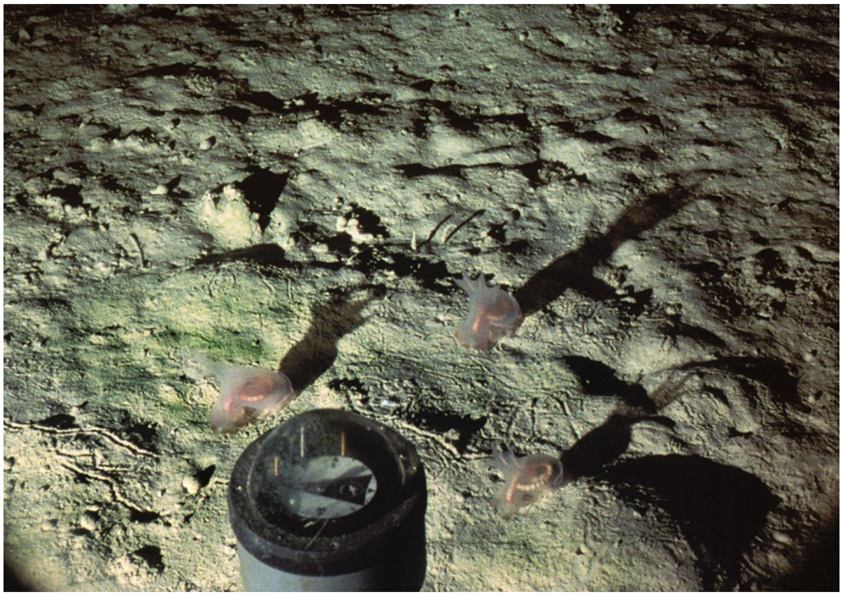
Deep-Sea Sediments:
The Known, the Unknown and the Unknowable



Report of the CoML workshop
Hatfield Marine Science Center, Newport, Oregon
21 to 24 August 2003.

The Participants of the CoML Workshop

Compiled by

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Picture on front cover: ***Amperima rosea*** on the Porcupine Abyssal Plain at 4850m. Photo: SOC.

Table of Contents

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Workshop Timetable

Thursday 21 August 2003
Daytime – participants arrive for Deep-Sea Sediments and Seamounts/Canyons workshops. Registration at La Quinta Hotel.

19:00 – Evening reception at La Quinta Hotel, 45 SE 32nd St., South Beach.

Friday 22 August 2003

Joint plenary session with Seamounts/Canyons workshop (HMSC Auditorium)
09:00 Welcome (George Boehlert)
09:10 The Census of Marine Life (Ron O'Dor)
09:30 Seamounts/Canyons (Karen Stocks)
09:50 Deep-Sea Sediments (David Billett)
10:10 Break – Sediments and Seamounts Groups separate after coffee

Deep-Sea Sediments - The Known (Part I). Chairman – Lisa Levin
10:30 Brief self introductions
11:00 Workshop goals - discussion
11:30 Where are we now? Pacific (Existing datasets/planned programmes)
12:30 Lunch

Deep-Sea Sediments - The Known (Part II). Chairman – Ann Vanreusel
13:45 Where are we now? Atlantic/Indian/Southern Oceans, Mediterranean Sea
16:00 Break

The Unknown – Gaps in our knowledge. Chairman – Paul Snelgrove
16:20 Open discussion
18:30 Transport to Hotels

20:00 Workshop dinner at Rogue Brewery

Saturday 23 August 2003
09:00 **Sub group organisation and workshop goals – reorganisation (David Billett)**

10:00 - **Detailed planning phase –sub groups formed**

1. Abyssal Plains: **Chairman - Craig Smith** **Rapporteur - Ben Wigham**
2. Continental Margins: **Chairman - Gil Rowe** **Rapporteur - Tammy Horton**
3. Temporal Issues **Chairman - Ken Smith** **Rapporteur - Andy Gooday.**

Draw up a list of priorities, existing and planned activities, critical gaps, new areas for international collaboration, funding sources for new research projects.

12:00 **Interim report of working groups – Plenary session**
12:30 Lunch

13:45 **Where now? Methodologies and Taxonomy. Chairman: Craig Smith**
15:30 Break

16:00 **Sub groups - CoML sampling protocols (mega-, macro- and meio-fauna)**
Meeting of continental margins and canyons group

Plenary session for Deep-Sea Sediments Group. Chairman – Bob Carney
17:00 Summary - Abyssal Plains Group (Craig Smith)
17:15 Summary – Continental Margins Group (Gil Rowe)
17:30 Summary – Temporal Group (Ken Smith)
17:45 Outstanding issues and next steps
18:30 Transport to Hotel

20:00 Workshop Dinner at Oregon Coast Aquarium (Transport by van)

Sunday 24 August 2003
Plenary session of Deep-Sea Sediments and Seamounts/Canyons Groups.
Chairman – Paul Tyler
09:00 Report from Deep-Sea Sediments Workshop (David Billett)
09:30 Report from Seamounts/Canyons Workshop (Karen Stocks)
10:00 Discussion on common issues
11:00 Adjourn. Transport to hotels and check out

12:00 Travel to Coos Bay, Oregon for Deep-Sea Biology Symposium

1. Introduction and workshop goals.

The following report comprises the aims, discussions and outcomes resulting from a two-day workshop organised on behalf of the Census of Marine Life (CoML) to discuss the “Known, Unknown and Unknowable” (KUU) of biodiversity in deep-sea sediments (abyssal plains and continental margins). The workshop aimed to take practical steps to:

1) Decide upon the key questions that need to be addressed by the international scientific community, and to create a list of the main scientific objectives.
2) Create a list of the current and proposed research programs in order to identify where collaboration can start, where gaps in current knowledge lie, and to discover how gaps can best be filled.

3) Plan how to resolve funding problems and create an international funding base with coordinated national funding, and industrial collaboration.

4) To discuss how biodiversity research can be placed within an inter-disciplinary research framework.

5) Agree upon an international CoML sampling specification. We must focus on the art of the possible
   –What are the key measurements?
   –What are the key methods?
   –What are the key environmental parameters?
   –How do we achieve a consistent taxonomy?

1.1 Deliverables from the Workshop

Creation of a report on the workshop for the Census of Marine Life International Steering Committee.

The report will be used as a basis for seeking national/industrial funding and to help with the drawing up of proposal(s) to allow on-going support for coordination of research. It is expected that one or more proposals will be written for submission to CoML as a result of the discussions at the workshop. The report will also be used to achieve a consistent approach to deep-sea sampling so that we achieve not only sampling for local and regional species richness measures, but also an appreciation of community structure and the relation of biodiversity measures to environmental factors.

1.2 Discussion of Workshop Goals – Friday 22 August 2003.

The initial discussion was directed towards the organisation of the workshop and how participants preferred it to proceed. Issues brought up during this session included:

- Discussion as to whether it was necessary to split the Abyssal Plains group and Continental Margins group (and indeed splitting Canyons from Continental Margins) since it was noted that there is gradual change from continental margins to abyssal plains rather than a defined break. It is important to remember the effects of water masses rather than bathymetry alone.

- It was agreed that after the summary session, groups should look at parallels and generic themes that are not split by environment. The importance of keeping overarching themes in mind was emphasised to make re-integration of abyssal plains and continental margins groups easier.

- It was agreed that Chairs of the various sessions should proceed by identifying key topics from responses to the questionnaire distributed before the workshop (Appendix 1). This would form the basis for discussion. The Chairs would summarise responses at the end of the session.

- The aim of the workshop was to decide upon 3 to 5 overarching themes, with prioritisation, which would provide a framework for future proposals.

2. The Known – where are we now?

This session aimed to discover the known aspects of deep-sea sediment diversity. Each participant was asked to give a short presentation to summarise their own or their institution's particular knowledge, experience and current/proposed field programs to enable a clearer picture of where the gaps and strengths in our knowledge lie. It was suggested that a database and map were needed of current sampling programs.

2.1 The Pacific Ocean

Lisa Levin - Lisa gave an overview and map showing the current Pacific programs that she was aware of (North US coast methane seeps, MBARI research programs, WUN/ChESS program for reducing habitats i.e. Oxygen Minimum Zones (OMZs), wood, whale falls, MBARI seep and OMZ programs). In particular, she pointed out that we know very little about trench ecology and that these environments could host novel habitats, assemblages, taxa, and symbioses, which are still waiting to be discovered. Work on the catastrophic disturbance caused by an earthquake in 1942 on the Aleutian margin was also mentioned. Ideas about linking different habitats in close proximity, including reducing and non-reducing settings such as those found on the Peru margin, can give insights into diversity processes. Such faunal comparisons have not been carried out for sediments but are in progress for reducing habitats (WUN/ChESS program). The importance of producing species level data was emphasised.

Craig Smith – Craig outlined the Kaplan project, an international program that is researching the potential impact of nodule mining activities. Work is focusing on studies of diversity, species ranges, and gene flow of polychaetes, nematodes and foraminiferans. There may be a need to merge alpha taxonomy and molecular approaches to identify many cryptic species. Web-based databases must be developed for outreach and taxonomic databases should be merged. Three sites in the Pacific Ocean are being sampled using box cores and multiple cores, and there is possible integration with CeDAMar (Census of the Diversity of Abyssal Marine life, see report from Angelika Brandt below). Molecular-sensitive sampling (sieving at 2-4 ºC, ethanol preservation) is being carried out, with some specimens being fixed in formalin and some in ethanol. In addition to species ranges, it is important that we focus on discovery of where biodiversity hotspots and novel habitats lie. Measurement of species ranges will help us to understand changes in dominant species across different regimes. How many different habitats are there in the deep sea? Key habitats must be identified because we currently sample without coordination among studies. Diversity may be controlled by a variety of factors (e.g. OMZs, food input), and these factors often have different time and spatial scales - is diversity historically, habitat, or water-mass driven? Data archiving will follow the Ocean Biogeographic Information System (OBIS) procedures.

Ken Smith – Ken described work at his Station M time-series station off California in the Pacific. This area has been studied since 1989 with measurements of POC and PON flux and climate indices over time in order to show seasonal and interannual variability. *Elpidia* (a holothurian) showed significant population changes. In recent times *Echinocrepis* (echinoid) abundance had increased while the numbers of *Elpidia* decreased significantly. The importance of time-series studies was emphasised to resolve trends in benthic community structure on a wide variety of scales. Other programs that are also ongoing include: the H_20 (Hawaii cabled observatory) program which has a time-lapse camera and sedimentation sensor attached to an underwater telephone cable midway between Hawaii and California at a depth of 5000 m. This observatory provides sea-floor photographs and sedimentation data to shore in real-time. Andy Gooday – Andy spoke of his collaboration with the Japanese Centre for Marine Science and Technology (JAMSTEC), which has taken samples in Pacific deep-sea trenches, including a sample from the Challenger Deep.

Yoshihisa Shirayama – There are numerous Japanese projects and field programs. The deep Sulu Sea is isothermal at 15ºC down to 5000m depth and is therefore very useful as a site for comparison with other study areas. Many projects are focused around the Japanese EEZ, but monitoring of the deep-sea environment is focused on physical characters. Long-term benthic sampling is only just starting. The issue of disposal of red clay waste from the aluminium industry (1 million tonnes per year) was highlighted. Recent survey shows red clay can be detected on the sediment surface at 4000m (UNCLEAR). The deep biosphere program for trenches allows access to fauna and sediment cores (preserved in formalin) collected by submersibles. Research carried out must be reported to the Japanese Oceanographic Data Centre (JODC), and the data should be submitted to the International Oceanographic Data Centre (IODC) database. Studies have been carried out with longitudinal consistency, and at a number of different latitudes (by 5 degrees), which is particularly interesting off Japan because it is not too variable by habitat. It is important to dissociate the effects of habitat variability when looking at latitudinal variability in the abyssal environment; working on a regional basis will help to achieve this goal.

2.2 The Atlantic, Indian and Southern Oceans and Major Seas.

Angelika Brandt – Angelika reported on the CeDAMar program (Census of the Diversity of Abyssal Marine life), which is focusing on abyssal plains. The importance of high quality taxonomy was stressed. We are currently losing expertise worldwide. We must put funding for taxonomists into our research proposals. Taxonomy is slow work and we need to speed it up – this can be achieved by using databases and interactive keys etc. But the speed of work does depend on what you want taxonomists to do – identification is different from description. CeDAMar is assessing diversity along latitudinal gradients, producing keys, analysing gene flow, and identifying centres of high biodiversity. Expeditions are dedicated to single ocean basins i.e. ANDEEP (Antarctica) and DIVA (Angola).

Pedro Martinez – Pedro again stressed the importance of species-level identifications for CeDAMar. The BIOZaire program of IFREMER encompasses large-scale sampling of habitats, and some stations will be included in the CeDAMar database. Future field programs include the Mediterranean and SW Atlantic off Brazil. CeDAMar is focussing on the Southern Atlantic for a 2010 CoML report. The Alfred Wegener Institute in Germany has Arctic deep-sea expeditions and is collaborating with CeDAMar. The German Biodiversity Centre (DZMB) provides consumables and gears at sea, technical training at sea, runs a database of sample collections, coordinates sorting of samples and customs declarations, registers the destination of samples, and runs training courses for marine taxonomy.

Tom Cronin – Tom described palaeoceanographic time-series in the North Atlantic, which focus on shell chemistry and faunal assemblages of ostracods, allowing reconstruction of bottom-water temperatures and deep-sea ecosystem response to climate and oceanographic changes. Using deep-sea cores, investigations are being made into how water mass and climatic changes affect diversity. Research has shown that the deep-sea benthic ostracod community is not stable over orbital (Milankovitch) and suborbital time scales, and is affected by these long-term climate processes. Over shorter centennial and decadal timescales, biodiversity variability is not well understood. The dynamic aspects of diversity are reflected in the climate record. Over longer time scales (evolutionary, millions of years) tectonic processes can also influence diversity. Local and regional extinctions do occur, e.g. the Norwegian Basin where sills have formed barriers to deep water mass movements and their associated fauna. However, in most cases species are not lost from the system, they appear to migrate up or down slopes along ocean margins as shown by bathymetric range changes during climatic cycles. The modern deep-sea fauna is known to be ancient and does not share species with shallow waters. Extinctions of species are taxon dependent responses and survival depends on the influence of life history differences.

Paul Snelgrove – Paul talked about Eastern Canada deep-sea work, and asked are deep-water corals critical habitats? Ever since the slumping events 1929 off Newfoundland there has been much interest in the Laurentian Fan, with possibilities of finding reducing habitats, and studying the responses of faunal re-establishments. Western Canada is involved with project NEPTUNE, a deep-sea observatory, looping fibre optic cable around the Juan de Fuca plate. Fluxes at the seabed will be measured with optical instruments, setting the context for biological sampling. The importance of public buy-in on such projects was emphasised.

Gil Rowe – In the Gulf of Mexico, deep-sea work is supported by the Minerals Management Service (MMS) in accordance with US Oil & Gas regulations. The project DGoMB (Deep Gulf of Mexico Biology) used community structure criteria to test 8 hypotheses; e.g. that density changes in relation to the depth gradient and/or the West to East gradient. There is a large input of organic matter at the Mississippi trough canyon head, and this input results in large changes in faunal abundance and dominance. Surprisingly, amphipods are numerically dominant, not polychaetes. The high densities found at this site enabled a comparison of community structure with ecosystem function. Future programs include looking at large escarpments, which have almost vertical cliffs. This vertical layering will allow examination of changes in fauna as a function of the exposed sediment on escarpments. The problem remains that of having major questions of interest to a wider audience in order to gain public buy-in, e.g. habitat loss as result of the activities of the oil industry and other users.

Mike Rex – Mike introduced us to the source-sink hypothesis. When neogastropod depth ranges are plotted by species, it is noted that there are few abyssal species and that most of those found in the abyss are actually range extensions from the bathyal. The deeper species also have a much greater proportion of planktotrophic larvae. This hypothesis suggests that larvae from the bathyal populations supply the abyssal ecosystem.

John Gage – John told us of the Northern Seas program at the Scottish Association for Marine Science (SAMS). The program covers a Norwegian/Greenland longitudinal transect passing through a range of benthic environments north to Spitzbergen. There is a sharp separation with the North Atlantic, i.e. Wyville –Thomson Ridge. The fauna north of the ridge is impoverished in terms of diversity and different in composition to Atlantic fauna. There is no latitudinal separation. This program will allow us to study to what extent faunal diversity difference drives a difference in ecosystem function i.e. biogeochemical fluxes. The Faroe-Shetland Channel time-series has been going for a few years and has noted large annual changes in benthic composition particularly in polychaete dominance differences. The area is one with significant deep-water oil and gas activity. Within the overlying Atlantic warm water mass at 200-500m, species extend into Arctic areas. There is a peak of diversity at 400m, which corresponds with the interface between water masses (North Atlantic and Faroe-Shetland Channel water) where large temperature fluctuations are associated with high diversity.

Kari Ellingsen – Kari described work on the Norwegian continental shelf and the use of environmental impact surveys around oil and gas fields for science. There is a macrofaunal database covering about 2000 stations and a total of about 2200 species (depth range 65-1550m). Alpha diversity is highly variable along the coast, with no clear relationship to depth, sediment type or latitude. Gamma diversity indicates environmental variability is important for explaining site-to-site differences. The group has also been involved in sampling sub-tropical macrobenthos in Hong Kong. Variable alpha diversity was again seen. Beta diversity was high. Kari stressed the importance of considering diversity at multiple spatial scales.

Andy Gooday – Andy reviewed existing sample sets and future sampling campaigns.
NW African margin: 1974-1977: trawl and epibenthic sledge samples (to 4800m)
Porcupine Seabight: 1977-1986: trawl, epibenthic sledge, core samples (200-4500m)
Porcupine Abyssal Plain (1989-2002): (4850m), Cape Verde Abyssal Plain (4600m) and Madeira Abyssal Plain (4950m) trawl and core samples
UK Margin: UK Strategic Environmental Assessment process (AFEN/DTI), 1996-2002 (200-3000m).
Angolan Margin: BP samples (~1200-1400m)
Arabian Sea: Oman and Pakistan margins (2002-2003) (200-3200 m)
Japanese (*Umitakamaru*, February 2004) and French (*Atalante*, July 2004) cruises.
OASIS: EU project, NE Atlantic Seamounts (Sedlo and Seine): *Meteor*, November 2003; RRS *Discovery*, July 2004; RRS *Discovery*, summer 2004.
Southern Indian Ocean, Crozet Plateau: late 2004/early 2005 (research proposal).
SW Pacific: World University Network (WUN) project addressing reducing environments on the Peru/Chile margin. Spring 2006, 2007 (research proposal).HERMES (Hotspot Ecosystem Research on the Margins of European Seas): ocean margin research from Norway to the Black Sea (EU Integrated Project proposal).
CoML Arctic Transect (under discussion). ROV cruises: Cayman Trough (Tyler/German).

Myriam Sibuet. Myriam described several investigations on ocean margins she has conducted in collaboration with her colleagues, including the BIOZAIRE program, which has been operational since the year 2000. The BIOZAIRE program is a scientific cooperation between IFREMER and Total, on the West African margin off Angola, Congo and Gabon. It seeks to describe deep-sea faunal diversity over a depth range of about 300 to 4000m. Different habitats have been studied including deep-water corals, cold seeps on pockmarks, and sediments on the continental slope and rise near the Zaire Channel and areas of interest for oil drilling. Four cruises have been completed, two with L'Atalante and the ROV Victor 6000. There is variation in the diversity and density of benthic fauna across the sampling sites. Studies show that macrofaunal abundance is higher close to the chemosynthetic communities discovered on large pockmarks at a depth of 3400m.

In the eastern Mediterranean, the Dutch-French MEDINAUT cruise in 1998 discovered mud volcanoes with vestimentiferan worms and small bivalves using the Nautile submersible. A new research project MEDIFLUX is part of the EUROCORE program on Euromargins. It is an integrated study of seepage through the seabed in the area of the Nile deep sea fan. The NAUTINIL cruise in September 2003 explored the Nile Fan, which is a heavily pockmarked area and mud volcanoes south of Crete. IFREMER has developed the BIOCEAN database for its deep-sea ecology programs. The database provides a way to coordinate samples and specimen data, both on board ship and in the laboratory.

Ann Vanreusel – Ann focussed on meiofaunal nematode research, and emphasised the difficulty in integrating data sets without clear species-level information. The ACES project (Atlantic Coral Ecosystem Study) involved studies of coral-associated meio-epifauna in the NE Atlantic. In addition there is a national research project in which meiofauna is being investigated in relation to habitat variability along a latitudinal gradient off the NE Atlantic margin. The importance of looking at habitat variability on differing scales and the need to study the degree of species turnover between habitats at different scales was highlighted.

Tassos Tselipedes – Tassos talked about the work in the Mediterranean that has shown an oligotrophic to mesotrophic gradient from east to west. There are a variety of geological environments in the Mediterranean deep sea. An increase in Mediterranean surface productivity over the last 10-12 yrs was discussed; material is channelled down canyons to basins; i.e. the Pliny trench area where input of OM has led to a monoculture of a particular polychaete species

Nagender Nath – Nagender told us of studies in the Indian Ocean. Work is currently taking place south of India on the continental margins, abyssal basins and mid-ocean ridges using a range of techniques, such as coring and photography. The impact of nodule mining is under study and a benthic impact experiment with artificial disturbance has been carried out. A large number of physical and chemical sediment parameters have been recorded. Constraints on species-level taxonomy were noted. Future work is proposed for the Somali Wharton Basins, the Indian continental margin in the Bay of Bengal and the Arabian Sea.

Gary Poore – Gary told us how species ranges, at least for crustaceans, are unlikely to be > 20º latitude. Known ranges are small. Until we get a consistent taxonomy we cannot really understand species turnover. The taxonomies of a few, if any, surveys truly overlap, so we need to get consistent taxonomy to determine true species distributions. When classifications of species reflect relationships of species (i.e. by improved taxonomy) patterns of biogeography begin to emerge. But, without this understanding we see apparent cosmopolitan species and higher levels of diversity. Gary demonstrated an interactive polychaete key by Wilson *et al.* from the Victoria Museum, Melbourne. The benefit of electronic keys and interactive data sharing will make it easier to describe/ differentiate species.

A large body of information from past Russian expeditions on deep-sea sediments could not be included at this stage in CoML planning, but is important to do so for the future.

2.3 Where are we now? Key Points

The following needs were identified:

(1) A map/database of deep-sea samples to date.
(2) A list of taxonomists who are working on particular groups.
(3) Recommended preservation of samples for both morphological and molecular work.
(4) Keep track of rare species, particularly among geographic areas, as we need to understand species turnover.
(5) Develop a global deep-sea taxonomy.
(6) Identify hotspots of biodiversity and novel communities.

3. The Unknown - The Big Questions

In reviewing our present knowledge of diversity in the deep sea and past and present sampling programmes, it was clear that we have a solid base on which to plan future work. However, we exposed major gaps in our knowledge in particular at large scales, driven in part by the lack of international coordination of sampling effort. To take a significant step forward we must coordinate research and funding to support international collaboration, in much the same way as has been achieved for physical oceanography (e.g. World Ocean Circulation Experiment - WOCE).

The workshop addressed how the 10 critical issues circulated for discussion before the meeting (Appendix 1) could be reduced to 3 or 4 strong issues for a CoML deep-sea biodiversity research program. The debate included discussion of the need to study deep-sea sediment biodiversity and hence the relevance of the key questions.

Fundamental questions, such as “Are any deep-sea taxa hyper-diverse?”, still wait to be answered. High alpha (local) diversity is fairly well characterised, but the important questions all relate to species turnover and regional biodiversity. How many deep-sea species are distributed basin-wide? It is relatively simple to understand a mechanism locally, but for a successful “census” global data are needed. The data must be of good quality and use a consistent taxonomy. Coordination of research at the international level is imperative.

The big question is still “How diverse is the deep sea?”

To consider this question we must learn answers to the following: What are the main processes maintaining diversity? Speciation in the deep sea has been ignored – what preserves and what generates diversity? Which species have had successful radiations? Why have they done so and is speciation related to geographic region? Why have they not been subject to extinctions?

In addition, we need to understand the vulnerability of the ecosystems to change. What are the impacts on ecosystem functioning of biodiversity loss? For work on ecosystem functioning, it is imperative to work at the species level. New experimental approaches *in situ* and *in vivo* need to be devised to study ecosystem functioning in the deep sea.

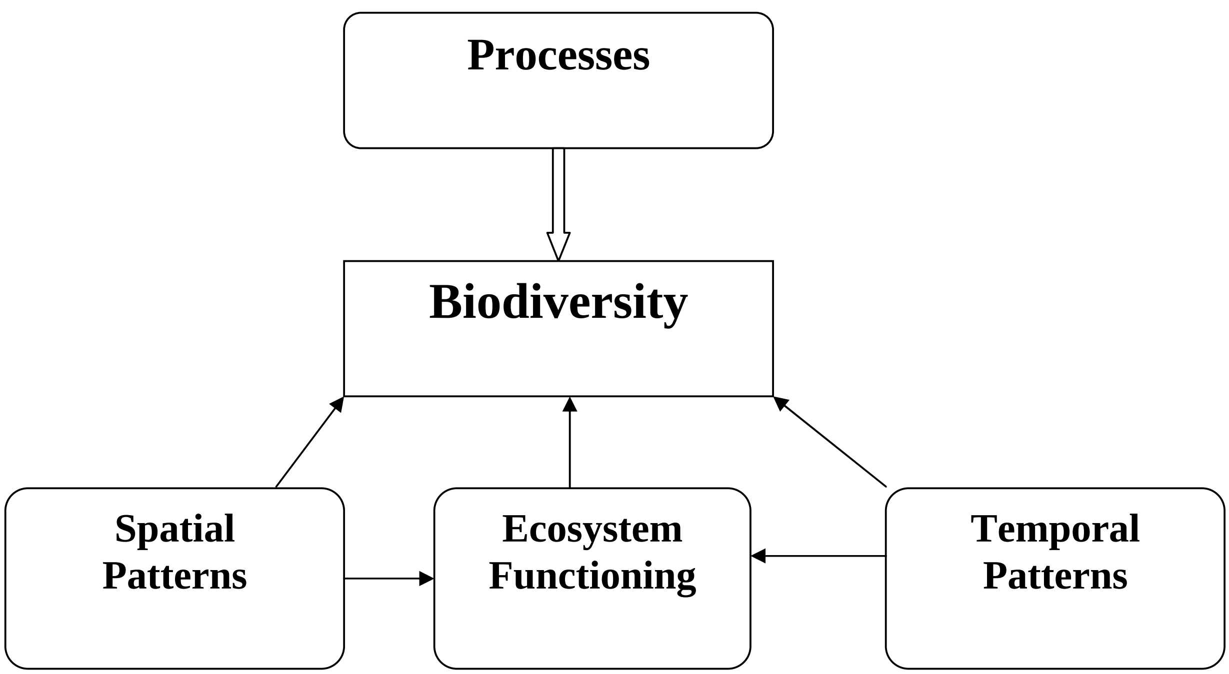
Studies of deep-sea biodiversity tend to focus on spatial variability in species richness and community structure. However, deep-sea sediment communities also change with time. We need to develop new approaches that consider biodiversity in both space and time. Deep-sea sediments are linked intimately to processes at the sea surface through the downward flux of organic matter. Natural changes with time in the diversity and dominance of the deep-sea benthos may be particularly sensitive indicators of change in surface waters. Benthic ecosystems integrate processes over space and time and therefore could be effective in detecting long-term change. The many small-scale processes at the sea surface make it difficult to detect long-term signals. Understanding present-day changes in biodiversity at a number of long-term study sites and relating these changes to the palaeoceanographic record could produce a significant step forward in understanding how climate variability affects biodiversity. The Arctic Ocean and Mediterranean Sea are particularly affected by impacts due to climate change and studying sediment communities in these systems could make significant advances.

Following broad discussions the workshop then focussed on three major questions relating to deep-sea sediment biodiversity:

- **Is the deep-sea hyperdiverse?**
- **How do changes in biodiversity (species richness and community structure) affect ecosystem functioning?**
- **How does, and has, biodiversity change(d) with time?**

While subsequent discussions addressed biodiversity and ecosystem functioning issues, it was not possible to prepare detailed plans within the time available at the workshop. It was pointed out that this topic is not very advanced in shallow water ecosystems let alone the deep sea. However, funding bodies will require application of biodiversity studies and therefore combining such studies, a major focus of the CoML programme, with ecosystem functioning work will be important in attracting research funding. In addition, the greater availability of Remotely Operated Vehicles (ROVs) will allow improved experimental studies to be carried out in deep water in the future and CoML wish to see the application of new technology in biodiversity studies.

Underlying the major questions posed above is the need to understand processes that, (1) drive change in space and time, (2) maintain high local diversity, and 3) affect ecosystem functioning. This can be represented schematically:



Implicit in this approach is the use of experiments to test hypotheses derived from studies of biodiversity pattern. This demands the use of new technology, notably the use of Remotely Operated Vehicles (ROVs) and pressurized aquaria / mesocosms for precision sampling, direct intervention with experimental packages and manipulations of environmental variables. The work needs to combine morphological and molecular approaches to characterising diversity, so that 1) cryptic species can be fully resolved. and 2) faster methods of characterising fauna can be devised, particularly in small size fractions. In addition, greater efforts need to be made in acoustic habitat mapping from ships and Autonomous Underwater Vehicles (AUVs). For time-series, it is important to adopt real-time observation methods using seabed observatories linked by cable and moorings with satellite communication. Such methods are currently being developed in Canada (NEPTUNE on the Juan de Fuca Ridge), the USA (H_2O in central Pacific, MARS in NE Pacific, Monterey Bay, and also NEPTUNE) and Europe (ANIMATE in the N. Atlantic and ESONET).

Technology advances and the improved access to existing systems will allow the oceans to be explored more widely. So little of the deep seafloor has been visited that there is immense potential for the discovery of novel ecosystems and of fundamental evolutionary patterns. The discovery of hydrothermal vents, cold seeps, gas hydrates and giant coral mounds in the last 30 years indicate the high probability of discovering novel habitats and fauna. This would apply particularly to areas where there has been little research effort to date, such as deep-sea trenches and areas in and around rugged topography. The discovery of novel sediment habitats and biodiversity hotspots is a vital component of the CoML programme. However, the workshop noted the difficulties in persuading funding agencies to support speculative exploration.

3.1 How to proceed? – Discussions about workshop sub group structure.

The workshop discussed whether studies on temporal change and ecosystem functioning fell within the stated aims and remit of the CoML program.

In relation to temporal change, it is clear that major changes can occur in deep-sea ecosystems over short (decadal) and long (geological/evolutionary) time periods. In terms of decadal change, species that have been apparently very rare in the past may suddenly become super-abundant. The processes underlying large-scale changes may be important in maintaining diversity in the deep sea. On evolutionary timescales, it is evident that major changes occur in diversity, species composition and distributions. Looking at biodiversity over various timescales will help us to understand present-day pattern. The workshop also discussed whether time series observations would be sufficiently mature to be considered within a 10-year CoML programme. Two time series, one in the Pacific Ocean and one in the Atlantic Ocean have been in progress since 1989. By the completion of the CoML project in 2010, both these time series will have 21 years of information and will make a valuable contribution to detecting decadal scale change in deep-sea habitats. Radical long-term change has been noted already where time series exist. In addition to long-term monitoring sites, paleo-biodiversity data on some groups (ostracods, foraminifera, molluscs) obtained from sediment cores from high sediment rate regions can augment our understanding of temporal trends at least for parts of the community. It is important to build towards long-term goals within CoML.

Similarly, arguments can be made for studying ecosystem functioning. Understanding ecosystem functioning is important if we are to apply biodiversity knowledge to sustainable management of the oceans and its resources. Ecosystem functioning is important in justifying biodiversity research to policy makers, industry and non-governmental organisations. In addition, fundamental relationships between species diversity and function are likely to create feedbacks that control future diversity trends in the deep sea.

Having decided on three over-arching questions for future research, the workshop then discussed dividing into three sub-groups for the second day, to prepare detailed plans that could be presented to the Census of Marine Life Scientific Steering Committee as a coordinated plan of action. The three themes entitled 1) Hyperdiversity, 2) Ecosystem Function and 3) Temporal Variability were considered to be applicable to both abyssal plain and continental slope environments.

However, it was agreed that to generate research plans within the time scale of the workshop it would be better to split into three groups, one focussing on regional diversity (hyperdiversity) on abyssal plains, one targeting regional diversity and ecosystem functioning on continental margins and one spotlighting temporal change. Novel environments were considered as a separate topic, but it was decided to pick these up as specific tasks within the abyssal plains and continental slopes groups.

In many ways, whether the abyssal plains and continental slopes should be viewed as separate systems or not depends on the taxa being considered. It is evident from macrofaunal groups that many apparent abyssal species are derived from populations that have the centres of their distributions on the continental slope. However, for many megafaunal groups there is a clear separation of abyssal and bathyal (continental slope) species. In the latter case, many species have their centres of distribution on the abyssal plains and decline in abundance towards the base of the continental slope. This difference in distribution pattern between taxa, and possibly size classes, in deep-sea sediments opens up interesting questions about the processes maintaining diversity.

In addition to differences in identity of some faunal groups between continental slopes and abyssal plains, abyssal plains have quite different physical characteristics that might influence the design of research programmes. The 1) lower large-scale habitat variability, 2) generally quiescent hydrography, 3) lack of depth variation and 4) horizontal vastness of abyssal plains, make them quite distinct settings. The accessibility of slope environments, in terms of closeness to land and the reduced depth (time) for operations, is also a powerful driver in adopting different sampling strategies, e.g. ROV operations. Continental slope environments allow sampling programmes with greater intervention and experimentation, than abyssal plains.

Finally, in terms of user focus, for justifying research and obtaining funds, the issues relating to the two types of environment are also different. For abyssal plains global change issues are important, while on the continental slopes impacts by man, through deep-sea fishing and oil and gas production, are currently of immediate interest.

Below is set out a summary of the discussions that were held during the workshop and the draft plans for each group. In many cases, this involved participants of the workshop refining the plan during the Deep-Sea Biology Symposium in Coos Bay, following the CoML workshop, and further e-mail exchanges in early September.

4. Continental Margins Group.

4.1 Group discussion

The continental slope is a highly heterogeneous environment ranging from mountainous rocky slopes incised by deep canyons to gently inclined, sedimented areas. The sediments range from coarse gravels to fine muds and occur in wide expanses on the seabed or in patches in and around rocky bottoms and within canyons and channels. In addition to topographic and hydrographic variability, continental slopes are home to one of the largest environmental gradients on Earth – depth. A number of key factors, such as temperature, pressure and food availability, change with increasing depth and their effects vary in different oceanic areas. For example while most upper slope regions show a sharp decrease in temperature with increasing depth, in other areas the water is isothermal to great depths (e.g. Sulu Sea).

How can we compare such heterogeneous environments? How can we devise a sampling programme that addresses this environmental variability?

Colossendeis proboscidea (a pycnogonid or sea-spider) on coarse slope sediments at 1500m north of the Faroe Islands. Photo: SOC, ©DTI UK

Some continental slope areas (e.g. NW and NE Atlantic) are relatively well known and can provide solid background knowledge for any future research programme, but most continental slope environments have not been characterised. The Census of Marine Life should address both well-known and virgin scientific territories, applying knowledge from the former to allow faster progress to be made in the latter.

The continental slopes are so vast and so varied that it would be impossible to conduct a full census in 100 years, let alone 10 years. This heterogeneity must be embraced as a possible driver of diversity rather than shunned as overly complicated. A subset of areas with varied depths, topography and hydrography, could be compared to provide general underlying principals of the processes regulating biodiversity. Progress towards determining the important processes maintaining deep-sea biodiversity is likely to be greatest in well-studied areas. Future plans therefore should test hypotheses devised in well-studied areas at the new localities.

The scale of the required sampling effort is immense. One possibility is to develop partnerships with oil and gas companies, which are taking seabed samples as part of their normal environmental monitoring activities. In some cases use of these samples have already led to major advances in deep-sea biodiversity knowledge. Some partnerships can be developed in areas with established species lists (NW Atlantic, Gulf of Mexico, West of Shetland) while others can be formed in areas where new sampling is being undertaken (Brazil, Angola, Zaire). To do so needs coordination of effort not only with the oil and gas sector, but also with the Governments of nations in which the study areas occur. Organisation of the science at the international level will facilitate access to regions and data from commercial sources.

Irrespective of whether the samples are taken in scientific or commercial programmes, a step-wise advance is essential in sampling methods and approaches. Blind sampling with no knowledge of the environmental setting should be steadfastly avoided (in all deep-sea settings). Environmental variables that must be documented include topography, sedimentology, oxygenation, water mass structure (?), near-bed current regime, other hydrography (e.g. internal tides, internal waves), geophysics, fluid flows from the seabed, benthic-pelagic coupling, OM downward flux from surface waters, downslope OM source and links to the benthopelagic realm. Such a large requirement needs a scale of resource far in excess of what is normally available and used by deep-sea biologists. However, there are a number of programs already in place i.e., West of Shetland, Gulf of Mexico, Brazil margin, Angola etc. where many of these data have been collected by the oil and gas industry; access to these data would be invaluable to science.

4.1.1 Heterogeneity

A stepwise approach to sampling continental margins is required to answer key questions:

1. Identify heterogeneity of habitats using:
    a) Geophysics (seismics)
    b) Seabed bathymetry and sidescan sonar
    c) Geochemistry
    d) Physical oceanography (water masses, currents, internal tides, etc.)
2. Propose and test hypotheses on how habitat changes influence diversity and species turnover at different scales.
3. Gather a species inventory to create a total species pool for comparison between regions. This should be set in a biogeographical and historical (evolutionary) context.
4. Test the hypotheses in other regions; e.g. is the impact on diversity, of river mouths/trenches/bathymetry/sediment structure the same between regions?
5. Design local experiments to test hypotheses.
6. Characterise ecosystem function and vulnerability. What is the role of biodiversity (e.g. ecosystem stability/resilience, remineralisation, carbon sequestration)?

4.1.2 Novel habitats

Using the stepwise process, it will be possible to predict where novel habitats may be found. For instance, using seismic 3D mapping, sidescan sonar etc. in areas where sediment structure changes can be identified. These areas can then be targeted for further investigation. Novel habitats may also be found by fast-track methods using new technologies, e.g. AUVs, ROVs, laser scanning, satellite applications (e.g.

methane release bubbles to locate seeps), seabed acoustics (e.g. as devised in mine warfare countermeasures), chemical techniques (cf. studies in shallow water on larval dispersal by detecting chemicals in cuticles/shells).

4.1.2.1 Trench environments

Potentially every trench system is a novel environment. We need to understand the taxonomy of their fauna to discover if different trenches have very different species assemblages. Trenches are fragmented and isolated habitats that can be used to answer questions about the dispersal potential and evolution of different faunal groups in deep-sea sediments. Trenches often lie under upwelling zones with high productivity and are useful in studying the effect of organic matter input into deep-sea ecosystems. They also are likely to support chemosynthetic habitats and organisms that may interact closely with other trench faunas. In addition, trenches are subject to episodic slumping events and could be used to study recolonisation rates. A number of samples from deep-sea trenches are available already from Japanese expeditions and from a campaign to the Atacama Trench by Italian researchers.

4.1.2.2 Canyon systems

Canyon systems were not within the original remit of the deep-sea sediments workshop, but became part of it during the course of the meeting. Another CoML workshop on seamounts and canyon systems was held in parallel at the Hatfield Marine Science Center. During the course of both workshops, it became evident that the work proposed for canyon systems fitted the aims of the continental margins sub-section of the deep-sea sediments workshop more naturally. In the case of deep-sea sediments, canyons were seen as part of the natural heterogeneity of slope environments. Canyons contain sediments of unique interest that are subject to episodic disturbance and higher OM input than the surrounding open-slope sediments. Canyons also appear to act as topographic barriers to the dispersal, and hence the distributions, of certain species.

Canyons are unique geological provinces/megahabitats connecting shelf environments with the abyss as a sort of fast track mechanism. Not only do they act as conduits for material flowing down slope, but also through the interaction of their topography and hydrography they supply nutrients upwards into shallow water, influencing surface-water productivity. Their proximity to near shore environments increases their susceptibility to human influences, and as they are possible nursery grounds for fish and feeding hotspots for cetaceans, there is particular interest in canyon biology and ecosystem functioning.

How do productivity and biodiversity differ on slopes with canyons as opposed to slopes without channels? What are canyons contributing to regional species pools? To address these questions it is important to view canyon systems as integral parts of the slope environments. However, because of their steep slopes and rugged topography, the latest technology advances in ROVs, mapping and imaging systems are required. Such technology is available, but because of its high cost and limited accessibility, coordination of these resources is needed at the international level.

It was not possible in the time to integrate the canyons work into the sediments workshop format. This will have to take place at future meetings to develop a continental margins theme in CoML.

4.1.3 Species turnover and regional species diversity

Species inventories of slope fauna are required to investigate zoogeography and the degree to which continental slope regions are interconnected. This will help us to address whether habitat or biogeography is driving and maintaining diversity. Is local diversity a function of regional diversity? To answer these key questions many samples from a number of regions are required. Other questions include: Are the scales over which diversity changes similar in different basins or in different taxa, or in different size classes? Is habitat change or distance more important in species turnover? It is important to study how local diversity accumulates along slope and down/up slope in order to estimate regional diversity. This requires a very large database, particularly to assess species turnover in relation to depth.

In answering these questions, we should consider how we can utilise existing data more fully (e.g. within OBIS) and what new data can be obtained economically within the lifetime of the CoML project. A problem with large-scale comparison of data sets is the consistency of taxonomic differentiation. To reduce the logistical nightmare it might be possible to focus on selected groups (e.g. molluscs), but the relationship between biodiversity and environmental variables varies for different taxa and size classes.

On the continental margin, the relationship between biodiversity and ecosystem functioning is important because there is an increasing need for sustainable ecosystem management. Is community structure determined by the specific functions, such as ecosystem stability or carbon sequestration? Do ecosystem processes vary because of differences in species composition in different regions? Do communities with high diversity have higher functional redundancy?

How important are species ranges and extinction rates? To answer questions such as these it is necessary to understand life-history parameters as well as making good species identifications.

Special slope environments should also be considered, such as Oxygen Minimum Zones (OMZs) and areas with high organic input, such as offshore at the mouths of major river systems. Other special areas include the sharp boundary between cold and warm water masses, such as in the Faroe-Shetland Channel. In particular, the boundaries of OMZs need to be sampled in greater detail. Recent work suggests that these boundaries are areas of high diversity change. Similarly, areas affected by riverine input provide sharp gradients in organic matter input.

4.1.4 Critical questions

What are the big questions we want, and are able, to answer within the time frame of the Census of Marine Life programme?

Examples for consideration include:

What is the interplay of habitat and biogeography in shaping biodiversity?
What are the geographic scales of species turnover with relation to distance and depth?
Does the level of habitat fragmentation change the rate of species turnover?

Following detailed discussions at the workshop, further work was conducted at the Deep-Sea Biology Symposium and by e-mail interchange. The following is a plan of action that participants considered could be achieved within the CoML framework and time scale. It will form the basis for more detailed planning. It should be noted, however, that many of the ancillary questions posed during the discussions noted above, could also be answered during the wider research program. The program will combine existing data sets with new scientific sampling and with environmental monitoring programmes of the oil and gas industry, both in well-studied regions and new areas.

4.2 Continental Margins – Plan of Action

Overarching question:
What scales of habitat heterogeneity and which processes are important in creating and maintaining high bathyal diversity?

Rationale:
1. Continental margin seabed habitats are still largely pristine, but face a rapidly increasing threat from unregulated exploitation, particularly deep-water trawling.
2. Continental margins play an important role within the Earth System. They have a disproportionate influence on oceanic productivity and organic carbon cycling, and in some areas act as important deposition centres for carbon.
3. There is an urgent need to predict the risks to biodiversity from man's activities and to assess how changes in biodiversity owing to anthropogenic impact will affect the Earth System. For strategies such as designating marine protected areas, improved knowledge on spatial scales and patterns of diversity is critical.
4. There is a need for a better understanding of natural spatial and temporal variability in biodiversity in order to evaluate anthropogenic influences.
5. To do this we need to determine the effect of environmental heterogeneity in space and time on species richness, community structure and distribution patterns.

The Known:
1. There is high local species diversity in many taxa in sediments on continental margins.
2. There is significant large-scale habitat heterogeneity on continental margins associated with historical, geological, biological and hydrodynamic processes.

The Unknown:
1. The contribution of natural spatio-temporal environmental variability to landscape- and basin-scale biodiversity patterns, particularly influences and

interactions with hydrodynamic, geological and biogenic habitat creating processes and the input of organic material.

2. The sensitivities of deep-sea biodiversity to anthropogenic impacts.
3. The restoration potential of impacted habitats.
4. The role that margins have played and might play in the recolonisation of continental shelf and abyssal plain regions.

The Unknowable:

1. Inventory and distribution of all species on all margins.

Program steps:

1. Assemble existing data sets with species-level information and identify and overcome obstacles to ensuring comparability.
2. Characterise regional hydrographic, topographic, and geological features. Foster relations with other major scientific research programmes and industry, to provide the background environmental data (mapping, hydrodynamics, organic matter input).
3. Identify and use existing cross-slope data sets to test hypotheses. Perhaps the largest of these data sets, and the easiest in terms of taxonomic comparability is the megafauna, with fishes as one of the key groups. The high mobility of fishes makes their generality for extrapolating to other taxonomic groups somewhat suspect. Many data sets are available for macrofauna, and target groups for such a study might include molluscs, polychaetes and crustaceans. Meiofaunal data sets might include the Porcupine Seabight downslope transects.
4. Identify continental margin areas where biodiversity is threatened by man's activities and areas that have already been subject to intense anthropogenic impact, in order to evaluate potential effects on biodiversity patterns and species loss. Of particular interest are areas where pre-impact data were collected or where adjacent less impacted areas provide a comparative data set.
5. Develop and standardise methodologies to examine diversity including:
    - The degree of species turnover across habitat gradients
    - Heterogeneous versus homogeneous margins
    - How habitat heterogeneity interacts with latitude and depth effects
    - The role of scale in determining the influence of habitat heterogeneity on diversity
    - Genomic, phylogenetic and paleontological approaches to understand speciation, particularly in relation to the colonisation of continental shelf and abyssal plain habitats.
6. Develop new field programs to:
    - Compare local and regional diversity patterns in relation to environmental heterogeneity
    - Use in-situ experimental approaches to test hypotheses on regulation of biodiversity patterns, and the specific roles of habitat heterogeneity, natural disturbance, larval supply etc.

5. Abyssal Plains Group

The abyssal group discussed patterns and then processes. Participants thought it imperative that a potential project focussed on 1) the limits of the possible and 2) what would be useful to achieve on a global scale.

Plesiopeneus sp. from the Madeira Abyssal Plain at 4950m. Photo SOC.

- **Unknown:** Distribution of abyssal species on regional and global scales.
- **Unknowable:** Inventory of all species at a single abyssal locality; Geographic ranges of all species (especially rare species)
- **Knowable:** Ranges of dominant abyssal species.

Therefore an approach that focuses on abundant species would be more successful and practical, bearing in mind also that the abundant species may also change with time (as has happened in the NE Pacific and NE Atlantic time series).

Abyssal plain samples are available from every ocean

–South Atlantic (DIVA – Angola Abyssal Plain)
–Central Pacific (Kaplan – Clarion-Clipperton Fracture Zone)
–North Atlantic (Cape Verde Porcupine and Madeira Abyssal Plains)
–North Pacific (Sta. M)
–Indian Ocean (Central Indian Basin)
–Southern Ocean (ANDEEP)

The Census of Marine Life project CeDAMar will generate data on large-scale variation in species richness in different ocean basins. The project will develop a network approach to abyssal plain studies, including programs focusing principally on abyssal plain environments in the Pacific Ocean. In particular, CeDAMar should ensure taxonomic consistency among international research groups. Additional data are required from a greater number of locations in the Pacific, Indian and Southern Oceans.

The key questions are:

1. Are the dominant abyssal species cosmopolitan?
2. What proportion of the total number of species is cosmopolitan?

3. Are common species distributed throughout basins or restricted to certain geographical areas?
4. What are the geographic ranges of abundant/dominant species?
5. Is the pattern consistent between taxa, size classes, reproductive strategies and other life history characteristics?

The rationale is that if dominant species are restricted to single basins, this implies a much higher global diversity than cosmopolitan distributions. Dominant species are likely to have been sampled in the past so taxonomists could provide biogeographic data from historical information. The aim would be to make a project that will provide the first picture of global patterns in the abyssal deep sea.

5.1 General issues:

We need to determine the phylogeography of individual genera and families. We need to determine whether data from existing programs can address the key questions, or whether new data are needed. If so, where from? Some existing data sets (e.g. from the NW and NE Atlantic abyssal plains) could be used to address the key questions if the data were archived in a consistent manner and adopted a common taxonomy. Development of electronic keys would aid the work. An inventory of interested and willing taxonomic experts, able to provide data on short time scales, needs to be compiled. Lack of taxonomic expertise at the global level is a major difficulty for a new field program. There is a need for specific taxonomic fellowships in key taxa at appropriate institutions worldwide. The group discussed that a mixture of government and industry grants might fund the new fellowships. An immediate start is needed to co-ordinate the activities of field program PIs and taxonomists. There is a need to 1) generate and standardize species abundance lists from existing programmes, 2) determine what level of taxonomic data is currently available and 3) plan for filling taxonomic expertise in key groups.

Morphological and molecular data are needed to compare community dominance in parallel basins across a range of size fractions and taxa. Molecular data may be generated from historical formalin-preserved material.

Data management will follow Ocean Biogeographic Information System (OBIS) procedures.

5.2 Abyssal Plains – Plan of Action

Overarching question:
Are dominant abyssal species cosmopolitan in their distribution?

Rationale:
1. Abyssal plains cover vast areas of the ocean floor.
2. Abyssal sediments contain a detailed palaeoceanographic record.
3. The reduced physical environmental heterogeneity (e.g. depth, temperature, topography, grain size) of most parts of abyssal plains allows processes relating to large-scale environmental factors, such as latitude and organic matter input from surface productivity, to be studied.
4. Present-day biodiversity pattern can be set within a long-term time frame to assess the effects of global change on deep-sea ecosystems.
5. The abyssal plains are so vast that the effects of habitat area (e.g. basin size) on species richness are unlikely to be important.

If dominant species are restricted to single basins, this implies a much higher global diversity than that suggested by cosmopolitan distributions. This research requires the archiving of existing data sets in a common format and the exploration of new abyssal areas where there has been little or no sampling in the past.

The Unknown:
1. The distribution of abyssal species on regional and global scales.

The Unknowable:
1. An inventory of all species at a single abyssal site; ranges of all species (especially rare species in the abyss).

The Knowable:
1. Ranges of dominant abyssal species.

Program Steps:
1. Create a coordination committee with representatives from major past, present and future sampling programmes and major taxonomic institutions, as proposed in CeDAMar.
2. Fund ten or more taxonomic fellowships, each focused on specific, important taxonomic groups, at oceanographic and taxonomic institutions that are leading current deep-sea research efforts.
3. Assemble existing data sets with species level information and identify and overcome obstacles to ensuring comparability.
4. Merge morphological and molecular taxonomy of dominant species in key faunal groups and size classes on the abyss from all sampling programs. (Potential taxa for taxonomic study include: echinoderms, polychaetes, peracarids, copepods, nematodes and foraminiferans).
5. Organise a series of inter-calibration taxonomic workshops.
6. Develop electronic taxonomic keys and method of access and quality-controlled update, for the rapid and wide dissemination of taxonomic information.
7. Follow organisational steps as proposed by CeDAMar for the coordination of international field programs linking to specific field project web pages.

8. Identify gaps in global sampling coverage and formulate plans and funding to address missing data.
9. Develop new field programs to fill gaps.
10. Coordinate research effort with teams studying how dominant fauna on abyssal plains change on seasonal, decadal and longer time scales.

Outputs:

- Global synthesis of across-basin patterns of dominant species.
- Expand the pool of current taxonomic expertise focusing on key deep-sea taxa.
- Application of novel/state-of-the-art molecular approaches to deep-sea biodiversity.

6. Temporal Change Group

6.1 Group discussions

The group recognised the importance of setting spatial studies in the context of different temporal scales (decadal, historical, geological). For instance, dominant species on abyssal plains may differ not because of spatial variation, but because of differences in decadal-scale variation in surface primary productivity.

There are various tracers of faunal change including benthic faunal markers (particularly foraminifera and ostracods), biochemical markers, geochemical markers and surface process markers (e.g. diatoms, dinoflagellates). A crucial task is to distinguish long-term faunal trends driven by environmental changes from stochastic change related to biological interactions. All possible causes of faunal shifts need to be evaluated and environmental drivers should not be assumed. This is where historical samples have an important role. It is essential to link changes at study sites to OM input and surface processes. We need to extrapolate these changes to global scale patterns e.g. using satellite imagery and modelling approaches. Exploiting new cabled observatory technology (e.g. NEPTUNE) for biological monitoring over long time scales is an exciting possibility for the near future.

The value of revisiting sites that have been sampled in the past was emphasised. If a sampling site database were to be created, as suggested in earlier workshop discussions, previously sampled sites could be re-sampled on an opportunistic basis. In addition, it is necessary to construct a database of existing samples and where they are held (e.g. old HMS *Challenger* samples at the Natural History Museum and other deep-sea expeditions, Shirshov Institute Collections, Moscow). Many of these historical samples will prove to be extremely valuable in the future.

The functionality of ecosystems can also be related to temporal change in diversity. Before we can understand function we need to understand the time scales at which bentho-pelagic coupling is working, because this coupling is thought to be a critical aspect of deep-sea ecosystem functioning. There are many studies ongoing and chronologically there are few gaps – these just need to be related in an ecological sense.

Temporal change in deep-sea biological systems is an area of great potential for synergy between geologists and biologists. The long temporal perspective (10^3 to 10^6 or more years) provided by the palaeoceanographic record offers unique insights into the macroecological processes that have shaped modern communities as well as benthic community responses to global climatic change. At the same time, long biological time series can help geologists to understand the causes of the faunal changes observed in the palaeo-record.

6.2 Temporal change -Plan of Action

Overarching Question:

What are the major oceanographic processes that cause changes in dominance and diversity with time?

Rationale:

1. Temporal changes in assemblage parameters (species abundances, diversity, dominance) are evident on abyssal plains on time-scales of 10 – 15 years.
2. Catastrophic events (e.g. turbidity currents caused by earthquakes, ash deposition from volcanic activity) cause immediate and dramatic changes in seabed assemblages, followed by gradual recovery (recolonisation) over decades to, perhaps, hundreds of years.
3. Fluctuations in diversity and other assemblage parameters are evident over geological time scales (10^3 -10^6) in relation to climate-driven changes in thermohaline circulation, bottom-water temperature, and organic-matter fluxes derived from surface production.
4. Spatial variability needs to be distinguished from temporal fluctuations in species abundances.
5. We need to understand the link (if any) between the short-term faunal fluctuations observed in biological time series and the patterns of faunal change that are recorded by microfossils in the palaeoceanographic record.

The Known:

1. Modern species assemblage composition and diversity parameters at the few deep-sea sites and selected faunal components (e.g. megafauna, macrofauna, foraminifera) where appropriate faunal data are available have changed over time scales of 10-15 years.
2. Fossil species assemblage composition and diversity parameters for some taxa (essentially Foraminifera, ostracods and some molluscan groups) are known to have changed at numerous deep-sea sites over time-scales of centuries to millions of years.
3. There is covariance between palaeo-environmental parameters and faunal diversity and composition.

The Unknown:

1. What are the specific patterns of deep-sea faunal change over historical time scales (multi-decadal to century)?
2. Whether or not decadal-scale faunal change is a "typical" aspect of modern deep-sea ecosystems.
3. Whether or not decadal-scale change affects entire benthic communities (bacteria to megafauna) or just certain components.
4. Whether we can link major oceanographic processes to decadal faunal change.
5. Relative importance of stochastic processes and natural vs anthropogenically-induced environmental fluctuations in driving faunal change.
6. At what point does faunal variability turn into sustained faunal change; i.e. how do we distinguish between short-term fluctuations and a regime shift?
7. Whether the few fossilisable abyssal benthic taxa (foraminifera, ostracods, some molluscs) can be regarded as proxies for entire benthic communities.

The Unknowable:

1. Faunal changes over geological time scales among soft-bodied, non-fossilisable taxa (i.e. most deep-sea species).
2. Role of biological interactions in driving faunal change in the geological past

Programme steps:

1) Maintain time series in NE Pacific (Station "M"), NE Atlantic (Porcupine Abyssal Plain – "BENGAL"), Eastern Mediterranean (Crete Time Series), western Pacific (Sagami Bay) and relate faunal patterns to environmental variables, in particular to surface productivity (ocean colour) and biochemical markers (pigments, lipids).
2) Develop new time series over period of CoML in relation to upper ocean biogeochemical time series (Hawaiian Ocean Time Series (HOTS) and Bermuda Atlantic Time Series (BATS)) in collaboration with the IMBER programme (Integrated Marine Biogeochemistry and Ecosystem Research).
3) Use new cable observatories to monitor time change in epibenthic sediment communities (e.g. H_2O site off Hawaii, Sagami Bay off Japan, NEPTUNE in the NE Pacific Ocean, ESONET site in Mediterranean Sea), and then try to link these to infaunal patterns.
4) Relate changes in Foraminifera, Ostracoda and Mollusca to the palaeo sedimentary record.
5) Combine with results from CeDAMar in modelling approaces to extrapolate to large scales, including the global scale.
6) Identify deep-sea sites characterised by high sedimentation rates (combined with low bioturbation) where it may be possible to recover a record of faunal change over historical (decadal-century) time scales.
7) Opportunistic examination of faunal recovery from sudden catastrophic events, particularly in areas where pre-disturbance fauna has been documented. Continued monitoring of DISCOL and Central Indian Ocean Basin sites for recovery following artificial disturbance.

7. Further discussions on sampling methodology, consistent taxonomy and environmental parameters

7.1 Introduction

It was recognised that in order to consolidate work on a global scale, data must be comparable. Progress was made towards achieving a consistent taxonomy, a standard sampling methodology and a common suite of environmental measurements. The following points were considered:

1. A plan for achieving a consistent taxonomy globally with internet access, interactive keys and molecular information.
2. A list of priority activities to be accomplished in each sampling area.
3. A CoML sampling specification of best practice in achieving priority measurements.
4. A CoML protocol for environmental parameters.

7.1.1 Sampling methodology discussion

In fine sediments, the box-corer can lose up to 50% of the fauna when compared with the Megacorer (an hydraulically-damped corer based on the original Barnett, Watson & Connolly multicorer, which has 110mm diameter tube cores (see http://www.osil.co.uk/xsight/osil.nsf/Products.html?ReadForm&Section=P1)). However, the area covered by the Megacorer is less than a full box-corer, (although it is similar in area to that covered by the central sub-cores in a vegematic box-corer). This reduced sample size may be particularly problematic where faunal densities are very low. An additional problem is that sediment grain size is limiting to different degrees for both corers, in that coarse sediments are difficult to sample. Are sampling systems in current use adequate, or do we need new equipment, e.g. gear that samples an area comparable to the box-corer, but with the hydraulic damping capacity of the Megacorer? GEOMAR has a prototype of a large Megacorer with 30cm diameter cores and guided deployment – perhaps this should be investigated.

Comparisons of the box corer and Megacorer are important because they may allow us to use historical data from the box-cores. Have the same broad patterns been seen with the box corer and the Megacorer? Are broad diversity patterns up and down slope the same with each gear? If so, then it is feasible that the box-corer can continue to be used to answer these questions. However, some consider that the box corer is no longer valid for measuring macrofaunal abundance and biomass (and therefore many diversity calculations), at least in fine sediment environments.

7.1.2 What is the best practice in achieving key measurements?

A standard protocol is needed for sampling each size class, and for both morphological and molecular taxonomy, in order to enable datasets to be globally comparable.

For molecular work, it is critical to process material quickly before DNA degradation takes place, e.g. in cold 95% ethanol or acetone. However, some taxa require specialist fixatives for both morphology and/or molecular work (e.g. foraminifera). In some cases, ethanol-fixed samples are rendered useless for morphological studies. Formalin-fixed material is considered to be a superior preservative for morphological studies. It is therefore dependent on the questions that are being asked as to whether or not specimens will be retained for molecular or morphological studies, or both.

While specimens are normally retained and archived, it is important to recognise that sediment residues should also be retained and that these are part of the historical sample database.

Digital images of fresh pre-preserved material can be important for identification purposes, and must be taken prior to preservation, after which specimens tend to lose their colour.

7.1.3 Which environmental parameters do we need to measure?

Priority measurements
Grain size diversity/granulometry – general descriptions more useful/easier
Sediment organic carbon (POC) – organic matter quality
Oxygen
Temperature
Salinity
Pigments
Core photos – stratified layer, sediment-water interface

Secondary measurements
Sediment accumulation rates
x-radiography
Pb-210 mixing depth
Pore water oxygen
Sulphide

Tertiary measurements
POC flux
Flow regime - ADCP
Nephelometry

7.2 Achieving a consistent taxonomy

The Questions

- How many species are there in the oceans?
- What are the geographic ranges of the species?
- Are different 'regions' biogeographically distinct?

The Problems

- Ecologists lack taxonomic/identification guides for the dominant species groups (scattered primary literature). Global taxonomic syntheses and keys are lacking or are incomplete for most faunal groups.
- Ecologists working within regions cannot address global questions about species identity or range.
- Taxonomists/biogeographers need access to specimens on a global scale from many regional studies.
- Information providers and information users are isolated. Biologists wishing to identify species in local faunas often work in different institutions (marine labs, government agencies, universities) from taxonomists (e.g. museums).

The Solutions

- Facilitate provision of taxonomic guides on a worldwide basis.
- Bring taxonomists together to set standards and begin to build user-friendly taxonomic tools (taxonomic workshops)
- Organise data-building workshops – once taxonomic tools are ready, bring taxonomists and ecologists together to:
    - (1) Add to and compare databases,
    - (2) Interchange taxonomic and distributional information.
- Establish a list-server for exchange of information and requests for specimens.

What are the priority taxa? (on basis of need and taxonomic expertise)

1. Nematoda
2. Polychaeta
3. Isopoda
4. Amphipoda
5. Tanaidacea
6. Echinodermata

Practicalities

- Establish a central clearing house and database centre to bring together species lists of all taxa from all surveys. Build on existing systems e.g. Australian Museums Online, this will require both biologists and IT support.
- Organise workshops for taxonomists of specific priority groups to discuss how to provide and develop taxonomic tools (e.g. CRUSTACEA.NET run by Jim Lowry of the Australian Museum).
- Organise workshops to coordinate and compare species lists.

7.3 Megafauna Sampling Protocol

What are the Key Needs?

- Intact morphology
- Intact DNA sequences
- Unbiased abundance

Preferred Collection Devices (in order of priority)

If possible, a video survey (e.g. towed video system) should be undertaken prior to commencing sampling.

Sample collection:

- Remotely Operated Vehicle / submersible
- Acoustically monitored, stable epibenthic sledge
- Otter trawl, beam trawl or equivalent
- Agassiz trawl (for ships with restricted wire capability)

Seabed imaging and abundance data

- Remotely Operated Vehicle/ submersible
- Suspended camera systems
- Autonomous Underwater Vehicle
- Acoustically monitored, stable epibenthic sledge
- Otter trawl, beam trawl or equivalent

What are the Key Methods?

- Observations of specimens in situ
- Fast fixation of samples
- Handling of samples for molecular work in cold laboratories.
- Fast freezing of samples for molecular analyses in liquid nitrogen.
- Consistent field of view and stability for imaging systems

Mesh size

The mesh recommended for nets depends on size and filtration area of the net. A 1cm stretch mesh size should be used in the cod end. A 1cm mesh net should be used for epibenthic sledges, but smaller meshes may be used if sample collection is to be used for larger macrofauna as well. For hyperbenthic macrofauna, a group that is not well studied, a finer-mesh epibenthic sledge may be the only effective means of sampling from a surface ship.

Minimum of four trawl/epibenthic sledge samples per sample site and sampling period.

Processing on board:

- Sort catch on deck and photograph entire catch and individual fauna.
- Note size and colour of fauna.
- Ensure detailed station numbering system and logging.
- Provide list of features for documentation in photographs for various fauna, so that these are recorded when experts in various fauna are not aboard ship.
- Separate samples as appropriate for morphological and molecular preservation.

Morphological preservation:

Fix specimens in minimum of 4% formaldehyde in seawater (= 10% formalin), buffered in borax. Transfer specimens to 70% Alcohol within 6 months following several washes in freshwater. During each wash leave to stand in freshwater for about half an hour.

In large specimens either inject formalin or make a small incision to allow ingress of preservative, to ensure good preservation of internal organs.

Molecular preservation

Take small samples of muscle tissue and preserve in molecular grade ethanol.

Take small samples of muscle tissue and other body parts and freeze in plastic bags at –80°C. If possible freeze tissues immediately using liquid nitrogen.

7.4 Macrofauna Sampling Protocol

What are the Key Needs?

- Unbiased abundance
- Intact morphology
- Intact DNA sequences

What are the Key Methods?

- Live specimen observations – photography/notes
- Care with quality of sample – rejection criteria for non quantitative/disturbed samples
- Low temperature fixation
- Careful handling/sieving

Preferred Collection Devices (in order of priority)

If possible, a video survey (e.g. towed video system) should be undertaken prior to commencing sampling.

- Megacore
- Box core
- Epibenthic sledge

Sieve size

Recommended sieve size is 300 micron (250 micron may be used, but coarser is not recommended).

Replication: Depending on the specific environment, a minimum of four separate cores (regardless of specific core type) is desirable, though in some instances a greater number of cores may be needed.

7.4.1 Megacore/Multicorer (~10cm internal diameter cores)

- On recovery of the corer, the function of each coring unit should be checked and recorded.
- Core lengths should be measured and recorded and any surface and profile features noted.
- Sample acceptance is based on the following criteria: cores > 10 cm in length; core surfaces essentially level (this is never the case on steeply sloped bottoms); the sediment-water interface intact. The latter criterion was partly relaxed where localised disturbance had been caused by the dislodgement of gravel during core penetration.
- Acceptable cores should be removed from the corer and transferred to the ship's laboratories for subsequent processing.
- In all cases, processing begins with the careful removal of the supernatant water to bucket/sieve using gentle overflow, pump siphon and/or syringe as appropriate to the sediment type.
- For macrobenthos samples, cores should be further processed as follows. Cores are extruded (by plunger from below) and sectioned into appropriate horizons, e.g. 0-5 cm and 5-10 cm.
- Samples are then carefully sieved. The resultant residues are then fixed and preserved in 10 % borax buffered formalin.

7.4.2 Box core (preferably with vegematic sub cores)

Once on deck the corer should be checked to decide if the core is acceptable. Sample acceptance should be based on the following criteria:

- cores $\geq$ 10 cm in length
- core surfaces essentially level (excepting relief deemed to be natural)
- sediment surface covering the full cross-sectional area of the box (excepting *limited*, (5 cm or less), lateral compression)
- essentially clear supernatant water - *limited* resuspension, particularly following a recoveries where the box core impacts the ship's hull is deemed acceptable.

If the core is judged to be acceptable the overlying water is carefully drained onto sieve and the surface of the core is examined and a record made (including either a drawing or photograph) of any surface features and/or fauna of note.

- Picking of megafauna, large macrofauna, nodules, stones.
- Slicing of appropriate layers e.g. 0-1cm, 1-5cm, 5-10cm layers.
- Sliced layers are placed into buckets of pre-chilled seawater.
- Buckets are placed in cold room, if available.
- Elutriation of sample and sieving in ideally <4 ºC water
- Careful sieving procedures to minimise damage to fauna e.g. in pooled, chilled seawater

Fixation:

For morphology, fixation in minimum of 4% formaldehyde in seawater (= 10% formalin), buffered in borax. Specimens later washed several times in freshwater and transferred to 70% Alcohol within 6 months.

For DNA extraction, samples are placed in chilled (-30 ºC) ETOH directly, with specimens being washed directly from the sieve with 100% ETOH.

7.4.3 Epibenthic sledge

Mesh size at cod end is 300 microns, mesh size of net is 500 microns.

Entire sample should be fixed in pre-cooled ETOH (e.g. for 1 litre of sample use 5 litres of pre-cooled 95% ETOH (-30 ºC) for at least 48hrs.
After picking (either on board or in lab later) the samples can be stored at 4 ºC.

General Comments

The above protocols are intended for use with the most common deep-sea sampling equipment. However, many deep-sea samples are now taken with submersibles and ROVs. These involve different sampling devices (e.g., tube cores, Ekman box cores) and place different constraints on sample size, depth in the sediment, number etc.Many of the experimental studies will need to use these sampling approaches. Further work is necessary to establish a standard protocol for such devices.

7.5 Meiofauna sampling protocol

What are the Key Needs?

- Unbiased abundance
- Intact morphology
- Intact DNA sequences

What are the Key Methods?

- Care with quality of sample – rejection criteria for non-quantitative/disturbed samples.
- Low temperature fixation.
- Careful handling/sieving.

Preferred Collection Devices (in order of priority)

- Multicorer (6.2 cm diameter)
- Megacorer (10 cm diameter)

(The Megacorer is recommended in order to collect sufficient specimens for taxa with lower densities)

Morphological analysis

Processing on board:

- On recovery of the corer, the function of each coring unit should be checked and recorded.
- Core lengths should be measured and recorded and any surface and profile features noted.
- The overlying water is collected separately including the phytodetritus layer if present. It is sieved over a 32µm sieve, which is defined as the lower size limit of the meiofauna.
- The cores are processed immediately after retrieval on board. They are kept cool and if possible processed in a cold room at in situ temperature.
- Virtual undisturbed cores are sliced in vertical layers.
- The sediment is sliced in layers of 0.5 cm for the upper cm, followed by layers of 1 cm up to 5 cm. Also the 5 to 10 cm layer of sediment is collected as bulk or sliced in 1 cm layers depending on the study. For biodiversity studies we recommend to analyse the upper 5 cm of the sediment. For ecosystem functioning studies it is often relevant to analyse the sliced core up to 10 cm depth.
- The sediment is fixed in borax buffered formaldehyde to an end concentration of 4 %. Filtered seawater is used for dilution of the formaldehyde.

Replication:

Replicates are retrieved from different deployments. Cores from the same deployment are considered as pseudoreplicates.

The number of replicates required depends on the question. In many cases a high number (> 5) is requested, but limitation in ship-time, and time of processing will generally allow less. A minimum of 3 replicates is recommended.

Extraction from the sediment:
Centrifugation (3 times at 4000 pm) with Ludox or Levasil (40%) with kaolin added is recommended for extracting metazoan meiofauna from fine sediments.

For protozoans (foraminiferans) hand sorting is recommended.

Samples are stained with rose Bengal

Molecular analysis

- Foraminiferans freeze, dry
- Nematode fix in acetone
- Others fix in ethanol

8. Practicalities – where next?

Abyssal:
- Determine role of CeDAMar in coordinating research in abyssal plain regions.
- Gather data from previous studies comparing fauna in different abyssal basins.
- Search for alternative funding sources for targeted taxonomic fellowships.
- Workshop for exchange of taxonomic knowledge and Internet keys (?Alfred P. Sloan Foundation).

Continental Margins:
- Creation of a coordination committee to write proposal to approach CoML for secretariat funding.
- Organise a synthesis of margin data – requires collation of existing datasets for meio-, macro- and mega-fauna into OBIS.
- Organise a species inventory by major taxon to look at gamma diversity across and down slope.
- Aim for taxonomic consistency of major Atlantic groups.
- Open discussion with oil and gas environmental advisors and directors for joint funding of activities.
- Search for alternative funding sources for targeted taxonomic fellowships.

Temporal variability:
- Co-ordinate joint activities.
- Establish Porcupine Abyssal Plain site as a European Atlantic time-series locality.
- Establish continued support for "Station M" Time series in NE Pacific.
- Establish contact with IMBER (Integrated Marine Biogeochemistry and Ecosystem Functioning) group to study common areas (HOTS, BATS).
- Establish links to group using cable networks for long term monitoring (NEPTUNE, H_2O, ESONET)
- Establish time series at JAMSTEC stations: 1100m and 4000m W. Pacific.

All groups:
- Coordination committee required to oversee work of the three groups
- Develop global map and database of samples to identify gaps (List of taxonomic groups studied, location of samples, what was done with them etc.)
- Develop regional databases in collaboration with OBIS
- Develop methods for consistent and fast taxonomic information.

Lack of taxonomic expertise at the global level is a major difficulty for a new field program. There is a need for specific taxonomic fellowships in key taxa at appropriate institutions worldwide. The group discussed how a mixture of government and industry grants might fund the new fellowships.

Appendix 1 - Pre-workshop questionnaire.

Many thanks to those of you that responded to the questionnaire. The responses were, as expected, many and various. I have made a synthesis of your replies and placed the various ideas in a proposed order of importance. This will stimulate our discussion in the first session. Some ideas relate to both abyssal plains and continental margins. Quite a number of the topics identified in the questionnaire responses could possibly have been accomplished in one area, on one cruise and by one group of researchers. While these are important, the CoML workshop needs to focus on science that requires us to act at the international level. This may be pooling of information from national cruises or the creation of international consortia to study certain areas or provide taxonomic expertise.

The Top 10 Scientific Tasks for the CoML Sediments Programme

1) **Rates of species turnover**. How does high local diversity translate into regional and global biodiversity? Is the relationship different in abyssal and continental slope regions?
2) **Species ranges and biogeography**. What are the basic patterns? How do we determine species ranges? Are cosmopolitan distributions the result of poor taxonomy? Do species ranges vary between taxa, size fractions? Do they reflect dispersal ability, reproductive biology? Can we use molecular approaches to determine gene flow?
3) **Replication of sampling along isobaths** at 0, 1, 10km scales. **Influence of depth** of fauna and their distributions
4) **Historical factors**. What is the influence of historical factors (e.g. hydrographic changes, sea level)? We need to integrate information from the palaeo record into hypotheses of modern diversity patterns. How do we design sampling programs to study the evolutionary-historical development of the deep-sea fauna? Link the evolutionary radiation and global spread of deep-sea faunas to long-term climate change.
5) **Time series** of faunal responses and biodiversity variability to changes in surface water production and surface water processes caused by global (decadal) change.
6) **How distinct are bathyal and abyssal faunas** in terms of standing stock, species diversity and make-up, diversity of higher taxa, feeding modes, and life-history traits?
7) **The role of biodiversity in ecosystem functioning**. If there is biodiversity loss through fishing impact or oil and gas production what effect does it have and how reversible is it? How resilient are ecosystems to biodiversity loss? How do variations in the abundance or diversity of certain taxa or size classes affect diversity in the other components of the benthic ecosystem?
8) **Heterogeneity in slope systems**. Do canyon systems contain unusual/unique communities, producing reproductively isolated populations in canyons, as well as producing biogeography boundaries across the slope?
9) **Microhabitat variability** and the relation of diversity to bio/geo/chemical sediment characteristics.
10) **Diversity maintaining processes**. How do these vary with depth and geographic location?