Vol. 397: 1–5, 2009
doi: 10.3354/meps08452

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published December 17

Contribution to the Theme Section 'Conservation and management of deep-sea corals and coral reefs'

OPEN ACCESS

INTRODUCTION

Recent advances in deep-sea coral science and emerging links to conservation and management of deep-sea ecosystems

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ABSTRACT: Conservation and management of deep-sea corals and coral reefs was the theme of the 4th International Deepsea Coral Symposium held in Wellington, New Zealand from 1 to 5 December 2008. A selection of resulting studies is published here. Recent advances in our understanding of deep-sea corals and associated ecosystems have demonstrated their high diversity, abundance, longevity and widespread global distribution. Such deep-water communities are increasingly threatened by anthropogenic environmental change (e.g. ocean acidity, fishing pressures) and require timely management policies and actions to reduce potential deleterious effects. The interdisciplinary nature of deep-sea coral research is a significant strength, helping to provide the broad base of knowledge and resources that are required for the conservation and management of this important ecological group.

KEY WORDS: Biodiversity · Ecology · Growth · Geochemical archives · Mapping tools · Conservation and management · Deep-sea corals · Symposium

The existence of deep-sea corals has been recognised since the time of Linnaeus, although only in recent decades have we developed the technology to fully explore the nature of deep-sea corals and coral reefs. Ironically, however, at a time when we are finally beginning to understand the incredible diversity and ecological importance of deep-sea coral ecosystems, we are also becoming aware of increasing threats to deep-sea corals, and the need for timely management to ensure their persistence.

Conservation and management of deep-sea corals and coral reefs was the theme of the 4th International Deepsea Coral Symposium held in Wellington, New Zealand, in December 2008. Continuing with the tradition of the previous 3 symposia (Willison et al. 2002, Freiwald & Roberts 2005, George & Cairns 2007) the meeting brought together almost 200 researchers, resource managers and policy makers from 23 countries, facilitating a global exchange of scientific knowledge of deep-sea corals and associated fauna. The Symposium was hosted by New Zealand and Australia, responsible for 2 of the largest exclusive economic zones in the world, both of which contain abundant and diverse deep-sea coral fauna (e.g. Gordon 2009), and hence there was a strong focus on management measures and options to conserve and protect deep-sea corals and habitat. The studies that comprise this Theme Section represent a selection from the symposium, and synthesise recent advances in our understanding and conservation of deep-sea corals.

Biodiversity

Most marine scientists are aware of the incredible diversity of shallow-water corals; however, few realise that deep-sea corals (defined as those occurring at depths >200 m and typically represented by species of Antipatharia, Scleractinia, Octocorallia and Stylasteri-

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dae) are as speciose (>3000 species described representing >65% of all corals; Cairns 2007), abundant, and widespread as their shallow-water counterparts. Despite the sustained efforts of leaders in the field of coral systematics — such as Frederick M. Bayer (Cairns 2009, this volume) — to document deep-sea corals, new species continue to be discovered. For example, 6 new species of stylasterids were discovered in a recent survey to seamounts on the Chatham Rise in New Zealand (Clark & Rowden 2009) and, of 95 octocoral species recorded on the Tasmanian Seamounts in 2007, close to 15% of these are new to science (Williams et al. 2008). Increasingly, molecular technologies are allowing us to better document diversity and understand evolutionary processes in the deep sea (e.g. Dueñas & Sánchez 2009, this volume); however, there remains much to learn. For example, isolation resulting in divergence and allopatric speciation has long been considered to be an important process affecting the diversity and distribution of seamount coral species. However, genetic data are beginning to show that many haplotypes and species are widespread and that the accepted paradigm of high seamount endemism many well be an artefact of limited sampling (Thoma et al. 2009, this volume).

Interdisciplinary research

One of the hallmarks of deep-sea coral research is its interdisciplinary nature; indeed papers presented at the Symposium covered themes as broad as systematics, ecology, paleoclimate and conservation. Notably, research on deep-sea corals involves collaboration across scientific disciplines; taxonomic resources are combined with studies of growth and ecophysiology, predictive modelling and mapping tools are used alongside diversity and distribution studies, proxies for deep-ocean conditions are being developed to elucidate climate change and ocean acidification, and all these resources are subsequently applied to conservation and management. One area where multidisciplinary research is particularly apparent is in the emerging links between environmental parameters and the distribution and biology of deep-sea corals. The work of Arantes et al. (2009), Carlier et al. (2009), Dodds et al. (2009), Hansson et al. (2009), Nonaka & Muzik (2009), Roberts et al. (2009), Thresher (2009) (all this volume) utilise cross-disciplinary approaches to link factors such as substrate or oceanography with food supply, growth, or ecophysiology to provide an improved understanding of deep-sea coral diversity, distributions, and the role and functioning of ecosystems (Bo et al. 2009, Mosher & Watling 2009, both this volume).

Growth rates

Growth is a key area of interest in deep-sea coral research, particularly how climate change and ocean acidification may affect skeletal architecture via dissolution and/or re-precipitation, and the consequences of this for the persistence of deep-sea coral species. Technological advances are facilitating *in situ* growth experiments such as have been undertaken in shallow water species for decades, and new studies confirm slow growth rates, high longevity, and low natural mortality for deep-sea corals, e.g. the recently reported longevity of Hawaiian proteinaceous corals in the order of several thousand years (Roark et al. 2009). Parrish et al. (2009, this volume) monitored colonies of the Hawaiian gold coral (*Gerardia* sp.) for 9 yr and reported gross linear growth rates of only millimetres per year, suggesting colonies are very long-lived (~950 yr). Radiometric validation methods provide veracity to *in situ* growth rates; radiocarbon and lead-210 (^{210}Pb) validation studies (Andrews et al. 2009, this volume) compare favourably with slow growth (up to 1.4 cm yr^{-1}) and high longevity (>145 yr) observed in previous studies of bamboo corals (Tracey et al. 2007). Thus the age and growth of complex branching forms of deep-sea corals appear akin to those of massive framework corals in shallow water that grow at rates of 5 to 40 mm yr^{-1} (e.g. Fosså et al. 2002, Freiwald 2002, Adkins et al. 2004, Brooke & Young 2009, this volume). Slow growth and longevity are 2 key life history parameters that contribute to the vulnerability of a species (e.g. Roberts & Hawkins 1999) and this, along with fecundity and recruitment (e.g. Pires et al. 2009, this volume), are important considerations in the development of protection measures in the deep sea.

Geochemical archives

We are on the cusp of generating calibrated proxy records from deep-sea corals that have enormous potential to unravel regional and localised paleoenvironmental, paloeceanographic, and climatic variability causes and effects. Variation in stable isotope ratios and elemental composition are the result of changes in environmental parameters and/or animal behaviour, which can range from annual- to century-scale frequencies. Geochemical signatures within deep-sea coral skeletons can be influenced by changes in skeletal architecture during growth, and this needs to be considered when developing geochemical archives (Wisshak et al. 2009, this volume). Recent work has focused on isotopic and elemental ratios as proxies for potential climate signals — e.g. temperature, biogeochemical processes and nutrient supply — with variable success. Sherwood et al. (2009, this volume) have demonstrated the use of stable isotopes in tracking biogeochemical processes (nutrient availability and trophic dynamics) across centennial time scales from long-lived bamboo corals, and Risk et al. (2009, this volume) have applied these approaches to contemporary studies of nutrification. Deep-sea coral records are also providing unprecedented time-series information (potentially through the Holocene and older) for a sector of the ocean that has sparse historical records, often at best a small number of shipboard observations, hence deep-sea corals are well placed to provide baseline evaluation of the impacts of future environmental and climatic change.

Mapping tools

The conservation and sustainable management of the marine environment requires, amongst other things, objective and quantitative measures of seafloor habitats. Methods for submarine habitat and biodiversity mapping within the deep sea have advanced rapidly, and have been aided by high-resolution non-invasive tools such as remotely operated vehicles (ROVs), video and still camera systems, and acoustic techniques. Exploration has highlighted the physical complexity of the habitat, the combination of environmental and biological conditions that promote habitation by a given species, and the difficulty of acquiring comprehensive and unambiguous data at the seafloor over large areas. Concomitantly, there has been a rapid rise in studies that document the spatial distribution and areal extent of deep-sea coral reefs and their contribution to continental margin sedimentary systems (e.g. Orejas et al. 2009, this volume), while predictive modeling as a tool for describing large areas of seafloor that have the potential to support coral gardens (e.g. Woodby et al. 2009, this volume) are also being used where physical data are few.

Deep-sea corals are often associated with seamounts and other complex underwater terrains that abound in the deep sea. These important biodiversity hotspots are increasingly observed via non-destructive techniques, often resulting in large databases which need to be assimilated for them to be useable by conservation, fisheries and intergovernmental managers and policy makers (e.g. Costello 2009, this volume). Innovations such as machine-learning algorithms that estimate coral density from remotely collected video footage (Purser et al. 2009, this volume) are leading the way in the synthesis of vast deep-sea datasets, and will undoubtedly have widespread application across marine science.

Threats and conservation

Some of the most important end-users of the accumulating knowledge on deep-sea corals and coral reefs are environmental science managers and policy makers. Deep-sea corals face considerable threat from ocean acidification or shoaling of the aragonite saturation horizon (e.g. Guinotte et al. 2006), and future distribution of deep-sea coral communities and ecosystems will almost certainly be influenced by climate change (e.g. Fautin et al. 2009, this volume). Climate change is not, however, the only process threatening deep-sea corals. Bottom trawl fishing both damages corals (Heifetz et al. 2009, this volume) and reduces coral biomass (Althaus et al. 2009, Bruckner 2009, both this volume). At an international level, the United Nations General Assembly (UNGA) Resolution 61/105 called for States to protect vulnerable marine ecosystems (VMEs), including cold-water corals, from destructive fishing practices in international waters. A precautionary best practice approach for minimising impacts from high-seas fisheries on VMEs has resulted in some regional fisheries management organizations and governments acting on the UNGA resolution to prevent significant adverse impacts to VMEs (Brock et al. 2009, Penney et al. 2009, both this volume). Some deep-sea corals have protected species status as a result of the closure of seamounts to fishing, and the effect of fishing closures on deep-sea corals is being carefully monitored in some locations. Critically, however, recovery of deep-sea corals from the effects of fishing is likely to be slow. Coral communities on Tasmanian seamounts showed no signs of recovery even 10 yr after closure of the area to fishing (Althaus et al. 2009), indicating critical time lags between management actions and measurable effects on coral communities.

Conclusions

The Deepsea Coral Symposium provided an important forum where those who are actively involved in research and management of deep-sea corals and ecosystems could establish current knowledge at the same time as discussing future directions. Continuing discoveries, and an increased understanding of biodiversity and distributions of deep-sea corals and their immediate threats, will input directly to the designation and management of high-seas marine protected areas (Hall-Spencer et al. 2009, this volume) as well as the identification of VMEs and management actions associated with these (Hourigan 2009, Parker et al. 2009, both this volume).

The outcomes of the symposium will enhance the study of deep-sea corals and ecosystems through improved international data sharing and collaboration, combined taxonomic resources, and the development of remote sensing and mapping techniques to substantially improve knowledge of ecosystem distributions. The calibration of environmental proxies derived from deep-sea corals, the climate variability that these elucidate, and their application to environmental questions are critical for providing time-series in a poorly known area of the ocean, especially in relation to the effects of ocean acidification. Advancing molecular technologies are also allowing us to better document diversity and understand evolutionary processes in the deep sea, contributing to development of global databases and the improved conservation and management of deep-sea corals. We look forward to a continuation of the trend of international cooperation, and to the establishment of a framework and strategy for deep-sea coral exploration, research, conservation and management.

Acknowledgements. We thank all the authors of the many manuscripts that were submitted for consideration to the Theme Section. Space was limited and many difficult decisions were made. We hope to see more papers generated from the symposium over future publications. The >100 reviewers that contributed thorough and thoughtful reviews are also thanked. The Symposium would not have been possible without the International Scientific Committee, the symposium host National Institute of Water and Atmospheric Research (NIWA), major sponsor the National Oceanic and Atmospheric Association (NOAA), as well as all the attendees. Other sponsors who ensured the success of the symposium were the Commonwealth Scientific and Industrial Research Organisation Wealth from Oceans Flagship, US Department of the Interior Minerals Management Service, NZ Ministry of Fisheries, NZ Department of Conservation, United Nations Environment Programme, United States Geological Survey, Neptune Minerals, NZ Deepwater Group, and the Royal Society of New Zealand. We wish all the best to Tjeerd C.E. van Weering, the Royal Netherlands Institute for Sea Research, and organisers of the 5th Deepsea Coral Symposium (to be held in the Netherlands, 2012), and look forward to continued interdisciplinary and collaborative discussions following on from those established by previous Symposia.

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