Knowledge transfer and deep-ocean management: a perspective from the deep-sea research community

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and the participants of the
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Introduction

The last 60 years have seen a global increase in human use of the deep-sea environment. Initially deep waters were used for the disposal of radioactive waste and munitions, but today the deep sea is impacted by many other activities, notably 1) fishing, 2) oil and gas exploration and production and 3) bioprospecting (Glover and Smith, 2003). With the increase in commercial exploitation of deep-sea resources comes the need to manage impacts on the environment. Deep-sea scientific research expeditions are encountering progressively more evidence of human impacts on ocean ecosystems. There is growing concern that proper environmental management is needed for the World's oceans before they are impacted irreversibly. At the 11th International Deep-Sea Biology Symposium (Southampton, UK, 9-14 July) scientists from around the World discussed issues relating to deep ocean management and the contribution scientific research should make to the debate. This paper is a summary of the discussions.

Policies for the management of deep-sea ecosystems within areas of national jurisdiction have generally used regulations developed for shallow water systems. In some cases these are not appropriate for the deep sea. In areas outside national jurisdiction the situation is more complex, and involves two different maritime regimes defined by the United Nations Convention on the Law of the Sea (UNCLOS): the "High Seas" and "the Area". Each has its own particular legal status. The Area relates specifically to the seabed and mining activities in international waters. It is governed by the International Seabed Authority. The High Seas are the overlying international waters. They are open to all states, with freedoms of navigation and overflight, to fish, lay submarine cables and pipelines and conduct scientific research. The freedom of the High Seas is an important principal for many people, but this needs to be balanced by the responsible exploitation of ocean resources and the enforcement of environmental protection measures. How can this be best achieved in the vast open expanses of the deep ocean?

Growing concern within the deep-sea research community about the impact of human activities on the deep-sea ecosystem prompted over one hundred scientists at the 10th Deep-Sea Biology Symposium in Coos Bay, Oregon USA in August 2003, to communicate their concerns by signing a joint statement calling for a moratorium on bottom trawling. Three years on, the problem of high seas management is now being addressed at the global level. The High Seas Task Force, launched on 1 December 2003 with ministerial backing from a number of Governments, has been charged with the task of developing an action plan designed to combat illegal, unregulated and unreported fishing on the high seas. There is also a global commitment in the form of the convention on biological diversity (CBD) and the World Summit on

Sustainable development (WSSD) to establish by 2012 in the marine area a global network of comprehensive, representative and effectively managed national and regional protected areas.

In an effort to aid the continued development of management strategies for deep-sea ecosystems (High Seas and EEZs) the 11th International Deep-Sea Biology Symposium organised a special session to discuss issues of ocean management, and specifically the possible implementation of High-Seas Marine Protected Areas. The aim of the session was to provide advice to policy makers on important questions in deep ocean management. In collaboration with managers, policy makers and scientists, a series of six questions were posed to the World's leading experts in deep-sea biology. Here we report on the responses to those questions. All conference participants were provided with the opportunity to comment on this paper prior to its publication to ensure the answers detailed were accurate and are the opinion of the deep-sea science community.

It should be stressed that it is not the goal of this paper to review current human use and its impacts of the deep-sea ecosystem. This has been well achieved elsewhere (Glover and Smith, 2003; Thiel, 2003; Smith et al., 2006). The aim of this review is to facilitate communication between science and policy makers by providing the collective opinions of the deep-sea research community on current topical questions in deep-sea marine environmental management. It recognises that 1) the key to good governance is knowledge, 2) scientists should play an active role in promoting their views and 3) we have a lot more to learn about the deep ocean environment.

Discussion

1. What are the most significant threats to the deep-sea environment?

The threats to the deep-sea ecosystems can be categorized as immediate and long term. Immediate threats include fishing, particularly bottom trawling, waste disposal, pollution (heavy metals, synthetic based drilling muds), and noise. Long term threats are indirect, for instance through climate change, including ocean acidification and increasing in CO_2 loading, and direct through sub-seabed sequestration of CO_2, oil and gas exploration, methane hydrate extraction, polymetallic nodule, sulphide and crust mining and bioprospecting for biotechnological and medical markets.

The most significant immediate threat to the deep-sea ecosystem is fishing. At present unsustainable catches are being harvested globally both inside and outside areas of national jurisdiction. Many of these fisheries are 'boom and bust' fisheries in which stocks are utterly depleted within ten years of fishing commencing (Koslow et al., 2000). The impact of fishing on ecosystems are wide ranging, and far beyond the simple removal of fish biomass. They include changes to community structure, changes in life history, disruption of food-web structure and habitat degradation (Jennings and Kaiser, 1998; Hall, 1999; Pitcher, 2000). In shallow-water environments fishing has fundamentally altered coastal marine ecosystems (Jackson et al., 2001). Even in the short history of deep-water fisheries there is evidence deep-sea ecosystems have been altered significantly already (Smith et al., 2006). The life-history characteristics of the deep-sea fauna suggest that direct and indirect impacts on many deepwater fisheries will be far more intense and persistent than those of traditional shallow-water fisheries. The question has been raised as to whether deep-water fisheries can ever be sustainable and economically viable (Clark, 2001; Roberts, 2002).

Technological advances have enabled the expansion of fishing into deep-water at a faster rate than our ecological understanding of deep-sea ecosystems is growing (Haedrich et al., 2001). Technological development is out-pacing ecological knowledge and is an increasing problem with the stepwise change in human use of the deep sea in recent years. For example, the oil and gas industry are increasingly using synthetic based drilling muds in their operations. The impacts of these muds on deep-sea communities have not been adequately studied. Further technological development will eventually facilitate the sub-seabed storage of CO_2, mining of polymetallic sulphides and the exploitation of gas hydrates. These activities may have a significant impact on deep-sea ecosystems. It is critical that impacts of existing and yet-to-develop human uses of the deep-sea environment are well understood and monitored over time. This will to ensure that informed choices are made on how the vast expanse of ocean is managed.

The most significant long-term threat to deep-sea ecosystems is climate change. Coupled ocean-atmosphere circulation models have predicted that with an increase in atmospheric CO_2, thermohaline circulation will either collapse (Manabe and Stuffer, 1993) or switch to a different state of operation (Broecker, 1997). Either of these possibilities will have a significant effect on deep-sea biology through changes in food and nutrient supply, oxygen concentrations, temperature, and patterns of dispersal. Recent research has indicated that climate-related fluctuations at the sea surface can cause significant changes in deep-sea macrofaunal and megafaunal communities (Billett et al. 2001; Danavaro et al., 2004; Ruhl and Smith, 2004). Coupled with climate change is the increase in dissolved CO_2 resulting in acidification of oceanic waters. Experimental evidence suggests that key marine organisms, such as corals and some plankton species, will have difficulty maintaining their external calcium carbonate skeletons, and in high latitudes this may occur within decades (Orr et al., 2005). Elevated CO_2 partial pressures will affect the physiology of many marine species (Pörtner et al., 2004). However, little research has been conducted on the implications of increased CO_2 on deep-sea species.

As with shallow water systems, multiple stresses and the additive effects of human activities over time will result in species mortality and changes in ecosystem functioning (Hughes and Connell, 1999; Jackson et al., 2001). It is vital, therefore, that we begin to consider the cumulative effects of all threats at a global scale and not just individual, localised impacts. .

2. What habitats and species are most sensitive/under threat?

A number of different approaches were stimulated by this question. The question was stimulated by the perceived need to focus scarce resources on areas with the greatest need, if these could be identified.

Overall, it was concluded that the nature of the life histories of most deep-sea animals means deep-sea ecosystems are unlikely to be very resilient to large-scale impacts (Smith et al., 2006). Many species are thought to have with long lifespans, low mortality and to produce few, high quality offspring (K-selected species). The ability of an ecosystem to “bounce back” after an impact therefore will be limited and slow, except in areas where life is regularly affected by large-scale natural disturbance events (such as submarine canyons and continental slope areas subjected to strong near-bed currents). Owing to their lower abundance higher trophic levels may be at greatest risk and least able to recover from perturbations.

Another approach to decide on which species are at greatest threat is to consider which are of the greatest economic value. Economic drivers will have to be incorporated into management strategies. However, as many non-target species will be impacted by commercial operations it is not simply of a case of focussing on the species with greatest economic value.

In terms of habitats (and their associated species assemblages) all biogenic-structured habitats, such as cold-water coral reefs and sponge fields, are highly sensitive to activities that cause a high degree of physical disturbance (e.g. bottom trawling). In the case of cold-water corals a single trawl can cause damage that may take hundreds of years to recover (ICES, 2004). Many biogenic ‘reef forming’ communities rely on chemical signals from settled adults to attract new larval settlement (Zimmer and Butman, 2000). It is therefore possible that degraded biogenic habitat may never recover from large physical disturbance.

Another perspective on how to prioritise ecosystems in greatest need of informed management and background research is to identify areas of the ocean that experience the greatest degree of human influence. In that respect the muddy continental slopes are most impacted by human activities, including bottom trawling, oil and gas exploration and cable laying. In addition, the pelagic environment is heavily impacted by fishing activities and we have little understanding of the consequence of these activities on the pelagic realm and bentho-pelagic coupling.

These arguments only consider immediate threats, however if changes in ocean systems occur as a result of climate change a wide range of species will be under threat. In deciding research priorities it is important to consider the future of marine populations (e.g. areas of ocean that may act as refugia for species from these large scale changes) as well as the present-day short-term impacts.

3. How do we ensure better communication between the research community and management bodies?

Many environmental managers are frustrated that the research community often does not provide advice pro-actively. Whereas Non Governmental Organisations lobby managers and policy makers, and are very effective in making themselves heard, scientists often consider their role is to provide impartial and independent advice and therefore do not promote any particularly view to policy makers, Very often the various communities "talk different languages" (in the figurative sense) and approach problems from different angles, which can lead to communication problems.

Part of the problem is that in many cases scientists do not receive any recognition or funding for providing advice directly to managers and policy makers. Where scientists are judged on scientific output (peer reviewed publications) alone, and are funded for specific pieces of research that must be fully costed in advance, and delivered to deadlines, there is little opportunity or time to provide detailed advice. The International Council for Exploration of the Sea (ICES) is a possible forum for transferring scientific knowledge into ocean management policies. The working groups rely on nominated members, who are experts in their field, to attend annual meetings and produce reports proving advice to bodies such as the North-East Atlantic Fisheries Commission and OSPAR. However, no financial support is provided to academic research scientists to allow their attendance at such working groups, and no recognition of the time it involves. As a result many experts do not attend. In addition, scientists often feel that independent and impartial best-practice advice is lost as the proposed legislation traverses through the political process.

Governments need to address the flexibility of funding available for scientists to engage in advising managers and policy makers. In the USA the idea of 'service' exists where scientists have a duty to engage in activities other than research. However, at present talking to managers and policy makers is not seen as service. New performance measures and rewards need to be introduced so that communication between scientists and policy makers can be improved. A good example of effective communication between researchers and policy makers was provided by colleagues from the Azores. There, deep-sea biologists have good contacts with fishermen and policy makers holding annual meetings to discuss joint issues.

The challenge is to communicate science directly to policy makers in a language that can be understood, linking recent research to social and economic needs. In addition, scientists need to improve communication with the public in order to change the public's perception of the deep-sea as a pristine habitat. The deep sea in many places is a varied and dynamic environment. Greater exposure of deep-sea science in the media is vital and the scientific community needs to ensure that high quality visual images from deep-sea submersible and ROV operations readily find their way into TV programmes and press articles. Major scientific institutions with access to these large-scale facilities have a particular responsibility in making sure their images are used for public awareness of the deep-sea realm. Another option is to develop a specific publication or journal that features papers tailored to answering managerial questions. The editing board and reviewing process should include both scientists and environmental managers to attract papers that are both of scientific merit and of value to managers.

4. How can the science community contribute to the policy requirements for a network of High Seas / deep-sea Marine Protected Areas as called for by World Summit on Sustainable Development (WSSD) (by 2012) and the Oslo-Paris Commission for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) (by 2010)

Many scientists are unaware of how to transfer their knowledge to policy makers in order to implement High Seas Marine Protected Areas (HSMPAs). Coordination through a collective outreach organisation that can communicate deep-sea research directly to users in an appropriate format may be an appropriate way, but the problem is funding and the body must provide the advice in an impartial manner. Existing programmes such as the Census of Marine Life may provide an appropriate forum for contribution of information directly to the development of HSMPAs, particularly through the various CoML field projects such as the Census of Marine Life on Seamounts (CenSeam), Continental Margins Ecosystems on a Worldwide Scale (COMARGE), Census of Diversity of Abyssal Marine Life (CeDAMar), Mid-Atlantic Ridge Ecosystems (MAR-ECO) etc.

An important component of the development of a network of HSMPAs will be the identification of bio-geographic divisions in deep-sea species distribution. The Global Marine Species Assessment that began in 2005 will be the first global review of the conservation status of every marine vertebrate species and of selected invertebrates and plants. This process could provide a good model to construct a report on biogeography of the deep sea.

5. What are the policy gaps with regard to our current understanding of deep-sea ecosystems?

There is currently no mechanism to ensure that activities undertaken on the high seas are subject to an independent environmental impact assessment prior to those activities commencing. In addition, the cumulative effects of all human activities in the deep sea are not monitored, reviewed and assessed at national and global levels. What is required is a global approach to high seas / deep-sea management. Regional and national approaches, while locally successful, generally act to shift the problem elsewhere. For example, since the recent EU ban on deep-water gill netting (but not on landing fish caught using deep-water gill nets) scientists in the Azores have noticed some deep-water gill netters operating in waters near the Azores where previously they have not fished. This is not to say that the ban was wrong, merely that there needs to be control of activities outside national jurisdiction as well as inside and this has to be organised at a global level. In the case of deep-water fishing the industry is currently not required to undertake any kind of environmental impact assessment, inside or outside the boundaries of national jurisdiction, and the industry is not controlled sectorally, as all other industries are.

Policies governing the complete utilisation of hydrocarbon resources that sustain cold seep communities are required. Many deep-water seep environments are the site of significant reservoirs of petroleum and natural gas. In the Gulf of Mexico, offshore exploitation of oil and gas in proximity to seep communities has been occurring for decades. The depletion of subsurface oil and gas reservoirs is likely to affect the energy supply to seep communities. However, no legislation exists to manage the resource and ensure the long-term health of these highly diverse communities.

MPAs are just one method of managing our marine environment, and should be considered as part of a toolbox of methods designed to control human activities and their impacts, rather than as the only method. The extension of shallow water policies into the deep-sea environment will be inadequate and inappropriate for the long-term management of this ecosystem.

6. What are the science gaps?

Advising on the creation of High Seas Marine protected Areas is compromised significantly because there is no clear understanding of the bio-geographic ranges of deep-sea species. This information is essential for assessing the likelihood of species extinctions. One of the problems is that deep-sea research is highly localised. Some oceans and seas have received little or no research attention. The research community must involve more people from developing countries to build capacity and ensure a more global approach to understanding deep-sea ecosystems.

Related to species biogeography is a need to understand the connectivity of populations and the relationship between species and habitats, the deep and shallow water marine environments, the pelagos and the benthos. To understand connectivity we must have a firm knowledge of the taxonomy and phylogeny of species together with knowledge of their life history traits (e.g. dispersal capabilities, reproductive cycles). The relationship between species and their preferred habitats is important in ocean management. Recent research has identified relationships between demersal fish species and benthic habitats (Uiblein et al., 2003). However, the classification of habitats is challenging and is only in the early stages of development. The relationship between the pelagos and benthos (benthopelagic coupling) is related to the transfer of energy to the deep sea via the food web and the cycling of organic matter within the benthic environment. Little is known of trophic relationships in the deep sea, but it is apparent that changes in the amount and type of organic matter reaching the seabed can have dramatic effects on deep-sea communities (Wigham et al., 2003). The impacts of removal of top predators through fishing in deep-water are unknown. In addition we know almost nothing about deep-sea microbial ecology. Bacteria form an important resource in deep-sea trophodynamics and are important for ecosystem functioning.

Long-term change in the deep-sea environment is poorly understood. There are only a as few long-term studies and all are funded precariously. The '*Amperima* Event' (Billett et al. 2001; Wigham et al., 2003) and similar regime shifts evident in the NE Pacific (Ruhl & Smith, 2004) clearly demonstrate that changes in deep-sea communities can be abrupt and that monitoring 'baselines' cannot be set on limited short timescale data. A great deal more information is needed to determine 1) how resistant and resilient deep-sea communities are to perturbation and 2) the recovery times for deep-sea systems following disturbance.

Conclusions

1. Human impacts on the deep-sea environment include fishing, waste disposal, pollution, noise, climate change, ocean acidification, increasing in CO_2 loading, CO_2 disposal, oil and gas exploration, methane hydrate extraction, polymetallic nodule and sulphide deposit mining and biodevelopments. The most significant immediate threat is fishing and in the long term, climate change.
2. Species that are K-selected, at a high trophic level, or have a high economic value are under most threat. Biogenic habitats and habitats that are exposed to the greatest degree of human activity, e.g. the continental slopes and margins, are also at risk.
3. Better communication between science and policy could be achieved if researchers were supported both financially and professionally in these efforts. Deep-sea researchers recognise the need for effective communication to a wider audience.
4. The deep-sea research community are willing to contribute to the development of high seas policy but must find an appropriate forum in which to achieve this.
5. Policy should be developed to manage human activities on the high seas at a global level. In accordance with the precautionary principle, activities should be subject to proper environmental assessment prior to development. Policies may be needed to manage the hydrocarbon resources supporting seep (and vent communities) to ensure appropriate protection. Extension of shallow water policies into the deep-sea environment is unlikely to be appropriate.
6. Clear science gaps are in the biogeographic ranges of deep-sea species, population connectivity, the distribution of habitats, trophic pathways, and energy cycling. Long-term studies are very important in future management of the deep sea and require committed long-term funding and research plans.