-1} (Lee and Wakeham, 1989)

Unifying principles in ecosystem effects of ocean warming and acidification?

Hans O. Pörtner

Alfred-Wegener-Institute for Polar and Marine Research, Marine Animal Physiology, Bremerhaven, Germany (hans.poertner@awi.de)

Climate change causes ocean warming and acidification on global scales. While effects of warming on marine ecosystems established effects of rising CO_2 are just emerging. Future scenarios indicate a threatening of marine life through the specific or synergistic effects of rising CO_2 levels, warming and more frequent hypoxia events. Beyond empirical observations, development of a cause and effect understanding and of realistic scenarios is required for a secure projection of ecosystem effects. Such understanding builds on the identification of key physiological mechanisms and their responses to progressive acidification, warming and hypoxia. In changing oceans, these are physiological characters which define species performance, including their capacity to interact, e.g. in food webs. Many current ecosystem changes likely occur when ambient temperature drifts beyond species specific thermal tolerance windows and causes a shift in phenology. Specific sensitivity to elevated CO_2 levels may involve a key role for acid-base regulation, with low capacities found in lower marine invertebrates. Present evidence indicates elevated sensitivity to elevated CO_2 levels towards the edges of thermal windows. The key consequence may be a narrowing of thermal tolerance windows and associated ranges of geographical distribution, of the scope for performance at ecosystem level and thus, an exacerbation of warming effects on marine ecosystems.

Effects of High CO_2 and Acidification on the Plankton

Toby Tyrrell

National Oceanography Centre, Southampton

I will describe some of the experimental and observational evidence relating to likely effects of high CO2 and ocean acidification on phytoplankton and zooplankton. A large number of experimental and mesocosm studies have examined the effect of elevated CO2 and lower pH on coccolithophores, with sometimes contrasting results. While these studies have been invaluable in giving an initial idea of acidification impacts they also suffer from drawbacks including a lack of consideration of possible evolutionary adaption, possible assemblage reassortment towards less sensitive species or even, for some experiments, physiological acclimation. Experimental studies must therefore be supplemented by alternative approaches including in-situ observations to investigate the extent to which coccolithophores thrive (or not) in real waters having naturally low pH and/or CaCO3 saturation states. Results of observational work to date will be summarised, along with an introduction to known current and planned work in different projects. Some evidence for acidification impacts on calcifying zooplankton, in particular foraminifera, pteropods and echinoderm larvae will be briefly reviewed. High CO2 and/or low pH may impact on physiological processes other than calcification, including rates of photosynthesis, nitrogen fixation and TEP; some current evidence will be shown.

Multi-species coccolithophore response to an anthropogenically-modified ocean

R. E. M. Rickaby[1], P. R. Halloran[1], I. R. Hall[2], E. Colmenero-Hidalgo[2], J. Henderiks[3]

[1]Department of Earth Sciences, University of Oxford
[2]Department of Earth and Ocean Sciences, Cardiff University
[3]Dept. of Geology and Geochemistry, Stockholm University, Sweden

Coccolithophores are one of the most important pelagic calcifying organisms in the present ocean to contribute to the organic carbon and carbonate pump of pCO_2 from the atmosphere into the deep ocean. As a major primary producer in the ocean, coccolithophores are responsible for fixation and draw down of dissolved inorganic carbon into the deep ocean via the biological pump. Coccolithophores also calcify, and the production and export of calcium carbonate releases CO_2. The net influence of coccolithophores on pCO_2 depends partly on the particulate inorganic: organic carbon ratio (PIC/POC).

Major questions surround the species-specific nature of coccolithophore calcification in response to rising atmospheric CO_2 levels and the likely biogeochemical feedback on future climate. Here we investigate the assemblage wide coccolithophore response to anthropogenically elevated pCO_2 using both culture experiments and field evidence from a North Atlantic core. The particle volume distribution data from the coccolith size-fraction of a rapidly accumulating North Atlantic sediment core appear to indicate that coccoliths produced by the larger coccolithophore species present at this location increase in mass in parallel with anthropogenic CO_2 release, in contrast to those of the smaller size which decrease in mass. This contrasting behaviour is consistent with the results of our culture experiments of different species under conditions of carbonate chemistry which is decoupled from pCO_2. A divergence between the calcification response of these two coccolithophore size-groups could reflect contrasting physiological controls and evolutionary adaptation to pCO_2. This has significant implications for the realistic representation of an assemblage-wide CO_2-calcification response in numerical models.

Atmospheric Inputs to the Ocean

Tim Jickells

School of Environmental Sciences, University of East Anglia, Norwich

In this presentation I will present distributions of atmospheric inputs of nutrients (N, P, Si and Fe) to the oceans world wide and then focus particularly on the Atlantic, using data from AMT transects and other cruises. I will consider the form and bioavailability of the deposited nutrients. I will consider what controls the deposition pattern and its potential current impacts on ocean biogeochemistry and also how this has changed in the past and may change in the future.

Combined effects of hypoxia and high pCO_2 on iron speciation

Maeve C. Lohan
University of Plymouth

There has been a growing interest in the cause and impact of hypoxic regions known as 'dead zones' that have increasingly appeared along the west coast of the United States and have caused widespread destruction to the crab and fishing industry in this highly productive region. I will present results which demonstrate that the combined effects of hypoxic conditions and low pH in the water column result in a marked increase in iron(II) concentrations which contribute to elevated dissolved and labile particulate iron concentrations. These elevated dissolved iron(II) concentrations result from two factors: 1) the low oxygen, low pH, and low temperatures act in concert to markedly slow down the oxidation rate of Fe(II); 2) the hypoxic water column allows extremely elevated iron(II) concentrations in reducing porewaters to exist close to the sediment water interface leading to an increased flux of iron(II) from the sediments. During upwelling, this process results in a major new source of iron that can upwell to surface waters, potentially increasing phytoplankton productivity, which can, in turn, lead to enhanced export flux, driving the system further into hypoxic, or suboxic conditions. There is the potential for a fundamental shift in these economically important coastal upwelling marine ecosystems.

Molecular underpinnings of adaptation to different nutrient limitations in the marine diatom *Thalassiosira pseudonana*

Thomas Mock
School of Environmental Sciences, University of East Anglia, Norwich

Diatoms are an exciting group of photosynthetic eukaryotes because their evolution is based on secondary endosymbiosis (red alga engulfed by heterotrophic host) what possibly make's them so successful in almost all aquatic environments. They contribute about 20% of total primary production on Earth and therefore drive many different biogeochemical cycles of elements. The diatom *Thalassiosira pseudonana* was the first marine alga for which a genome sequence became available and we used this resource to develop microarrays (tiling and gene-specific) for the identification of novel transcribed regions in the genome and for transcriptome profiling under important environmental conditions (e.g. iron, silicon, nitrogen limitation). One unique outcome of this work is the coupling of silicon and iron pathways in this diatom, which might have profound ecological significance. Phytoplankton primary production is limited by iron in ca. 30% of the global ocean and these areas are also low in dissolved silicon suggesting that both silicon and iron may play a role in regulating diatom productivity.

Ecosystems End to End: A BASIN scale perspective.
(Based on interactions during the development of the International BASIN Program as well as discussions with EU BASIN contributors and Ken Frank)

Mike St. John
University of Hamburg, Germany

One of the central issues in the International IMBER program is to understand and predict the impact of climate change on the key species relevant to biochemical and ecosystem processes. To this end, an understanding of how food webs are controlled or regulated by their environment and human activities is critical. Developing an improved predictive understanding of these interactions will ultimately enhance our ability to manage and conserve marine resources in a system of global change. To this end, key research themes and the core questions for examination will be presented. These are as follows;

Theme 1. How will **climate variability and change** – for example changes in temperature, stratification, transport, acidification – influence the seasonal cycle of primary productivity, trophic interactions, and fluxes of carbon to the benthos and the deep ocean?

- How will the ecosystem's response to these changes differ across basins and among the shelf seas?
- How are the populations of phytoplankton, zooplankton, and higher trophic levels influenced by large-scale ocean circulation and what is the influence of changes in atmospheric and oceanic climate on their population dynamics?
- What are the feedbacks from changes in ecosystem structure and dynamics on climate signals?

Theme 2. How do **life history strategies** of target organisms, including vertical and horizontal migration, contribute to observed population dynamics, community structure, and biogeography?

- How are life history strategies affected by climate variability?
- How will life history strategy influence the response of key species and populations to anthropogenic climate change?

Theme 3. How does the **removal of exploited species** influence marine ecosystems and sequestration of carbon?

- Under what conditions can harvesting result in substantial restructuring of shelf or basin ecosystems, i.e., alternate stable states?
- Do such changes extend to primary productivity and nutrient cycling?
- How is resilience of the ecosystem affected?

- What is the potential impact on the sequestration of carbon?

An impending need for scientific advice on the impact of fishing on marine food webs

Mike Heath[1], with input from Emma Guirey[1], Simon Greenstreet[1], Dougie Speirs[2] and Bill Gurney[2]

[1]FRS Marine Laboratory, Aberdeen
[2]Department of Statistics and Modelling Science, University of Strathclyde

There is a growing requirement to consider fisheries management in an ecological context. EU Directives require that populations of all commercially exploited fish and shellfish in EU waters are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock. Meanwhile, after several years of data analysis by ICES, the OSPAR Commission has recommended the adoption of an Ecological Quality index for fish communities as a whole to be used in the 2010 Quality Status Report for North-East Atlantic waters. The index is based the proportion by weight of fish in the demersal community as a whole which exceed a certain length threshold, and the theory is that fishing acts to depress this index by removing and mitigating against large fish and species which grow to a large size. In the North Sea, the value of this index is currently well below what has been set as the target level of 30% by weight larger than 40cm in length, even though populations of some commercial species are within what is considered to be safe biological limits. The question now is “what changes in fishing pattern and intensity would be required to restore this index to its target level within a given time period, and under a given climate scenario, and what will be the consequences for yields of commercial species?” Providing advice of this sort requires modelling approaches which ecompasses the end-to-end food web and the physical drivers, the dynamics of the multi-species predator-prey structure within the fish food web, and the dynamics of fishing activity. The task of bringing these issues together is at the frontiers of marine science. This presentation will summarise ongoing work to address the problem, and how it will relate to the various requirements for ecosystem-based advice on fisheries management.

Predicting the impacts and socio-economic consequences of climate change on global marine ecosystems and fisheries: the QUEST_Fish framework

Manuel Barange and the QUEST_Fish team[2]

Plymouth Marine Laboratory

Climate change is accelerating and is already affecting marine ecosystems and the services they provide. Both models and ocean observations indicate that the world's oceans are warming and patterns in atmospheric variability are changing, resulting in changes in oceanic stratification and vertical mixing, circulation patterns, sea ice and light supply to the surface ocean. Biological responses to these effects include changes in primary production, species composition, process seasonality, and distribution. Impacts of climate change on global fish production, however, are difficult to estimate, mostly because of a) difficulties in downscaling Global Climate Models to scales of biological relevance, b) lack of adequate global ecosystem models capable of scaling up from aquatic future net primary production to fish production across food webs, and c) difficulties in separating the multiple additional biological and socio-ecological stressors affecting fish production, including differential geographical and temporal exploitation patterns and economic policies. In addition, the economic risks and societal vulnerabilities of these impacts require the development of methodologies capable of estimating human vulnerabilities to these changes at all scales. QUEST_Fish, a research consortium between leading UK and international institutions, is addressing some of these challenges through an innovative, multi-scale, multi-disciplinary approach focused on estimating the added impacts that climate change is likely to cause, and on the subsequent additional risks and vulnerabilities of these effects to human societies. The project is anchored on coupled shelf seas biophysical ecosystem models forced by Global Climate Model forecasts to predict ecosystem functioning in pre-industrial (~1850), present, near future (2050) and distant future (2100) time slices. For each time period we estimate plankton production in 20 Large Marine Ecosystem units around the world. We link primary production to fish production with models based on macroecological theory, thus bypassing much of the species-based complexity of marine food webs and instead express fish production by body size classes. We will then develop improved ways of assessing vulnerability of fisheries to future climate change, in the context of other drivers of change, and specifically investigate the consequences of the results on the markets for major fish-based global commodities, such as fishmeal and fish oil. The results should provide a new framework to study fluctuations in natural resources subject to climate and

[2] Icarus Allen (PML), Eddie Allison (WorldFish, Malaysia), Marie-Caroline Badjeck WorldFish/UEA), Julia Blanchard (CEFAS), Benjamin Drakeford (CEMARE), Nicholas K. Dulvy (SFU, Canada), James Harle (POL), Robert Holmes (PML), Jason Holt (POL), Simon Jennings (CEFAS), Jason Lowe (Met), Gorka Merino (PML/UoP), Christian Mullon (IRD, France), Graham Pilling (CEFAS), Emma Tompkins (LeedsU), Francisco Werner (RU, USA)

market impacts, providing new insight into the complex interactions between humans and nature.

Multiple-pathways for impacts of climate change on fisheries social-ecological systems

Tim Daw, Marie-Caroline Badjeck*, W. Neil Adger, Katrina Brown and Eddie Allison*

*University of East Anglia (*and World Fish Centre, Penang)*

Most of our research on the impacts of climate change on fisheries systems emphasises changes in ocean productivity and its impact on fish distribution and production. This is only one of many ways in which changing climate may impact fisheries and fisherfolk, which may include movement of people to coasts, disruption of markets, and impacts on coastal infrastructure and living space. Such indirect climate effects, mediated through socioeconomic systems, will interact with, amplify, or even overwhelm more familiar biophysical climate impacts . Non-climate drivers of change occurring at the local or global scale, for example changes in markets, demographics, overexploitation and governance regimes, will also interact with climate change further complicating impacts on fisherfolk and fishing communities. We propose a research agenda that addresses climate impacts on fisheries as linked social-ecological systems, and review the concepts of vulnerability, adaptive capacity and social-ecological resilience for understanding such impacts.

Science and Policy Integration: Rusty Gate or Revolving Door?

Tavis Potts

Scottish Association for Marine Science

What came first – science or policy? While the question seems rather pedantic, the relationship between scientific methods and outputs and the process of policy formation and implementation remains an important and relevant topic. In an age where issues such as climate change or the sustainable use of natural resources have scientific, economic and social ramifications (and solutions) both scientists and policy makers have critical roles to play in addressing a range of globally important issues.

The relationship between science and policy is a temperamental one. Despite the recent attractiveness of terms such as ‘science policy integration’, the problems facing the meaningful integration of these epistemologies have persisted for decades. While issues such as climate change are dependent on rigorous science to understand their extent, impact, and consequences this, however, represents only half of the equation. As is increasingly recognized, addressing environmental issues requires social and economic mobilisation and political action including adaptive policy formulation, delivery and review.

This paper explores and characterises the issues that surround science and policy integration with examples from the marine sector. It highlights the epistemological differences and challenges, the role of knowledge and power in policy development, and the contribution of quantitative and qualitative disciplines. Finally the avenues that allow the application of scientific knowledge into the policy process and broader social change will be reviewed.

Governance mechanisms which respond to marine and coastal change: the evolving UK framework and opportunities for scientific input

Tim Stojanovic

Marine and Coastal Environment Research Group, Cardiff University

The very notion of 'governance' highlights the complementary roles of different spheres of society in contributing towards sustainability outcomes. This paper draws on current research amongst social scientists, economists and geographers that have sought to elucidate those characteristics which lead to more effective governance.
Firstly, the paper presents the results of research which have investigated the role of marine science within policymaking. The findings show the importance of recognizing the different cultures and rewards systems in order to generate successful collaboration. Secondly, the paper outlines existing regimes for planning and management around the UK continental shelf. New governance mechanisms are being proposed including a system of marine (spatial) planning under a Marine Bill in 2009. Arguably, human activities are expanding offshore and we are witnessing a 'colonisation' of marine space. Adaptation to change is likely to be crucial to the success of these planning and management initiatives. It is therefore an opportune time for IMBER scientists to reflect on which arrangements will lead to closer coupling between science and policy. Some preliminary findings are reported from an example network operating at a sub-national scale- the Severn Estuary Climate Change Research Advisory Group.

POSTER PRESENTATIONS

Session 1 : Remineralisation in the mesopelagic layer and exchange between the seafloor and water column

Does the supply of organic matter to the deep ocean affect the biochemistry and diversity of Holothurians ?

Fisher E. H. [1], Smith T. [2], Holtvoeth J. [1], Chaillan F. [1], Wolff G.A. [1], Bett B. J. [2] and Billett D.S.M

[1]*University of Liverpool, Department of Earth and Ocean Sciences,*
[2]*National Oceanography Centre, Southampton*

Much of the Southern Ocean is a high-nutrient, low-chlorophyll regime (HNLC). However, there are productivity 'hotspots' associated with topographic features which are thought to be fertilised by iron (Pollard et al., 2007; Blain et al., 2007). The Crozet Plateau is such a hotspot and provides an ideal location to study benthic-pelagic coupling in the deep sea. We chose two abyssal locations (M5 and M6) which had the same depth, bottom water mass and sediment type but were only 400 km apart. Our hypothesis is that iron fertilisation of HNLC waters around Crozet and the subsequent algal bloom leads to enhanced particulate organic matter (POM) fluxes and enrichment of the abyssal sea floor (4000 m) at M5, whereas M6 is less enriched. Using pigment and lipid analyses we show how the benthic fauna respond to enrichment at M5 and how the molecular composition of the POM flux is imprinted on the benthic megafauna and influences their diversity.

Pollard *et al*. (2007): The Crozet Natural Iron Bloom and Export Experiment (CROZEX). *Deep Sea Research Part II*, 54, 1905-1914.
Blain *et al*. (2007): Effect of natural iron fertilization on carbon sequestration in the Southern Ocean. *Nature*, 446, 1070-1075.

Sexual biochemistry in the deep sea – the link between phytoplankton and abyssal holothurians.

Tania Smith, David Billett, George Wolff

National Oceanography Centre, Southampton & University of Liverpool

Holothurians dominate the abyssal megabenthos. They are important because they rework large amounts of organic matter (OM), playing a significant role in carbon cycling. Holothurians require essential organic compounds, such as carotenoids, for their reproduction. Carotenoids are photosynthetic pigments that cannot be synthesised *de novo* by the holothurians, only by phytoplankton. The abyssal holothurians assimilate carotenoids from the phytodetrital flux arriving at the seafloor from the upper water column. Enhanced carotenoid concentration in the ovaries of echinoderms, as well as specific carotenoids such as xanthophylls, can increase reproductive output and larval survival. To examine the link between diet and reproduction in deep-sea holothurians, the phytopigment biochemistry of the abyssal sediment, holothurian gut sediment chlorophyll-a concentration (to determine feeding selectivity on fresh OM), and holothurian ovarian carotenoid biochemistry were compared over two consecutive years from the Porcupine Abyssal Plain, Northeast Atlantic. Gut sediment chlorophyll-a concentration (µg g^{-1} DW) showed that *Amperima rosea*, *Peniagone diaphana* and *Oneirophanta mutabilis* selectively feed on high quality OM, although when this is scarce, *O. mutabilis* switches to more refractory material. All three species also show consistent ovarian carotenoid profiles and have relatively high ovarian carotenoid concentrations. *Psychropotes longicauda*, *Paroriza prouhoi*, *Pseudostichopus aemulatus, P. villosus* and *Molpadia blakei* are all non-selective feeders that show little or no temporal variation in their diet. These species passively assimilate relatively low concentrations of carotenoids. Favourable conditions, either through the supply of specific carotenoids required by holothurian species with consistent ovarian carotenoid profiles, or through the supply of xanthophylls that are assimilated passively by the non-selective species, may create reproductive advantages. Therefore, changes in the quantity and composition of the OM supplied to the abyssal seafloor may lead to large community changes, as seen at the PAP. Such community changes can influence the reworking rate of the sediment, ultimately affecting the sequestration of carbon.

Biogeochemical time-series from fixed-point deep ocean observatories

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Fixed-point deep ocean observatories are an integral part of monitoring the marine environment, producing high resolution, long-term time-series data sets of climatically and ecologically relevant variables. These data enable a greater understanding of short-term variation and ecosystem dynamics, allow episodic events to be captured and lead to a deeper understanding of longer-term variation and climatic trends.

We present a suite of multidisciplinary biogeochemical data measured *in situ* at the Porcupine Abyssal Plain (PAP) observatory in the North East Atlantic (49°N, 16.5°W) over the past 20 years. The observations cover the entire water column and the seafloor beneath (4800 m). Data include autonomous measurements of temperature and salinity (to 1000 m), biogeochemical data at 30 m (including nitrate, chlorophyll and CO_2) and deep ocean studies from benthic time-lapse photography and deep sediment traps. Seasonal and inter-annual variations in biogeochemical processes will be presented in terms of winter mixing, surface circulation and benthic-pelagic coupling.

This multidisciplinary data set makes the PAP site a unique surface to benthic observatory in the NE Atlantic. Future developments of the PAP site will be discussed both within the context of Oceans2025 and relevant European and international initiatives including EuroSITES, an EU FP7 project to integrate European deep ocean observatories.

Session 2 : Effects of speciation of carbon, nutrients and trace metals and susceptibility/adaptability of organisms

Understanding the role of bioturbation in determining the structure, function and diversity of N-cycling bacteria in acidified oceans

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Nitrogen cycling is a key function of marine sediments and is closely coupled with the pelagic system and primary production. In coastal environments, up to 80% of the nitrogen needed by photosynthetic microorganisms can come from the regeneration of organic nutrients in sediment. Although sediment nitrogen cycling is primarily driven by microorganisms, biological interactions between microbes and other sediment fauna can have significant effects on nitrogen transformations and fluxes. The physical mixing and irrigation of the sediment by infaunal macrofauna, a process known as bioturbation, is important in setting the structure, function and diversity of benthic microbial communities. In particular the construction of permanent or semi-permanent burrows can lead to a 10-fold increase in bacterial abundance compared to surrounding sediment. This increase is thought to be a result of several positive effects – increased availability of organic material, the presence of biopolymers within the burrow wall, and an extension of the oxic-anoxic interface – all of which enhance redox reactions and solute transport. Consequently, environmental stressors that change the behaviour and success of infaunal bioturbating species can have a significant effect on microbial communities, and therefore on sediment nitrogen cycling. This poster describes the structure and function of microbial communities inhabiting the burrows of two species of bioturbating shrimp, *Upogebia deltaura* and *Callianassa subterranea*. Using molecular techniques, the diversity of these bacteria and the expression of functional nitrogen cycling genes throughout the burrow is investigated. Plans for future research will be described. This research will further elucidate the important relationship between burrowing macrofauna and microbial community structure and function, and how this relationship could change in response to ocean acidification.

Processes influencing the distribution of intertidal communities in a high CO_2 ocean

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The barnacle *Semibalanus balanoides* is a major space occupier on rocky shores in Northern Europe and hence changes in its population ecology can have a broad influence on other species. Despite its ecological importance, the impact of a warmer, more acid ocean on this species, and hence on intertidal communities, remains unclear. In this paper we demonstrate how temperature and carbon dioxide interact to affect *S. balanoides* egg development, nauplii development and cyprid development. Changes in abundance and viability of the early life stages will impact the supply of larvae arriving in the intertidal and post settlement mortality will determine the number of individuals reaching reproductive age. Laboratory experiments indicated that changes in pH and temperature slowed the metamorphosis of cyprids thereby increasing their exposure to desiccation. Nevertheless, increased temperature and CO_2 concentration had greatest impact on smaller individuals prior to metamorphosis; with poor survival being linked to slow growth and ability to calcify. The paper also also discusses how this experimental data can be used to develop models for the prediction of changes in population distributions as well as aspects such as secondary production and calcium carbonate production.

A whole organism approach to the physiological impacts of ocean acidification

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Investigations into the impact of ocean acidification on an organism can be achieved by studying physiological processes. Currently, calcification and growth are popular proxies to quantify a species response because of their vulnerability to the changing carbonate chemistry predicted in a high CO_2 world. However, hypercapnia and acidosis have the potential to affect many other physiological processes within an organism. Moreover, these processes are frequently interdependent and by focussing on just one area (e.g. growth/calcification) there is a high possibility of overlooking sub-lethal impacts of ocean acidification. A series of mesocosm experiments have been conducted to investigate how key survival processes are affected by ocean acidification. These experiments have been conducted using the ophiuroid brittlestar *Amphiura filiformis*, a calcifying species which is an ecosystem engineer widespread across European temperate waters. Investigating how pH affects metabolism, ecosystem function (nutrient flux), reproduction, muscle maintenance, arm regeneration and differentiation, in addition to growth and calcification, gives a clear picture of how this organism is affected by, and potentially copes with ocean acidification. The results for *A. filiformis* show metabolic up-regulation and increased calcification, which result in a trade off with other physiological processes. While the

results of the study indicate an increase in growth and calcification, and therefore suggest no detrimental effect of increase pH, the whole organism approach reveals a different picture; the trade offs and prioritisation reveal the survival of this species in a high CO_2 ocean could be at risk.

Consequences of ocean acidification - implications for immune function & disease resistance in marine invertebrates

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Anthropogenic increases in atmospheric CO_2, are acidifying the world's oceans, and by 2100 this decrease in surface water pH could be as much as 0.5 units. Furthermore when coupled seasonal upwelling of waters already undersaturated with respect to aragonite, which is only being exasperated by OA, (Feeley et al 2008) this phenomenon is impacting both as a long term and immediate problem. To date a growing array of studies incorporating both traditional and novel techniques have investigated different physiological and life-history traits to elucidate the impact of OA on the marine biota. However, little attention has been directed to understanding the potential implications of stress-induced immune dysfunction and reduced resistance to disease. This is perhaps surprising given the recent advances in constructing molecular tools that can be applied to studies of (marine) invertebrate immunity, and the likely sensitivity of immunological responses to OA-related disturbance. Consequently we are investigating the impact OA, and other cumulative environmental stressors, could have on cellular and humoral immune functions in the blue mussel, *Mytilus edulis*, augmented by the use of novel genomic, and other molecular, methods that can be applied throughout the lifecycle of *M. edulis*. We will also explore how OA alters an organisms' susceptibility to pathogenesis and how any such changes might impact on fitness. This will be done through an integrated assessment of climate change-relevant environmental stressors.

The effects of high CO_2 on the fixed nitrogen inventory of the Western English Channel

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The oceanic absorption of anthropogenic CO_2 has reduced sea surface pH by 0.1 units since pre-industrial times with further decreases of up to 0.6 pH units predicted by the year 2100. The physiochemical speciation of nitrogen and its bioavailability are expected to vary as a function of seawater pH. Thus there is a need to develop a mechanistic understanding of the effects of decreased pH on the nitrogen cycle and associated impacts on phytoplankton communities. During this study surface seawater collected from the Western English Channel was filtered and purged with compressed air mixtures that represented present and future scenarios of atmospheric CO_2 (380, 500, 760, 1000 ppm). Measured pH values correlated well with computer based predictions of future atmospheric pCO_2. This study demonstrated that a CO_2 derived reduction in seawater pH can lead to an increase in the surface ocean concentration of total ammonium. This enrichment is a result of the thermodynamic drawdown of gaseous ammonia from the overlying atmosphere to the water column. As a consequence, changes in the fixed nitrogen inventory and thus the nitrogen to phosphorus ratio were observed. It is likely that such phenomenon will impact phytoplankton community structure and ecosystem functioning with potential feedbacks for primary production and carbon export.

Session 3 : Effects of change in inputs, distribution and stoichiometry of nutrients, increases in hypoxia & anoxia

Basin scale gradients in limiting nutrients and nitrogen fixation in the Atlantic Ocean.

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Nutrient limitation of primary production and (di)nitrogen fixation (diazotrophy) constrains the influence of upper ocean biological productivity on net air-sea carbon partitioning. Over large (inter- and intra-basin) scales the relative importance of different nutrients in limiting these key biological processes in the upper ocean will reflect differences in their supply ratios. Atmospheric wet and dry deposition may represent one such source of potentially limiting nutrients to oligotrophic waters. Bioassay experiments designed to asses which nutrients limit both phytoplankton productivity and diazotrophy were performed on the Atlantic Meridional Transect (AMT) 17 cruise. The AMT transect allowed sampling in both the North and South Atlantic tropical and sub-tropical gyre regions.

Results from the North Atlantic confirmed previous data suggesting a system close to co-limitation by nitrogen (N) and phosphorous (P). In contrast the South Atlantic gyre was strongly N limited, with a large unutilised inorganic P pool and hence no secondary productivity response to added P. No response of phytoplankton to Fe addition was observed in either basin. Along transect measurements indicated that N_2 fixation was highest in the tropical North Atlantic and very low within the South Atlantic. Inter-basin gradients strongly suggested a role for Fe in governing the distribution of diazotrophs, in particular *Trichodesmium* spp., with implications for patterns of nutrient limitation both of diazotrophs and the ecosystem as a whole.

Total dissolved Co in bioassays from the tropical Northeast Atlantic using flow injection-chemiluminescence detection

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Cobalt is an essential element for phytoplankton growth as it is required in the carbon concentrating mechanism (ccm) of photosynthetic cells and is a cofactor in vitamin B_{12}. As cyanobacteria have an absolute requirement for cobalt and are known to play a key role in the regulation of the global carbon cycle, shipboard incubation experiments were designed to investigate the effect of cobalt on phytoplankton growth.

This poster presents data on the role of cobalt in the oligotrophic North Atlantic gyre. Samples were collected during the UK-SOLAS cruise, INSPIRE, to the tropical North Atlantic (16 - 26°N) in November and December 2007. Six stations were occupied in areas of high, medium and low primary production (0.3, 0.1 and 0.07 µg L^{-1} chl-*a* respectively), and samples collected at each station. Forty-eight hour bottle incubations were conducted on board ship to assess the trace metal limitation of microbial processes (*e.g.* nitrogen fixation) using a matrix of 0.05 - 2 nM additions of Fe, Zn, Co, Cu and N to waters at each station. Total dissolved Co concentrations from the incubations were determined in the laboratory by Flow Injection with Chemiluminescence (FI-CL) detection. The results provide an insight into the biogeochemical cycling of cobalt in the North Atlantic oligotrophic gyre and its role in the global carbon cycle.

The Atlantic Meridional Transect Programme

Malcolm Woodward, Andy Rees and the AMT team

Plymouth Marine Laboratory

The AMT programme undertakes biological, chemical and physical oceanographic research on cruise transects through the north and south Atlantic oceans. The transects cross a range of ecosystems from sub-polar to tropical and from euphotic shelf seas and upwelling systems, to the oligotrophic mid-ocean gyres. The programme provides opportunity for nationally and internationally driven collaborative research and a platform for multi-disciplinary oceanographic research. AMT is an *in situ* observation system, and will provide further information on changes in biodiversity and function of the Atlantic Ocean ecosystem during this period of rapid change to our climate and biosphere. The first AMT cruise was in 1995 and the latest AMT-18 voyage ended in November, 2008. The measurements of hydrographic and bio-optical properties, plankton community structure and primary production completed on the first 12 transects (1995-2000) represent the most coherent set of repeated biogeochemical observations over ocean basin scales. This unique dataset has led to several important discoveries concerning the identification of oceanic provinces, validation of ocean colour algorithms, distributions of picoplankton, identifying new regional sinks of pCO_2 and variability in rates of primary production and respiration. Between 2002 to 2006 the programme addressed a suite of cross-disciplinary questions concerning ocean plankton ecology and biogeochemistry and their links to atmospheric processes. The data collected will be distributed for use in the development of models to describe the interactions between the global climate system and ocean biogeochemistry. Further cruises will add to the data sets and help to investigate the sensitivity to change of biogeochemical cycles in the Atlantic oceanic system, on the time scales from yearly to decadal.

Automatic biota (freshwater & seawater) recognition based on taxonomic features

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Plankton form the bottom of the marine food chain and changes in their density and distribution have far reaching consequences as, for example, fish stocks deplete or relocate from former grounds.

It has been stated that the identification of organisms is one of the major problems hindering research in many areas of biology. This has become increasingly apparent in the field of plankton identification as the number of identification specialists decreases and the volume of unanalyzed data grows. Identification by human means can also be slow and inaccurate and this has led to the need for an automatic method of identification. With their ability to perform repetitive tasks with consistent accuracy, computers appear to offer an ideal solution by analyzing photomicrographs of plankton collected in situ. However, the development of a reliable method has proved problematic with no “ideal” solution having been found.

The current automatic approach can be characterized as “bottom up” where a series of measurements are made by the computer from plankton images which are then submitted to a classification algorithm. Classification works by finding features shared by different objects and thus grouping them into classes. This approach can yield a success rate of around 65 - 75%.

In order to improve upon this, the current project has the following aims

1. To explore what features are used by human experts to identify zooplankton genera and species and learn the keywords used to map classification of images derived from microscopy.
2. From this, develop a plankton species identification system based on morphological features rather than arbitrary machine extracted measurements and so mirror the process used by human experts. For this project proof of concept restricts the plankton studied to a single species.

Comparative Evaluation of Ecosystem Models in a Marine Model Test-bed (MarMOT)

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The need to predict the response of ecosystems and biogeochemical cycles to environmental change on global scales demands robust representations of the marine biota in ocean general circulation models (OGCMs). However, the range of possible representations is poorly constrained in terms of model structure, process parameterizations and the values of uncertain or poorly quantifiable parameters. Exploration of different possibilities within a global OGCM is limited by computation time. This motivates the development of more flexible test-beds in which many different ecosystem model runs can be performed in data-rich areas.

The Marine Model Optimization Test-bed (MarMOT) is a new integrated environment designed for computationally intensive analyses of candidate ecosystem models. It provides a common interface for different ecosystem models in which ecosystem variables are forced by physical model output at observation locations. In a preliminary experiment using the prototype test-bed, alternative Nutrient-Phytoplankton-Zooplankton-Detritus models are calibrated to identical data from the Bermuda Atlantic Time-series Study site. The calibrated models are evaluated against independent data from a different year to test predictive skill. Parameters selected for optimization are common to each model but have very different post-calibration values due to the different internal constraints built into each model. The results of such calibration experiments are invariably compromised by uncertainty in both the observations and the physical forcing data and are unavoidably dependent on subjective decisions regarding the definition of the model-data misfit. MarMOT will provide a powerful tool for investigating these issues and determining appropriate weights for different observational constraints.

Biogeochemical studies in the sea-ice, marginal ice zone and open waters of the Arctic north of Svalbard: preliminary results from the international “Ice Chaser” Cruise, (Summer 2008).

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Rapid climate-induced changes in Arctic sea-ice and water column structure will have a significant impact on the Arctic marine ecosystem and carbon cycle, and the accurate prediction of such changes is a major challenge for the Arctic marine science community. During July and August 2008 a multidisciplinary programme of observational and experimental research was undertaken on the RRV *James Clark Ross* in shelf seas to the north of Svalbard in the European Arctic. The objective of the UK-led expedition was to improve our understanding of the ecology and biogeochemistry of the region and thereby help refine models of ecosystem response to environmental change. A range of physical, chemical and biological observations and experiments were conducted in the water column and sediments at ice-covered, marginal ice zone and open water stations. Oceanographic conditions were colder than expected with extensive ice cover due to northerly winds driving pack ice into the region; the marine ecosystem was therefore characterised by typical Arctic species. Preliminary results revealed the presence of a post-bloom recycling community characterised by an active but relatively slow growing phytoplankton community, and an active microbial community which was uncoupled from the phytoplankton. Healthy populations of large herbivorous zooplankton were also found in deep waters indicting the presence of an earlier under-ice phytoplankton bloom. This poster summarises these and other preliminary findings from the expedition.

Session 4 : Impacts of harvesting marine resources

Integrating Climate and Ecosystem Dynamics: circumpolar analyses of Southern Ocean ecosystems

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Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED) is a new multidisciplinary international programme, launched to address the challenges of integrating research on Southern Ocean ecosystems, biogeochemistry and climate at the circumpolar scale. Understanding the processes driving ecosystem responses to climate change and harvesting is of fundamental importance in both developing management strategies for the Southern Ocean and elucidating the role of the Southern Ocean in the Earth System. ICED has been developed as part of IMBER and GLOBEC and provides the scientific framework for major national and international integration activities, with a focus on linking biogeochemical and ecosystem research in the Southern Ocean. This decade-long programme will initiate, coordinate and integrate three main areas of activity: historical data synthesis, fieldwork and model development. The ultimate goal of ICED is to improve predictions of ecosystem dynamics, including responses to climate change and harvesting. This will be achieved by developing a hierarchical set of models of ocean circulation, biogeochemical cycles and the end-to-end operation of foodwebs with different spatial, temporal and trophic resolutions. ICED enters the implementation phase in 2009 and the initial focus will be on synthesis activities and the initiation of planning for major new field activities.

Session 5 : Relationships between marine biogeochemical cycles, ecosystems and human society

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