Proposal for a SCOR Working Group
Global Analysis of cold-water Coral Ecosystems - GLACES

Summary

We are witnessing exponential growth in cold-water coral research. Recent discoveries have revealed cold-water corals as significant structural habitats on continental margins, seamounts, and mid-ocean ridges. Solitary corals are even found in the abyssal ocean. Many species are long-lived, and some form long-lasting reef and mound structures providing unique archives of faunal biodiversity and oceanic change. However, there has been no systematic research programme that links the interdisciplinary fields of coral biology, ecology, biodiversity and palaeoceanography at the global scale. A programme of this scope would only be possible through interdisciplinary, international collaboration. The first attempt to create an ocean basin-scale programme, the Trans-Atlantic Coral Ecosystem Study 'TRACES', was launched in February 2008 and has gathered momentum by bringing a disparate group of ecologists, geologists and palaeoceanographers together to develop its Science Plan. In early 2009, European members of the TRACES community put forward 'EuroTRACES', a European Science Foundation research programme, and this application was approved in early 2010. EuroTRACES will focus on the North Atlantic Ocean.

This SCOR Working Group proposal seeks to establish an international group to build on the momentum generated through TRACES to start work on development of a truly international, global research programme. This Global Analysis of cold-water Coral Ecosystems – GLACES – will develop an integrated global cold-water coral study, ensuring consistency in research approach, and effective reporting. It will produce a planning document outlining the programme and this overview will be widely distributed both in print and online. We also plan a number a specialised, peer-reviewed papers alongside materials of wider appeal including online summaries and downloadable slide sets on each of the GLACES thematic areas. The SCOR-GLACES working group will begin to design and co-ordinate a concerted field programme for the global ocean. It will follow clear terms of reference with expertise across the thematic areas of the programme encompassing ecosystem processes, climate records, and overarching issues relevant to all aspects of the programme.

Rationale & Scientific Background

The last ten years have seen great advances in our understanding of cold-water corals as significant ecological engineers on continental margins, offshore banks, seamounts and canyons [1, 2]. Stony (scleractinian) cold-water corals can develop large deep-water reef frameworks providing complex three-dimensional habitat for a spectacularly diverse associated fauna. Other groups of corals, such as gorgonians and black (antipatharian) corals also provide long-lasting habitat, notably on seamounts and mid-ocean ridges. Indeed, recent dating studies show that antipatharian corals can live for thousands of years [3]. But cold-water corals are not only a biological or ecological curiosity. They form perhaps the most structurally complex and biodiverse deep-sea habitats and their long-lasting skeletons and the mound structures they form provide new archives of the variability of ocean properties during climate change [4-7]. Possibly more than any other habitat, cold-water coral reefs are threatened by ocean acidification and further study of their health and history is crucial at this moment in time.

Ecosystem research

Linkages & connectivity: Cold-water coral habitats provide a natural laboratory to study genetic relationships between spatially separated marine populations. Sessile benthic marine species such as corals may be genetically connected (i.e. exchanging genetic material) by larval dispersal. Understanding how one coral population is (or is not) genetically related to others is vital to understanding ecosystem dynamics in space and time and to designing ecologically coherent marine protected areas.

Biodiversity & biogeography: Cold-water corals are among the most three-dimensionally complex structural habitats in the deep sea. As such they provide a great variety of physical niches and support high biodiversity [8-10]. In turn the variety and spatial patchiness associated with cold-water coral habitats creates significant variation in species between habitats, promoting high species turnover [11, 12]. However, while they clearly form biodiversity 'hotspots' our understanding of spatial biodiversity and biogeographic patterns in cold-water coral habitats remains poorly developed. This is largely because studies to date cannot be compared due to variable sample collection protocols (e.g. trawl, submersible, box corer) and inconsistent taxonomic resolution (differing expertise between research groups leading to

biases in the species subsequently identified). The GLACES programme proposes an ambitious study to examine biodiversity and biogeographic patterns building upon work now beginning through TRACES. Analytical consistency and co-ordinated use of international taxonomic experts organised through networking activities will reveal new species and revisions to existing species descriptions. Such a programme of work will complement and add to previous large-scale biodiversity initiatives, such as the Census of Marine Life, by targeting biodiverse cold-water coral habitats likely to contain many undescribed species.

Coral biology: Information on critical aspects of cold-water coral biology, such as feeding, physiology, trophic ecology, growth patterns and reproductive strategies, has only begun to become available in recent years but remains restricted to very few species. Understanding reproductive and larval biology is central to understanding population connectivity. Furthermore, lack of physiological data limits our ability to understand cold-water coral responses to ocean warming and acidification, both causes of great current concern. In the North Atlantic, EuroTRACES will support investigation of the reproduction, feeding ecology, growth and ecophysiology of major habitat-forming cold-water corals. Internationally, GLACES will apply these approaches to cold-water coral habitats globally. It will capitalise on recent advances in maintaining cold-water corals under controlled laboratory conditions allowing studies of coral response to predicted scenarios of ocean warming and acidification. Finally, repeatedly sampling field sites where year-round access is achievable can provide new insights regarding reproductive periodicity in a seasonal context.

Climate records research

The GLACES palaeoceanographic projects have two overall aims: first to examine environmental effects on cold-water coral habitats and biodiversity, and second to understand the role of ocean circulation in a changing Earth climate system. These will be addressed using investigations of the recent past (millennia) coupled with instrumental records to provide a clearer picture of anthropogenic changes to ocean chemistry and circulation. Records of the past 25,000 years and beyond, on the other hand, can provide unique information on ocean circulation during times of radically different mean climate and rapid climate change. GLACES research projects on climate records will contribute to the following major issues:

- Links between past changes in ocean circulation and coral vitality
- Links between global climate and the rate of ocean circulation
- Recent and long-term history of the carbon cycle and ocean acidification
- Deep-ocean productivity, nutrient cycling and trophic changes

For the study of the past ocean, cold-water corals offer a unique combination of uranium-rich, unbioturbated skeletons that serve as faithful archives of the water in which they grew. Using uranium disequilibrium dating, it is possible to independently constrain a fossil coral's age [13, 14]. Because the coral's skeleton is a banded archive with nearly perfect stratigraphy, it records rapid climate change events at ice core-like resolution, thus surpassing the ability of many ocean sediment-based measurements to record climate change. These features of cold-water corals have been used to track the extent of bomb ^{14}C penetration to the ocean interior and to document the speed with which the deep ocean participates in past climate change over timescale of just a few decades. This unique new archive of past climate change is just beginning to be widely exploited by the research community.

In addition, the past distribution of fossil Scleractinia in space and time has shed new light on the extent of population movements in the deep sea. Records from the New England Seamounts show that cold-water corals thrive at times of rapid climate change and are nearly absent during the Holocene [6]. In the Northeastern Atlantic, on the other hand, coral development is greatest during interglacials at higher latitudes [15] and during glacial periods at mid-latitudes [16, 17]. These differences in population dynamics provide an important target for modern studies of coral ecosystems to explain how changes in the environment (ocean acidity, circulation, temperature and productivity for instance) work to structure the community. This is one of several fruitful new lines of research between ecology and palaeoceanography that our SCOR working group plans to develop. Over and above these ambitions the GLACES Working Group will engage with PAGES (Past Global Changes), the well-established International Geosphere-Biosphere Programme (IGBP) project, since there are many aspects where our research objectives complement PAGES overall goals (www.pages-igbp.org).

Further studies will capitalise on the wide geographic sampling planned during TRACES and GLACES to run proxy calibration exercises (e.g. to test temperature proxies across latitudinal transects, to calibrate nutrient proxies, and to refine proxies for past ocean ventilation, intrinsically linked to past atmospheric CO_2 levels). The perceived paucity of cold-water corals on the seafloor and in existing museum collections remain significant limitations to the more widespread use of cold-water corals in climate studies. A key goal, and a pressing job for the SCOR working group, is to organise the existing information about where corals have been collected and to identify the most urgent needs for new field collection. Therefore work to co-ordinate suitable collections through research cruise proposal planning is vitally important.

Overarching issues

Mapping & habitats: High-quality mapping and habitat characterisation will underpin all GLACES studies and take advantage of the survey and processing improvements made in recent years. Existing relevant regional data would be amassed using Geographic Information System software. Key areas currently unmapped would be surveyed at sea and ground-truthed using appropriate visual and sampling techniques. GLACES will produce one of the largest integrated deep-water habitat mapping efforts and will greatly assist standardisation and habitat categorisation by working closely with existing schemes and government agencies. In addition to refining existing and developing new habitat maps, GLACES also incorporates the emerging science of predictive habitat mapping. Furthermore, dating fossil corals found during mapping surveys will enable researchers to produce 'habitat maps' of corals for the past, which in turn can be linked to ecological niches required for coral growth (i.e. for particular time periods or climatic and oceanographic conditions).

Oceanography & food supply: Understanding the hydrographical context of cold-water coral habitats is vital to study food supply mechanisms, near-bed sediment flux and larval transport. The importance of these issues places physical oceanography as a key overarching theme of GLACES. The programme aims to support studies addressing both local-scale physical characterisation of study sites alongside interpretation of larger-scale boundary currents, density horizons and internal wave dynamics.

Policy: The policy regime in which marine conservation measures are developed is complex and constantly evolving. For example, cold-water corals were among the 'vulnerable marine ecosystems' covered under UN General Assembly Resolution 61/105 calling upon states to implement precautionary measures for the long-term conservation of High Seas habitats. As well as providing data on population connectivity towards marine protected area design, GLACES will contribute to the review and compilation of relevant information of maritime policy both at national, European and international (High Seas) levels. The policy work will ensure clear two-way communication between the pure science projects and the policy-maker end users. Several social scientists are members of the existing TRACES community and their research will for example focus upon regional governance case studies to critically evaluate the process of conservation policy development for cold-water corals and deep-sea habitats in general. Once again, we aim to apply the approach developed through TRACES in an Atlantic context to the wider global ocean related to new initiatives such as the Global Ocean Biodiversity Initiative (GOBI, http://openoceansdeepseas.org/).

Timeliness

An international global cold-water coral programme is feasible now for a number of reasons: (1) baseline habitat mapping provides a database of target sites across key ocean basins such as the Atlantic, a global centre of cold-water coral records; (2) genetic markers (notably microsatellites) have recently been developed for a number of cold-water corals, allowing issues such as their genetic connectivity and clonality to be examined; (3) geochemical advances have now produced coral skeletal proxies for parameters including ocean ventilation history, temperature, nutrient status and pollution; (4) seagoing infrastructure (e.g. remotely operated and autonomous underwater vehicles, coring and observation tools) and cold-water coral expertise have both expanded dramatically over the last decade.

Understanding deep-water, suspension-feeding systems, such as those formed by cold-water corals, requires integrated interdisciplinary research involving marine biologists, chemists, geologists and physicists. Developing appropriate tools for their long-term conservation not only requires understanding

their ecological connectivity but also the policy context in which conservation strategies can further develop. Here social scientists and those working at the interface of science and policy are needed.

Our thematic approach meshes well with this year's SCOR focuses on marine geology, chemistry and palaeoecology, and the long term results will be important for:

- Identifying limitations to predictions in the future state of the ocean
- Climate related studies in preparation for the next IPCC assessment
- Interactions and mechanisms in abrupt climate change

International Approach

Research into cold-water coral ecology and palaeoceanography has in large part been restricted to exclusive economic zones with funding from either national or regional agencies. Research has also typically been driven by individual scientific disciplines with ecological work focussed on describing the diversity of life in these complex habitats and geochemical work focussed on developing accurate dating techniques and novel environmental proxies from coral carbonate. There is now a clear scientific community consensus that to advance our understanding of cold-water coral ecology and realise the full potential of their palaeoceanographic archives we need to work in a unified, interdisciplinary manner at the scale of individual ocean basins and beyond. This consensus was explored through workshops and discussions over the last two years during the development of the Trans-Atlantic Coral Ecosystem Study. The TRACES initiative was launched in February 2008 and was followed by two scientific workshops in Wilmington NC (USA) and Faro (Portugal). These workshops attracted 85 participants from 14 countries who collectively discussed and prioritised the overall TRACES research agenda. Following these two workshops the TRACES Science Plan was prepared by a writing team where both European and North American researchers prepared each chapter. The writing team met at a Science Plan workshop (Woods Hole MA, USA) and the TRACES Science Plan and reports from the earlier workshops are available online (www.lophelia.org/traces).

With this work in place we successfully applied for a European Science Foundation EUROCORES programme and the EuroTRACES call for proposals was opened in January 2010 to researchers from Belgium, Germany, Ireland, Luxembourg, Netherlands, Poland, Portugal, Slovenia and Spain (see www.esf.org/eurotraces). EuroTRACES represents the first dedicated call to support TRACES research, but it is limited to these nine European countries.

To capitalise on the progress with TRACES and EuroTRACES, the GLACES Working Group will start work to develop the first truly international, global research programme on cold-water coral ecology and palaeoceanography. This Working Group will provide the international scientific oversight for this nascent programme. It will form the first Steering Committee responsible for co-ordinating activities, ensuring projects are correctly standardised and maintaining the programme's overall Science Plan. It will produce clear published guidelines and presentational materials summarising each science theme. The Group will keep close links with funding agencies and policy makers to create an international Advisory Board. Finally, it will organise international conference sessions in 2014 and 2015.

Terms of Reference

1. Identify representatives from funding and regulatory agencies to involve in Working Group activities and eventual formation of a GLACES International Advisory Board.
2. Produce and publish field-based guidelines for consistent sampling and reporting of samples and data required to be a GLACES-compliant research cruise.
3. Identify priority areas for research cruises and sampling across the global ocean and compile information on planned cruises.
4. Examine ways that TRACES may expand from its initial North Atlantic focus to become a global study of cold-water corals.
5. Organise international conference sessions at 5th International Symposium on Deep-sea Corals (Netherlands, 2012) and 12th International Reef Symposium (Australia, 2012). Apply for special session at AAAS Annual Science Symposium in 2014 with professional assistance from the Communication Partnership for Science and the Sea (COMPASS) and SeaWeb.

Proposed Meetings
Spring 2011 Initial meeting (Edinburgh, UK)
Video/phone conference at 6 months
Second meeting during International Symposium on Deep-sea Corals (April 2012, The Netherlands)
Video/phone conference at 18 months
Final meeting (AAAS Science Symposium, USA, February 2014)

Working Group Members
Jess Adkins (USA) (co-chair) – palaeoceanography
Scott France (USA) – phylogenetics & deep-sea ecology
Norbert Frank (France) – palaeoceanography
Akihiro Kano (Japan) – palaeoceanography & deep-sea drilling
Alberto Lindner (Brazil) – genetics & biology
J Murray Roberts (UK) (co-chair) – biology & ecology
Laura Robinson (UK) – palaeoceanography
Tim Shank (USA) – genetics & population connectivity
Ron Thresher (Australia) – palaeoceanography & ecology
Claudia Wienberg (Germany) – palaeoceanography & geology

Existing Support
Initial discussions with the European Science Foundation on how this working group could link to EuroTRACES networking activity have taken place. Members of this proposed working group are both partners and associated partners in currently proposed EuroTRACES projects.

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