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INTEGRATED EUROPEAN RESEARCH INTO COLD-WATER CORAL REEFS

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ALL THOSE INVOLVED IN MARINE EDUCATION, CONSERVATION, OR RESEARCH *will at some stage struggle to convince the public or those in power of the value of understanding ecosystems that remain hidden from view at the bottom of the sea. However, in recent decades greater access to survey and visualization tools has given us opportunities to study benthic ecosystems and pass on a shared sense of wonder and excitement to the general public. Here we describe how efforts across the European Union have been focused to study and understand cold-water coral reefs, until recently a curiosity known only to a handful of marine scientists.*

Imagine you are standing on the deck of a ship in the northeast Atlantic. To the south is Scotland and to the east the convoluted coastline of Norway extends up through the Arctic Circle to reach Murmansk in Russia. In the summer, you are bathed in 20 hours of daylight, but during the winter, the sun will appear above the horizon only briefly. Now imagine that you are able to peer through 300 m of seawater beneath the ship to the seafloor. What might you see? Perhaps a few fish like cod or tusk making stately progress through the chilly 8°C Atlantic waters. Pull further back and you begin to see occasional boulders dropped by icebergs in the last ice age. Further back still, and the huge scars gouged by these icebergs as the ice sheet retreated from northern Europe 12,000 years ago become visible. On some of these scars, you begin to make out clusters of white rocky outcrops. Move in to take a closer look and you quickly realize these weren't rocks at all but intricately branching reefs growing to form what look like giant white cauliflowers on the seabed.

These are coral reefs formed predominantly by a species called *Lophelia pertusa*. Of course, we can't peel back 300 m of seawater like this, but by using sophisticated sonar we can now survey the seafloor using sound waves and gradually build a map of the shape and structure of the seafloor (Figure 1). These acoustic techniques, coupled with research submersibles able to navigate the complex reef structures on the seabed, are allowing researchers unparalleled access to these hidden ecosystems. Cold-water coral reefs aren't only found off the Norwegian coast, they extend along the ocean margins and on underwater mountains or seamounts around the world (Freiwald et al., 2004).

EUROPE'S OCEAN MARGIN RESEARCH CONSORTIUM

From 2000 to 2003 the European Union supported a family of deep-water marine research projects designed to find out more about the geology and biology of cold-water coral reefs. Through the fifth Framework Programme, European universities and marine research institutes teamed up to focus research efforts onto a series of sites along Europe's Atlantic margin. The GEOMOUND and ECOMOUND projects examined the geological processes underlying the formation of giant carbonate mounds. These massive seabed mounds were first discovered just over 10 years ago in the Porcupine Seabight, southwest of Ireland. Using geophysical tools to make profiles through the seafloor, geologists discovered clusters or provinces of giant mounds up to a mile in diameter and 100 m high. When the first cameras were lowered onto these mounds, some were found to support diverse cold-water coral reefs. The biology and ecology of cold-water coral reefs was the focus of a third European project, the Atlantic Coral Ecosystem Study (ACES).

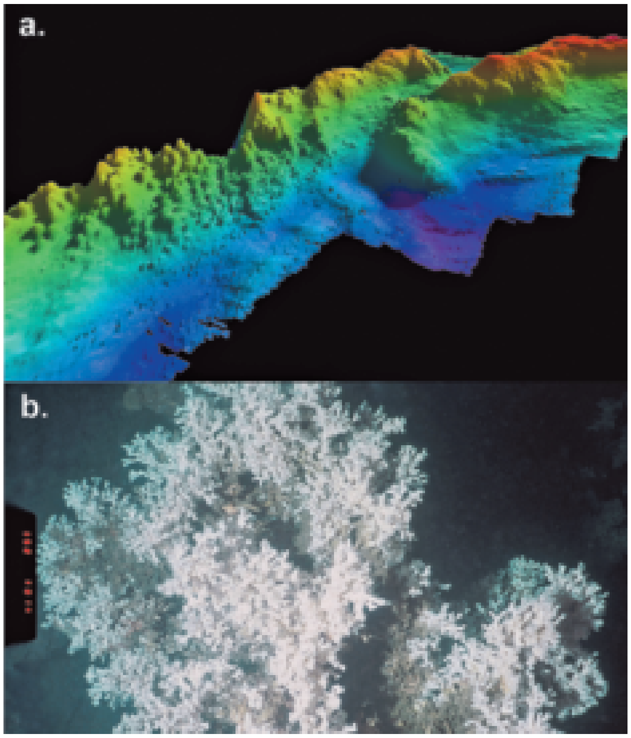

Figure 1. (top: a) Multibeam echosounder survey showing the characteristic seabed mounds formed by a *Lophelia* reef. (bottom: b) Live colonies of *Lophelia pertusa* form these mounds.

Figure 2. Study sites for the European Atlantic Coral Ecosystem Study.

The ACES project studied a series of cold-water coral sites from the Galicia Bank off Spain to the Sula Ridge on the mid-Norwegian continental shelf (Figure 2). Biologists, chemists, and geologists from six nations provided a diverse range of expertise, equipment, and research vessels to tackle the major interdisciplinary themes of the project. These themes included: mapping and describing the physical and biological characteristics of cold-water coral ecosystems, assessing sediment and current dynamics, coral biology and behavior, and coral sensitivity to natural and anthropogenic stressors.

These research themes were intimately linked with the goals of identifying conservation concerns and management issues affecting cold-water corals, increasing public and political awareness of these issues, and making recommendations for the sustainable use of cold-water coral ecosystems. Thus, at its outset, ACES was designed with both scientific and environmental management issues in mind. This approach has proved very effective in raising the profile of an ecosystem otherwise out of sight and out of mind.

NEW FINDINGS

By integrating cold-water coral research across Europe, the ACES project gave individual marine scientists access to the large-scale infrastructure they needed to work on an ecosystem found beneath many hundreds or even thousands of feet of water in the challenging environment of the northeast Atlantic. Ask the most basic question about any deep-water ecosystem–what lives there, for example–and the logistical problems and expense of collecting the data needed to test your hypotheses quickly spiral. Simply gathering a sample of cold-water coral and its associated fauna from the surface of a carbonate mound will require an offshore research vessel with a crew of between 20 and 100, the technology to find your target over 600 m beneath the hull, and the equipment to collect, transport, and deliver the sample to scientists anxiously waiting on deck. Manned submersibles, unmanned remotely operated vehicles (ROVs), and benthic landers have provided researchers with the technology to survey the reefs, put instruments in place, and recover samples–safely and without damaging the reef ecosystem (Figure 3). Over its three years, the ACES project used 11 research vessels, completed 19 offshore cruises and 73 inshore cruises, and gave participating scientists 361 days at sea to study cold-water coral reefs. This intense research effort has revealed some exciting new aspects of cold-water coral reefs.

The skeletons of cold-water corals like *Lophelia pertusa* form a complex framework that can trap and retain seafloor sediments. As the coral framework grows, it can develop over time to produce a reef. *Lophelia* reefs are characterized by broad zones of live coral colonies, areas of dead coral framework, and deposits of coral rubble mixed with sediment. This diversity of seabed structures, combined with the complexity of the coral framework, produces a huge range of physical niches for different organisms to occupy. This is reflected in the high biodiversity associated with cold-water coral reefs. The ACES project compiled a list of over 1,300 species recorded from cold-water coral reefs in the northeast Atlantic. However, our understanding of how these species interact with one another in the reef ecosystem remains poorly developed. The highest recorded species diversity is associated with the coral rubble habitats, where suspension-feeding epifaunal taxa colonize coral rubble and infaunal taxa are found in the sediment caught within coral rubble. Here, sponges, bryozoans, tunicates, and crinoids are often abundant, but our ability to produce quantitative studies of biodiversity are often hampered by the difficulties of collecting intact reef samples.

Relatively few species occur in the live coral habitat, where the coral surface is well-protected from settling organisms by a layer of mucus. Despite this, a few animals are able to survive among live *Lophelia* polyps by adopting different strategies. For example, the foraminiferan *Hyrrokkin sarcophaga* seems to parasitize live polyps. It is able to overcome the polyp's defenses and embeds itself into the coral's skeleton where it appears to grow and develop fuelled by its host polyp (Cedhagen, 1994). On the other end of the spectrum, *Lophelia* corals form a mutualistic symbiosis with the polychaete worm *Eunice norvegica*. This large polychaete, growing to over 10 cm in length, forms a delicate parchment tube that entwines with the coral's branching skeleton and is eventually calcified by the coral. By studying the coral-polychaete association in aquaria, researchers have observed some intriguing features of this relationship. The polychaete appears to clean the coral polyps, sometimes to steal food caught in their tentacles (Mortensen, 2001), and, surprisingly, is able to move adjacent coral fragments and join them. This effectively allows sessile corals some limited mobility and seems likely to enhance the rate of reef aggregation and patch formation (Roberts, 2005). These are some of the first glimpses of the natural history of cold-water coral reefs.

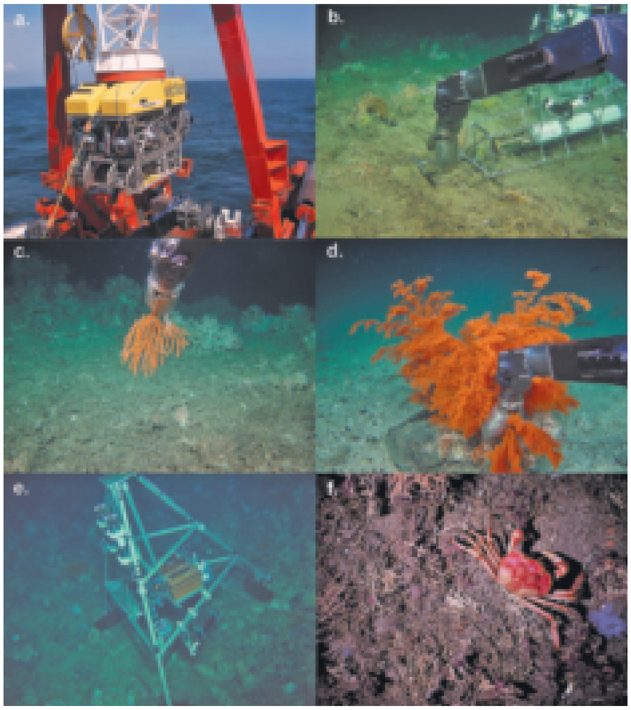

Figure 3. Submersibles and benthic landers provide the technology to study cold-water coral ecosystems at great water depths. A giant carbonate mound at 2400 feet water depth is shown. (a) The *Victor 6000* ROV. (b) An ROV manipulator arm used to move a current meter and put it into position. (c,d) An ROV manipulator arm used to gather precise samples of gorgonian and antipatharian corals. (e) The SAMS photolander deployed on the Galway carbonate mound to record environmental variability and take time-lapse photographs. (f) A lander photograph showing a benthic crab (probably *Geryon (Chaceon) affinis*) on the coral-covered surface of the carbonate mound.

The ACES project has shed light on many other important aspects of cold-water coral biology in the northeast Atlantic. For example, it is now known that *Lophelia* colonies are separate sexes and they seem to be preparing to spawn in the first or second month of the year (Waller, 2005). Using molecular genetic techniques to compare coral populations along the European margin, researchers found that certain coral populations, such as those associated with the Darwin Mounds in the northern Rockall Trough, are composed predominantly of genetic clones, suggesting that they will be slow to recover if damaged (Le Goff-Vitry and Rogers, 2005). Fundamental information of this sort not only improves our basic scientific understanding of these species, but provides valuable, practical insights to help conservation managers when they consider strategies to form linked networks of marine protected areas (MPAs).

Deep-water ecosystems in the northeast Atlantic are profoundly influenced by the seasonal input of food to the benthos following spring phytoplankton blooms. As well as providing evidence that the dominant reef framework-forming corals reproduce on a clear seasonal cycle, research from the ACES consortium investigated the seasonality of food flux to the coral community. Using a benthic lander equipped with a sediment trap and fluorometer, Duineveld and colleagues (2004) recorded the seasonal flux of food particles to the coral community of the Galicia Bank. By analyzing stable isotopic composition, they were able to show that this community feeds on a mixed diet of phytoplankton and zooplankton. Looking at trophic relationships in more detail, Kiriakoulakis and colleagues (2005) analyzed the lipid and isotopic composition of corals and particles trapped by pump sampling near the seabed. Their results suggest that some species, such as *Lophelia pertusa*, could be more carnivorous in their diet than others, such as *Madrepora oculata*, which may be more likely to feed on a higher proportion of algal debris. Using a lander equipped with time-lapse cameras, current meters, and optical instruments, Roberts and colleagues (2005) recorded the density of large, mobile animals near a *Lophelia* reef complex in addition to measuring water currents and estimating sediment movement. Such *in-situ* observations and measurements are fundamental to developing our understanding of the natural dynamics and variability of cold-water coral reef environments. By understanding this variability, we begin to predict how sensitive these species may be to environmental impacts and changes.

PUBLIC AWARENESS AND CONSERVATION EDUCATION

Until the late 1990s, cold-water coral reefs were known only to a few specialists. Increased research interest has improved their visibility in the scientific community, but it is the reports of damage inflicted by bottom trawling that have attracted the most media and political attention. It is now clear that many, if not most, cold-water coral habitats show scars inflicted by trawling for deep-water fish stocks. In 2002, Norwegian researchers estimated that between 30 and 50 percent of Norway's cold-water coral reefs had been damaged by bottom trawling (Fosså et al., 2002). From the other side of the globe, heavily-fished seamounts near Tasmania were shown to be stripped of their suspension-feeding coral fauna (Koslow et al., 2001). During the ACES project, several research teams found evidence of direct physical damage to cold-water coral reefs caused by bottom trawling as well as lost fishing nets and ropes (Figure 4).

As similar evidence has accumulated around the world, legislation to limit bottom trawling in areas where cold-water coral reefs are found has been put into effect. (Examples of such MPAs and the processes followed in their designation can be found in Freiwald et al., 2004). Many vulnerable cold-water coral reef habitats are found on the high seas, beyond the jurisdiction of any single nation, making their protection and conservation uncertain. However, the conservation of the Darwin Mounds in waters fished by several member states of the European Union provides an interesting case study of offshore conservation involving several nations. Discovered in 1998 at water depths of almost 1,000 m, the Darwin Mounds support scattered colonies of cold-water corals and were known to have been damaged by bottom trawling (Masson et al., 2003).

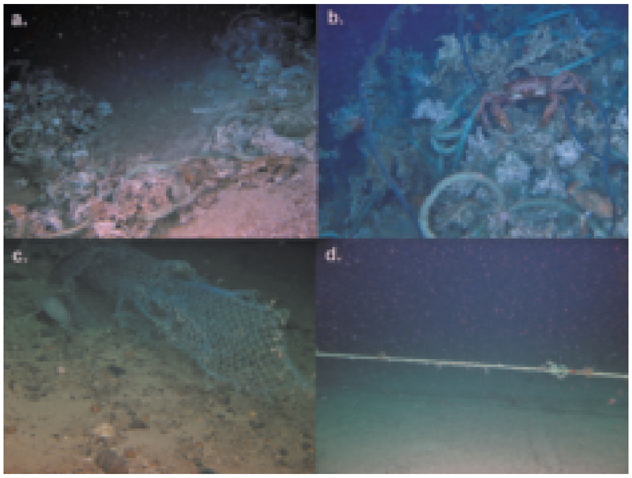

Figure 4. Fishing impact recorded on carbonate mounds in the Porcupine Seabight. (top: a,b) Coral debris caught in a lost trawl net. (bottom: c,d) Lost fishing net and lines.

In 2003, following a formal request from the UK government, the European Commission imposed an emergency measure to close this area to bottom fishing for six months under the European Common Fisheries Policy. This emergency closure was repeated for a further six months, and from August 2004, bottom-trawl fishing was permanently banned from the area of the Darwin Mounds. The UK government now intends to designate this area as a Special Area of Conservation following the European Union Habitats Directive.

The issues of marine conservation are many and varied. Offshore in high seas areas, these issues are only compounded by the legal and diplomatic complexities of agreeing to establish MPAs in international waters. The work to protect the Darwin Mounds from bottom-trawl fishing shows that agreement on the conservation of cold-water coral areas can be reached in an area fished by several European nations. How successfully this approach translates to truly international waters farther offshore remains to be seen.

NEW DIRECTIONS

From 2005-2009 the European Union sixth Framework program includes a large-scale integrated project, Hotspot Ecosystem Research on Europe's Deep-Ocean Margins (HERMES), focusing on four broad ecosystems:

- cold-water coral ecosystems and carbonate mounds;
- cold seep and microbially driven ecosystems;
- canyon ecosystems; and
- open-slope ecosystems.

These will be studied by a consortium of 45 partners from 15 European nations (see Weaver et al., 2004 for summary).

Work on cold-water coral ecosystems and carbonate mounds will develop themes started by the ACES, ECOMOUND, and GEOMOUND projects, and use the latitudinal spread of coral ecosystems from the Norwegian margin to the Mediterranean Sea to study topics from biodiversity trends to trophic relationships. Researchers will benefit from access to research vessels and equipment available in other nations. Life-history studies will be completed at specific study sites and the physical characteristics important in cold-water coral reef sites will be assessed using long-term benthic landers and moorings. Sites where cold-water corals are known to exist close to active hydrocarbon seepage, such as near pockmarks on the Norwegian Shelf or mud volcanoes in the Gulf of Cadiz, will be used to examine any direct coupling between coral communities and the geosphere. The potential environmental archive stored in the skeletal remains of cold-water coral reef fauna will be used to examine mixing processes between productive surface waters and the deeper ocean environment. The colonization of cold-water coral ecosystems after the retreat of ice sheets will be followed using radiocarbon and uranium-thorium dating techniques (see Tsao, this issue, for more).

The overarching objectives of the HERMES project are to closely link scientific assessment and measurement with the efforts of ecosystem modelers to produce integrated models to quantify geochemical or food-web flows. Such objectives are intended to provide fundamental new insights into the functioning of Europe's oceanic margin ecosystems that will inform environmental policy. However, to really understand the ecological significance of cold-water coral reefs, one needs to consider their occurrence and potential linkage on an ocean basin scale. As research in the U.S. and Canada to map and characterize cold-water coral reefs develops, it is time to consider an integrated trans-Atlantic approach to understanding these largely hidden ecosystems.

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FOR MORE RESOURCES:

Scottish Association of Marine Sciences:
www.sams.ac.uk

The Atlantic Coral Ecosystem Study (ACES):
www.cool-corals.de/

HERMES Project:
http://www.eu-hermes.net/

For more information on Cold-Water Corals:
www.lophelia.org

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Did You Know?

You can help...

Bottom trawling is the gravest human-induced threat to the survival of deep-sea corals. This destructive fishing method crushes and uproots fragile corals, and leaves innumerable fishes that live in and around corals homeless. You as a consumer can help stop this habitat demolition by opting not to purchase seafood caught by destructive fishing gears!

Want to be savvy in your seafood choices? Learn how at:
Seafood Watch program of Monterey Bay Aquarium (http://www.mbayaq.org/cr/seafoodwatch.asp);
Blue Ocean Institute (http://www2.blueocean.org/Seafood_Detail/36); and
Seafood Choices Alliance (http://www.seafoodchoices.com).