Integrated Marine Biogeochemistry and Ecosystem Research (IMBER)

Three IMBER *imbizo* workshops on ecological and biogeochemical interactions

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An *imbizo*, in the Zulu language, is a forum for enhancing dialogue and interaction. It defines the IMBER approach to it's first set of three concurrent interacting workshops held in Miami in November 2008. The workshops covered Ecological and Biogeochemical Interactions in (a) End-to-End Food Webs, (b) the Mesopelagic Zone and (c) the Bathypelagic Zone. Each workshop was structured to provide a synthesis of current knowledge and key questions for future research within IMBER. The workshops had common plenary, poster and summary sessions.

End-to-End Food Webs

There is increasing recognition that analyses of biogeochemical cycles, climate impacts and the effects of exploitation in ocean ecosystems requires the development of integrated views of food web operation. With this focus on integration, a new term has appeared – *analysing the end-to-end operation of food-webs* – encompassing the concept of linking food web operation from microbial systems (that dominate the carbon flows in marine systems) through to the highest trophic level species that may also be subject to exploitation. Attempts to define the end-to-end food web — or *e2e* for short — have led to broad definitions that are equivalent to the widely used definition of an ecosystem.

The term *e2e* has brought attention to the complexity of the interactions involved in food-webs. Dealing with that complexity was recognised early in the workshop as probably the central challenge we face. The importance of and therefore the need to consider the emergent properties of food webs generated through complex interactions at a wide range of scales. The meeting also demonstrated that many of the major issues faced in *e2e* analyses are already being tackled by groups working on a range of regional systems. The major scientific task is now one of integration, building on previous and ongoing regional analyses and detailed process studies. Comparative studies between regional systems such as the Arctic-Antarctic and Benguela-Humboldt are also emerging and global comparisons of ecosystem structure and function are being developed. At the same time, generic models (e.g. based on size or simplified functional group representations) are being applied globally or as standard model frameworks parameterised for different regions. The challenge for IMBER, as GLOBEC comes to an end, is to develop the interdisciplinary integration capacity, linking scientists with interest in biogeochemistry and food web operation, while accounting for the complexity of oceanic ecosystems. This emphasis on integration requires both a major shift in thinking and a stronger focus on the perennial issues of ensuring iterative links between modelling and observation programmes and maintaining multidisciplinary teams. Developing a range of analysis and modelling approaches will be crucial, with a requirement for comparison based on both general ecosystem properties (e.g. size structure and patterns of energy flow) as well as specific metrics (e.g. productivity, harvesting yield or stoichiometric balance).

The Mesopelagic Zone

The mesopelagic zone, between depths of about 100 and 1000 m, is a zone of significant decomposition, recycling, and repackaging of particulate and dissolved organic matter. The interplay between biological and geochemical processes in this zone has significant effects on the magnitude of the biological pump, which regulates in part atmospheric carbon dioxide and hence can impact climate. While important processes regulating organic matter transformations and remineralization in the mesopelagic zone can be tightly coupled with the euphotic zone, the time and space scales of these processes are different in the mesopelagic zone, which is critical to predicting the ability of the biological pump to sequester carbon in the deep ocean.

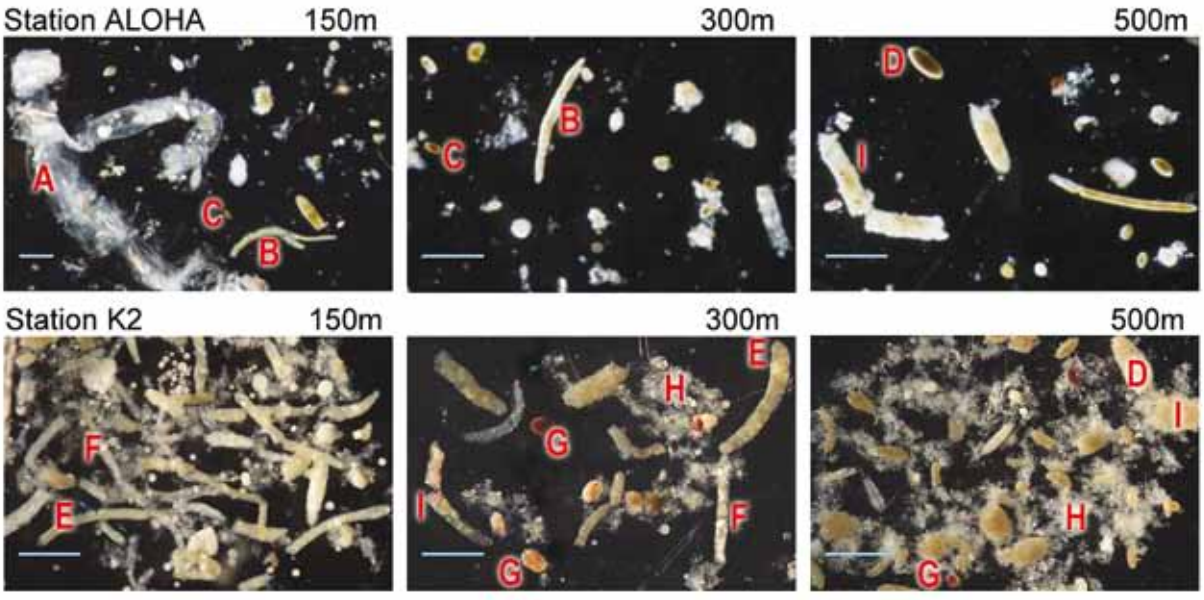
The aim of the workshop was to identify the current state of

our knowledge about mesopelagic food-web processes, particle flux and dynamics, and biogeochemical cycling, and to identify gaps in our knowledge. The workshop addressed the following topics: particulate and dissolved organic matter (POM and DOM) distribution, characterization, and flux; planktonic food web controls on vertical transport, cycling, and composition of POM and DOM; linking microbial and metazoan diversity to function; ecological and biogeochemical approaches to estimating remineralization rates; models; methods and new technologies; regional comparisons in food-web structure and biogeochemistry; and potential responses of the mesopelagic zone to environmental change. The workshop participants recommended that future research programmes on the mesopelagic zone should integrate across disciplines (chemistry, microbiology, ecology, physics), and throughout water column (i.e. link with surface processes). The location of future studies may include time-series sites, places of contrast, sites with strong gradients and where effects of global change are large. Spatial and temporal variability must be considered. It was also recommended that species or functional groups should be the focus. In addition to measuring stocks, mechanisms need to be understood to contribute to mechanistic models. Characterization of physical processes (e.g., lateral advection, deep- and mode-water formation) is important for constraining mesopelagic carbon and nutrient budgets. Technological advances to help address future challenges in the mesopelagic zone include: pressure samplers for measuring *in situ* respiration, neutrally buoyant sediment trap designs, remotely operated vehicles with sampling capabilities, automated underwater vehicles and floats for increased spatial coverage, and underwater observatories for long-term monitoring.

The Bathypelagic Zone

The bathypelagic zone is one of the great unexplored realms of the global ocean. The biological pump connects surface processes to the deepest ocean layers, where biological processes occur at very low rates relative to the upper ocean. With deep ocean residence times at centennial to millennial scales in time and global scales in space, the system is only slowly ventilated and circulated. Biogeochemical signals in the deep ocean are integrative of processes occurring over very long periods. Biological processes in the deepest ocean layers are intimately tied to particle dynamics and microbial food webs, much of which are still only poorly characterized.

The central aim of the workshop was to gather the expertise required to identify what is known about this system, and to identify and pursue outstanding uncertainties. The cross section of disciplines represented included biogeochemistry, organic geochemistry, microbial



Changes in fecal pellet types with depth indicate zooplankton repackaging of sinking particles in the mesopelagic zone. This figure shows changes in major types of zooplankton fecal pellets from sediment trap samples from the subtropical Pacific (Hawaii Ocean Time-series, HOT, station ALOHA) and subarctic Pacific (Japanese time series site K2). Scale bar is 500 um: A) heteropod Carinaria sp., B) large copepod or euphuasiid, C) small copepod, D) larvacean, E) Neocalanus spp., F) euphausiid, G) unknown carnivorous zooplankton, H) fecal "fluff", I) broken pellet [1]

dynamics, trace element and isotope geochemistry, genomics, particle flux and dynamics, and modeling. Presentations on the biogeochemistry of organic matter covered composition, structure, distribution, fluxes, reactivity, etc., while those on microbial dynamics considered the turnover of the organic matter, processes controlling microbial abundance, as well as deep autotrophic production. Three papers are under development to synthesise our understanding of, (i) deep sea microbial dynamics, (ii) the biogeochemistry of organic matter and (iii) deep ocean metabolism, focusing on the relative roles of autotrophic and heterotrophic processes. The first two syntheses will consider the same deep ocean system, but from the unique perspectives of biogeochemistry and microbes.

The presentations from the *imbizo* can be found at http://www.confmanager.com/main.cfm?cid=1185

Two special issues of *Deep Sea Research* (Elsevier, The Netherlands) will be published: *The Dark Ocean*, and *End to End Food Webs*. These will include both presented papers and synthesis papers resulting from the workshop discussions.

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New developments in marine ecosystem research

Recommendations for IMBER II

J. Field

A Transition Task Team has been set up to recommend to SCOR and IGBP how the second phase of the Integrated Marine Biogeochemistry and Ecosystem Research programme (IMBER) should proceed to accommodate new developments in marine ecosystem research that need addressing after the completion of the Global Ocean Ecosystem Dynamics research programme (GLOBEC) at the end of 2009.

The Team was asked to make recommendations to SCOR and IGBP for a second phase of the biogeochemistry and ecosystem research programme (IMBER) after 2009, bearing in mind:

1. Key new scientific questions arising from global ocean ecosystems dynamics research by GLOBEC
2. Scientific results of IMBER on marine and biogeochemistry and ecosystem research, to date
3. New developments in marine ecosystem science
4. Projects currently within GLOBEC that are planned to continue after 2009

With accelerating global change the urgency of achieving the IMBER vision and goal is even more apparent five years after the IMBER Science Plan was written. The Transition Task Team identified areas that need new or renewed emphasis so that IMBER Phase II will achieve its scientific vision and goal, and will build on the IMBER activities to date. These areas are:

- integrating human dimensions into marine global change research
- regional research programmes
- comparative studies

Transition Task Team members at the National Academy of Science, Washington, DC, December 2008.
From left to right: Ken Drinkwater, Qisheng Tang, Roger Harris, Kathleen Miller, John Field (Chair), Eileen Hofmann, Hugh Ducklow, Mike Roman. Inset: Olivier Maury. Absent: Raleigh Hood, who is thanked for his participation on SIBER discussions on 15 December.

within and across regional programmes, including ecosystem models that incorporate the human dimension
- incorporation of emerging scientific themes.

The report from the Transition Task Team, currently undergoing peer-review, lists IMBER activities to date, outlines some GLOBEC science highlights (taken from the GLOBEC synthesis book *Marine Ecosystems and Global Change* which will be published by Oxford University Press in 2009) and lists some emerging scientific issues such as CO_2 enrichment and ocean acidification, new metabolic and biochemical pathways, the role of viruses, thresholds and surprises, coupled biogeochemical-ecosystem model projections, and the characterization of uncertainty.

The main recommendations include a number of research approaches that could be adopted in the second phase of IMBER:

1. Innovative approaches
2. Innovative technologies
3. Process studies
4. Sustained observations
5. Palaeo-oceanography
6. Molecular genetics and functional groups
7. Integration of human dimensions in ecosystem models
8. Comparative approach between ecosystems
9. Synthesis and modelling.

IMBER II will have regional programmes that were not established when the original implementation strategy was written. The research approaches listed above have been adopted in several of the regional programmes. In order to achieve global coverage, the Transition Task Team strongly recommend that seven regional programmes be incorporated into IMBER II, provided that they agree on terms of reference with the IMBER SSC. These include Integrating Climate and Ecosystem Dynamics Programme (ICED) (Southern Ocean), Sustained Indian Ocean Biogeochemical and Ecological Research (SIBER), CLimate Inpacts on Oceanic TOp Predators (CLIOTOP), Ecosystem Studies of Subarctic Seas (ESSAS), Small Pelagic fish And Climate Change (SPACC, upwelling regions), Basin-scale Analysis, Synthesis and Integration (BASIN, a proposed North Atlantic comparative studies) and Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Ecosystems (FUTURE, a proposed PICES North Pacific Programme).

Recommendations are also made with regard to funding, potential sponsors, data management, implementing mechanisms and a timetable.

This report, which includes a draft Implementation Strategy for a second phase of IMBER (2010-2014) will form the Appendix to the *IMBER Science Plan and Implementation Strategy* (SPIS) which was published by IGBP in 2005. The Transition Task Team had input from the IMBER and GLOBEC SSCs and the report has been posted on the IMBER and GLOBEC websites for community comment before peer-review by IGBP and SCOR.

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