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Cold-water coral reefs

Out of sight – no longer out of mind

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Messages

'The planet's life-support systems are the source of stability for all peoples, all nations. Cold-water coral reefs are emerging as a new piece in this vital web of life which now requires our urgent attention.'

Klaus Toepfer, Executive Director, UNEP

'Cold-water coral reefs form a remarkable and truly valuable ecosystem off our coasts which our nations must work together to protect.'

Minister Martin Cullen, Department of the Environment, Heritage and Local Government, Ireland

'Cold-water coral reefs are vitally important ecosystems, with immense biodiversity value; a treasure that must be preserved for future generations. The UK has secured a permanent ban on bottom trawling over *Lophelia pertusa* cold-water coral reefs in the Darwin Mounds through action at European Community level. However, further international cooperation is needed to conserve vulnerable marine ecosystems in areas beyond national jurisdiction.'

Elliot Morley, Minister for Environment and Agri-Environment, Defra, United Kingdom

'These reefs are underwater oases, biological treasures and important habitats for fish. It is amazing that such major new discoveries can still be made. The reefs are slow growing and extremely fragile, and must, as a matter of urgency, be protected from further damage.'

Børge Brende, Minister of the Environment, Norway

'At last, advanced science and world leaders recognize that the oceans' resources are finite and now require thoughtful stewardship and intelligent management. We call upon government and industry leaders to take urgent action to conserve the spectacular and unique ecosystems of cold-water coral reefs.'

Dr Claude Martin, Director General, WWF International

Foreword

Only in the last 20 years has the sea given up one of its deepest secrets. Far beneath the sunlit surface corals thrive, close relatives of the species found along tropical shores and familiar to scuba divers the world over, but adapted to cold, dark, deep water. Found in all the world's oceans, almost from pole to pole, they form physical structures, even reefs that rival in size and complexity those in warmer, shallower waters. These cold-water reefs are usually far beyond the reach of divers and require specialized submersible vehicles to collect samples, to photograph and study the ecology of the corals themselves and the dazzling array of animals that depend upon them.

Undoubtedly this is why cold-water corals have been outside our consciousness for so long. Remote from the daily lives of most people, only a few scientists have studied them, and we are grateful to the five leading members of this community for their efforts in preparing this report on 'Cold-water coral reefs'. Through their work and that of others we now know that cold-water coral reefs are important and ancient reservoirs of marine biodiversity and are essential nursery habitats for many commercially important fish species. We are also now aware that these reefs are within the reach of one of the most destructive human activities in deep waters, bottom trawling, and so are at serious risk.

The gaps in knowledge are also brought to our attention by this report. We do not yet know how much coral reef covers the deep ocean floor, or even where reefs occur outside a few well-studied locations. While we do understand the threats to cold-water reefs, policy makers do not yet have all the necessary regulatory tools to protect them. I therefore welcome the recommendations made by the authors. As a result of their work, cold-water corals – for so long out of sight – will no longer be out of mind.

Mark Collins

Mark Collins
Director
UNEP-WCMC

Executive summary

Over the last few decades the exploration of deep-water environments using new technologies has revealed insights into parts of our planet that challenge conventional wisdom. Coral reefs, once thought to be restricted to warm shallow waters in tropical and subtropical regions, have been found found in dark, cold, nutrient-rich waters off the coasts of 41 countries so far. They occur in fjords, along the edge of the continental shelf and around offshore submarine banks and seamounts in almost all the world's oceans and seas. To date, most studies have been carried out in high latitudes, where cold-water reefs occur at depths of hundreds of metres to just 40 metres. However, cold-water corals are increasingly being observed in the tropics, where they thrive at greater depths.

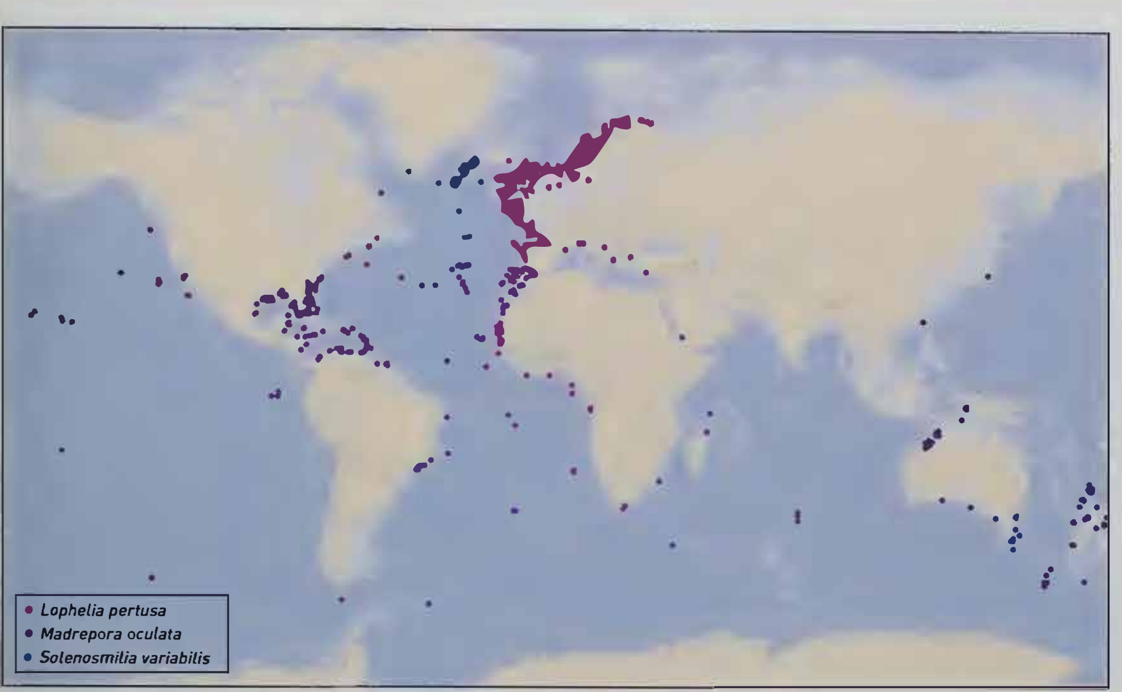
Reef-building and habitat-forming corals in cold waters are derived from several systematic groups. The most important of these are the colonial stony corals (Scleractinia), true soft corals (Octocorallia), black corals (Antipatharia) and calcifying lace corals (Hydrozoa). Several species of these groups create reefs and three-dimensional, forest-like structures on the sea floor, comparable to their warm-water cousins in size and complexity. These cold-water reefs and structures act like islands in the normally flat, featureless and muddy surroundings and harbour a distinct and rich ecosystem, providing niches and nursery grounds for a variety of species, including commercial fish species.

Cold-water coral ecosystems are long lived, slow growing and fragile, which makes them especially vulnerable to physical damage. Regardless of the depth at which these reefs occur, the impact of human activities is evident in almost every survey undertaken. Bottom fisheries, especially using trawls and heavy gear, have already destroyed or scarred several reefs, and represent one of the major threats to cold-water corals. Other documented and potential sources of impact are hydrocarbon and mineral exploration and production, cable and pipeline placement, repair and dumping.

We are still only beginning to understand the principal ecological aspects of cold-water corals, including the environmental factors (temperature, salinity, nutrition) and biological processes (reproductive biology, molecular genetics, predation, parasitism and bioerosion) which regulate their life and distribution. It is


Fosså et al., 2000

A model of a cold-water reef



Global distribution of cold-water coral reefs: points on the map indicate observed reefs of varying size and stages of development, but not the actual area covered. The high density of reefs shown in the North Atlantic most probably reflects the intensity of research in this region. Further discoveries are expected worldwide, particularly in the deeper waters of subtropical and tropical regions

UNEP-WCMC, sourced from A. Freiwald, from various sources

evident that there are large gaps in our knowledge of cold-water coral reefs which need to be closed by further mapping and integrated, multidisciplinary research including modelling of distribution, geology, biology, ecology and the assessment of human impact.

However, already the scientific results and findings clearly demonstrate that cold-water coral ecosystems are important biodiversity hotspots and a biological resource with intrinsic and socio-economic value. In the light of the documented and potential threats, there is an urgent need to prevent further degradation of these vulnerable reefs.

Information campaigns and strategic programmes, largely driven by academia and non-governmental organizations have in recent years increased the awareness and recognition of the international community and stakeholders of the importance of protecting vulnerable marine ecosystems and biodiversity within and particularly beyond national boundaries.

At the time of preparing this report, the need to conserve, protect and manage cold-water coral reefs sustainably is being recognized by governments and major international fora/conventions. Cold-water coral reefs and other high-seas habitats are starting to appear on political agendas and to influence political decision making. Various countries and regional bodies have adopted, or are in the process of establishing, regulations and measures for the protection and management of vulnerable deep-water habitats, including cold-water coral reefs. These range from the use of fisheries regulations to requirements for environmental impact assessments and the development of specific management plans and regulations, including protected areas.

In support of these emerging actions, the report concludes with a set of recommendations aimed at providing national and international policy makers and stakeholders from developed and developing countries with a 'toolbox' of options to be considered in the conservation, protection and sustainable management of cold-water corals within and beyond the limits of national jurisdiction. A total of 24 recommendations have been made (page 63) covering information management and research; improving monitoring and assessment; regulations and measures, including precautionary, preventative and interim measures; and international coordination and awareness.

Contents

1. Introduction

Coral reefs have long been recognized as one of the most spectacular ecosystems on Earth, forming a broad belt around the subtropical-tropical zone that is even visible from space. Any geologist or biologist knows that corals are found in shallow, well-lit, nutrient-poor tropical seas where the polyps are packed with symbiotic algae that provide them with energy, help them to grow and produce the calcareous skeletons that eventually form limestone when they die. Tropical coral reefs form complex habitats that act as centres of evolution in providing opportunities for species specialization. These coral reefs support some of the most diverse species assemblages in the marine realm. The survival of shallow-water tropical reefs is currently causing great concern internationally, due to widespread coral bleaching, which may be linked to human-induced climate change, and other threats. To use tropical coral reefs as an example, it is estimated that 60 per cent of reefs are seriously at threat from human activities (Cesar et al., 2003).

Although their existence has been known for centuries, the observation and study of cold-water coral habitats in their natural surroundings began only in the last decade, when scientists around the globe used increasingly sophisticated instrumentation to explore deep-water environments. The use of advanced technology, such as manned and robotic submersibles, has challenged conventional wisdom that coral reefs are confined to shallow and warm tropical and subtropical regions. Scientists have been able to explore a variety of coral ecosystems thriving in deep, dark and cold waters, currently most studied at high latitudes. Some of these cold-water corals construct banks or reefs as complex as their tropical cousins. Through radioactive dating techniques, it is now known that some living banks and reefs which have been found are up to 8 000 years old. Geological records show that cold-water coral reefs have existed for millions of years.

Cold-water coral systems can be found in almost all the world's oceans and seas: in fjords, along the edge of the continental shelf, and round offshore submarine banks and seamounts. Living without light and in relatively nutrient-rich seawater, cold-water coral ecosystems function in a very different way from shallow-water coral systems. Cold-water corals, living at depth in the dark, have no light-dependent symbiotic algae (marine plants) and therefore depend on the supply of current-transported particulate organic matter and zooplankton for their food. To capture the food efficiently, many cold-water corals produce tree-like branching structures supporting colonies of polyps sharing a

IFREMER, ARK-19/3a, 2003

Cold-water corals and glass sponges, 850 m deep, off Ireland

common calcium carbonate frame. These structures form the complex three-dimensional habitat that provides a multitude of micro-niches for the associated animal community.

The most spectacular reefs are constructed by stony corals down to depths of several hundred metres below sea level. These stony corals form colonies that vary tremendously in size from small, scattered colonies no more than a few metres in diameter to vast reef complexes measuring several tens of kilometres across. Such cold-water reefs are constructed by only a few coral species. In the North Atlantic, the Mediterranean Sea and the Gulf of Mexico, *Lophelia pertusa* and *Madrepora oculata* are the most abundant reef builders. The continental slope off Atlantic Florida and North Carolina is the home of reefs constructed by *Oculina varicosa*. In the southern hemisphere, especially around Tasmanian and New Zealandian seamounts and oceanic banks, *Goniocorella dumosa* and *Solenosmilia variabilis* are the most prominent reef-building species.

Cold-water coral ecosystems are not exclusively the domain of stony corals. The North Pacific, for example, is known to harbour fabulous examples of soft coral ecosystems, the so-called octocoral gardens that are among the richest and most strikingly colourful communities found in deep waters at high latitudes.

It is only recently that we have begun to understand some of the complexities of these hidden cold-water coral ecosystems. Like their tropical counterparts, cold-water corals are home to thousands of other species, in particular animals like sponges, polychaetes (or bristle worms), crustaceans (crabs, lobsters), molluscs (clams, snails, octopuses), echinoderms (starfish, sea urchins, brittle stars, feather stars), bryozoans (sea moss) and fish.

Conrad Neumann, University of North Carolina

***Lophelia* growing on a lithoherm, Florida Strait**

Recent discoveries are changing our knowledge of reef-forming processes and where they occur. Researchers are beginning to realize that cold-water reefs belong to a continuum where, at one end, the evolution of light-dependent symbiosis has allowed corals to survive under low nutritional regimes in the shallow tropics and, at the other end, a sufficient supply of food allows corals to thrive as carnivorous organisms in deep and cold waters.

Sadly, as we expand our understanding of the distribution, biological dynamics and rich biodiversity of cold-water ecosystems, we are also gathering evidence that shows clearly that these vulnerable ecosystems are being damaged by human activities.

Undoubtedly, the greatest and most irreversible damage is due to the increasing intensity of deep-water trawling that relies on the deployment of heavy gear which 'steamrollers' over the sea floor. There is also concern about the potential effects of oil and gas exploration, in particular the potentially smothering effects of drill cuttings.

This UNEP report summarizes the recent and rapid increases in our understanding of cold-water coral reefs in order to provide comprehensive and up-to-date information to political decision makers, environmental stakeholders and to the public about cold-water ecosystems. It identifies gaps in knowledge, especially related to the proper management of such ecosystems. The report presents scientific findings, addresses threats to the ecosystem and socio-economic issues, and provides recommendations for measures that can be taken for the protection, conservation and sustainable management of cold-water coral reefs. Many of the issues concerning the cold-water environments introduced here are global and interconnected. There are, however, a number of relatively localized areas, geographic features, habitats and coral communities that, by virtue of their living and non-living resources, may be of particular scientific, societal or economic interest.

Cold-water coral reefs have recently become an important topic on the political agenda of various national and international bodies due to the realization that many of the most spectacular examples discovered so far could be gone in less than a generation... if we do not act quickly. Cold-water coral reefs are out of sight – but no longer out of mind.

Table 1: Similarities and differences between cold-water and warm-water coral reefs

	Cold-water coral reefs	**Warm-water coral reefs**
Distribution	Global – potentially in all seas and at all latitudes	Global – in subtropical and tropical seas between 30°N and 30°S
Number of states, countries and territories with corals	41 so far	109
Coverage	Unknown – but studies to date indicate global coverage could equal, or even exceed, that of warm-water reefs	284 300 km^2
Country with highest coral reef coverage	Unknown – at least 2 000 km^2 in Norwegian waters alone, according to a rough estimate	Indonesia (51 020 km^2)
Largest reef complex	Unknown – Røst Reef (100 km^2) discovered in 2002 in northern Norway is so far regarded as the largest	Great Barrier Reef (more than 30 000 km^2), Australia
Temperature range	4°-13°C	20°-29°C
Salinity range	32-38.8‰	33-36‰
Depth range	39-1 000+ m	0-100 m
Nutrition	Uncertain, but probably suspended organic matter and zooplankton	Suspended organic matter and photosynthesis
Symbiotic algae	No	Yes
Growth rate	4-25 mm/year	Up to 150 mm/year
Number of reef-building coral species	Few – only 6 primary species	Around 800
Reef composition	Mostly composed of one or a few species	Mostly composed of numerous species
Age of living reefs	Up to 8 000 years	6 000-9 000 years
Status	Unknown – most reefs studied show signs of physical damage; some reefs in NE Atlantic completely lost due to bottom trawling	30% irreversibly damaged; another 30% at severe risk of being lost in the next 30 years
Rate of regeneration/ recovery	Unknown – slow growth rate indicates that if regeneration/recovery is possible at all, it might take decades to centuries for a damaged reef to regain its ecological function	Slow (years to decades) – in most cases, regeneration/recovery will lead to reduced coral diversity, a shift in coral species composition or even a change to an algae-dominated ecosystem, especially where human impact is evident
Main threats: natural and induced by climate change	Unknown – climate change could cause changes in current systems and affect food supply in deeper waters	Increased episodes of higher than normal sea temperatures leading to more widespread and lethal coral bleaching
Main threats from human activities	❑ Bottom fisheries ❑ Oil and gas exploration and production ❑ Placement of pipelines and cables ❑ Others, e.g. pollution, research activities, dumping	❑ Overfishing and destructive fishing (especially dynamite and cyanide fishing) ❑ Pollution and sedimentation from land-based sources and coastal development ❑ Tourism and anchoring
Ecological importance	Reefs provide habitat, feeding grounds, recruitment and nursery functions for a range of deep-water organisms, including commercial fish species. The number of species depending on or associated with these reefs, and their full ecological importance/value, is still unknown	An estimated 1 million plant and animal species are associated with warm-water coral reefs. There are approximately 4 000 coral reef fish species (a quarter of all marine fish species)
Socio-economic importance	Unknown – but initial observations suggest importance for local fisheries, including coastal line/net fisheries and deep-water fisheries (especially around seamounts)	Reefs provide coastal protection and a source of livelihood for more than 1 billion people; net potential benefits provided by reefs are estimated at US$30 billion/year
International awareness and attention	Increased over last 2-3 years	Increasing over last 1-2 decades, and especially after bleaching events in the 1990s; more than100 non- and inter-governmental organizations involved

Data on warm-water coral reefs taken from Spalding et al., 2001, Veron, 2000, Cesar et al., 2003, Birkeland, 1996, Wilkinson, 2002

2. Description and distribution

CORALS OCCURRING IN COLD-WATER ENVIRONMENTS

Corals as habitat-forming organisms in cold waters derive from several systematic groups belonging to the Cnidaria (Box 1). This report is most concerned with corals which build reefs and provide the habitat for a diverse associated fauna. These species include the colonial stony corals (Scleractinia), true soft corals (Octocorallia), black corals (Antipatharia) and calcifying lace corals (Hydrozoa). Over generations these dense populations eventually form reefs or coral-rich grounds.

Cold-water stony corals (Scleractinia)

Stony corals that occur in cold and usually deep waters and almost dark conditions tend to be non-symbiotic. They lack the symbiotic light-dependent algae that are characteristic of warm-water corals. At present about 1 334 stony coral species are described of which the majority, 672 species, belong to the non-symbiotic group (Cairns, 2001). Only 26 per cent of non-symbiotic corals exist in water depths shallower than 40 metres (m), while the majority thrive in deeper waters down to abyssal depths (from 4 000 to 7 000 m), with the deepest reported at 6 328 m (Keller, 1976).

Most of the non-symbiotic stony corals consist of a single polyp encased by a calcareous skeleton and therefore are called solitary corals. In contrast, 26 per cent (174 species) are colonial corals, but only a few of them have the potential to form constructional frameworks (Cairns, 2001). The spatial range and density of these coral framework accumulations on the seabed varies: there are areas where colonial scleractinian corals form more or less dense aggregations, from smaller reef patches, a metre high and metres or tens of metres wide, to much larger reefs tens of metres high and kilometres in length. The most important cold-water coral reef builders are: *Lophelia pertusa*, *Madrepora oculata*, *Enallopsammia profunda*, *Goniocorella dumosa*, *Solenosmilia variabilis* and *Oculina varicosa*. These cold-water reefs are in many ways comparable to warm-water coral reefs in terms of their three-dimensional topography, ecological function and mode of growth (Rogers, 1999).

Box 1: What are Cnidaria?

The name Cnidaria derives from the Greek word 'cnidos' meaning stinging nettle. When touched, many cnidarians will eject barbed threads tipped with poison (nematocysts).

Four major groups of cnidarians are known: Anthozoa, which includes true corals, anemones and sea pens; Cubozoa, the amazing box jellies with complex eyes and potent toxins; Hydrozoa, the most diverse group with siphonophores, hydroids, fire corals and many medusae; and Scyphozoa, the true jellyfish. Cold-water coral ecosystems are formed by members of the true corals: the stony corals (Scleractinia), the true soft corals (Octocorallia), black corals (Antipatharia) and members of the Hydrozoa, the lace corals (Stylasteridae).

Lophelia pertusa

L. pertusa is the most common habitat-forming, reef-building cold-water coral. It forms bush-like colonies measuring several metres across and consisting of thousands of coral polyps. As the colony develops, adjacent branches tend to join together, thus considerably strengthening the entire framework. Although *Lophelia* is known as 'white coral', there are several colour variations of the generally translucent tissue, with yellow, orange or red patterns.

The full extent of the present geographic distribution of *L. pertusa* is still unknown. This coral has been found most frequently in the North Atlantic but has a cosmopolitan distribution (Zibrowius, 1980) (Figure 1). It occurs throughout the Atlantic, taking in parts of the Mediterranean Sea, the Gulf of Mexico and the Caribbean Sea. It is also known from a few locations in the Indian Ocean and the Pacific Ocean (Zibrowius, 1973; Cairns, 1984).

A dense girdle of *Lophelia* stretches from the southwestern Barents Sea along the eastern Atlantic continental margin down to West Africa. Evidence is emerging from ongoing scientific deep-sea expeditions of a similar belt along the western margin of the Atlantic, from off Nova Scotia to the Florida Strait and into the Gulf of Mexico. The northernmost *Lophelia* occurrence known is in the southwestern Barents Sea near Hjelmsøybank at 71°21'N, 24°00'E (Fosså et al., 2000), while the southernmost location is the subantarctic Macquarie Ridge off New Zealand at 51°S, 162°01'E (Cairns, 1982). The shallowest occurrence of live *Lophelia pertusa* is recorded at 39 m depth from the Trondheimsfjord, mid Norway, and the deepest from the New England seamount chain in the North Atlantic, at 3 383 m, and off Morocco, at 2 775 m (Zibrowius, 1980).

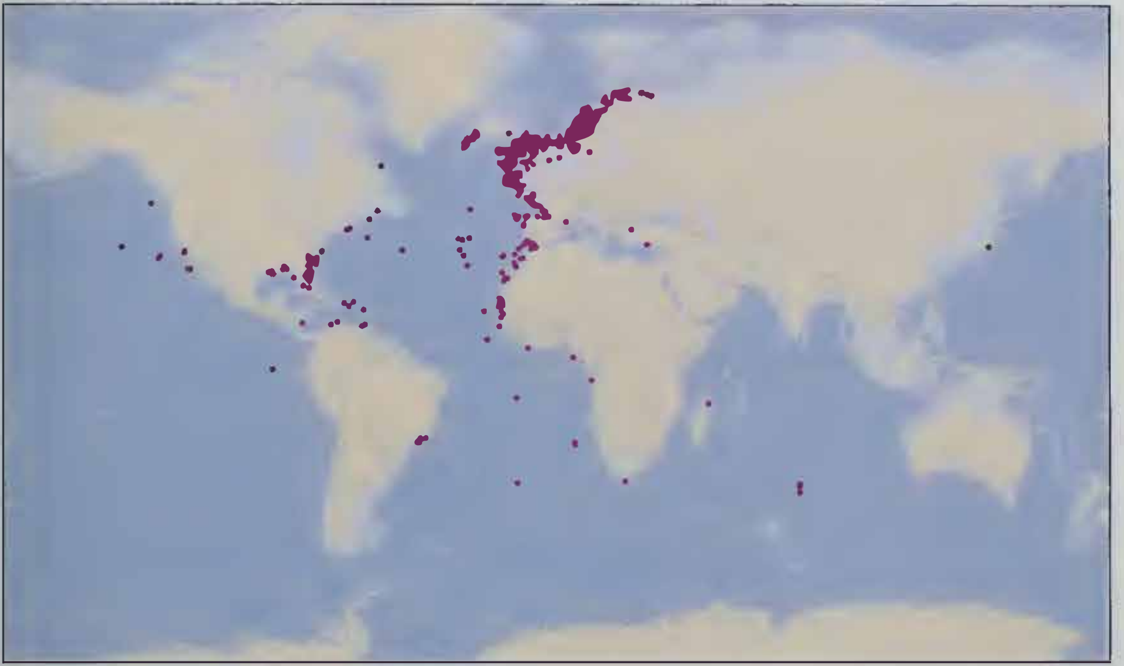


Figure 1: ***Lophelia pertusa*** **occurrences**

UNEP-WCMC, sourced from A. Freiwald, from various sources

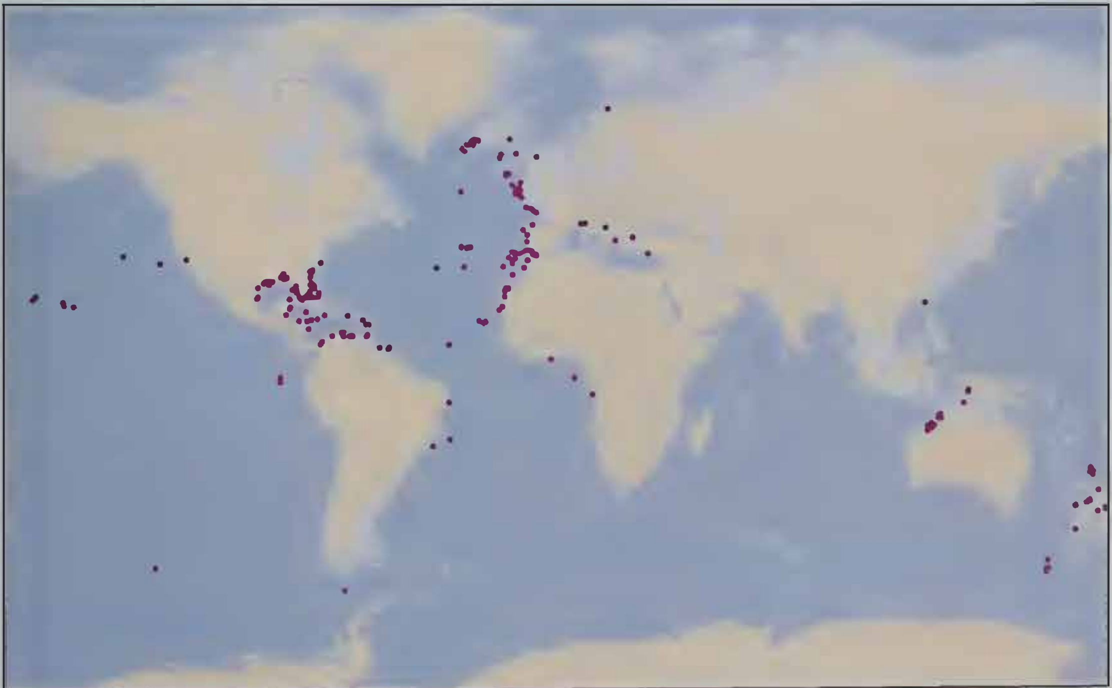


Figure 2: ***Madrepora oculata*** **occurrences**

UNEP-WCMC, sourced from A. Freiwald, from various sources

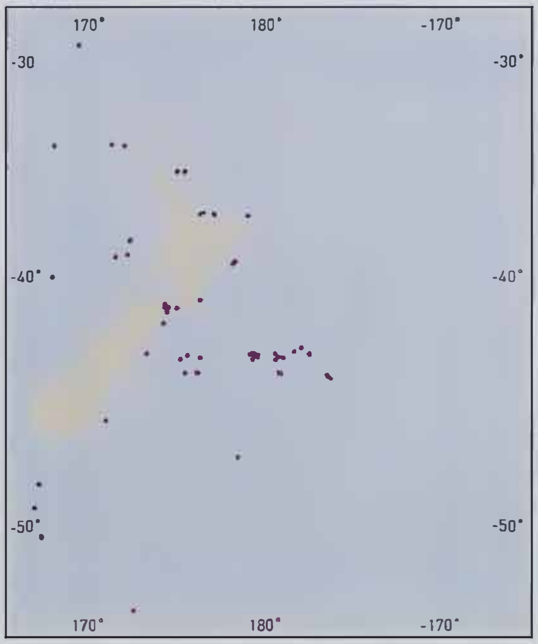


Figure 3: Findings of *Goniocorella dumosa* in New Zealand waters Based on data compiled by Cairns, 1995

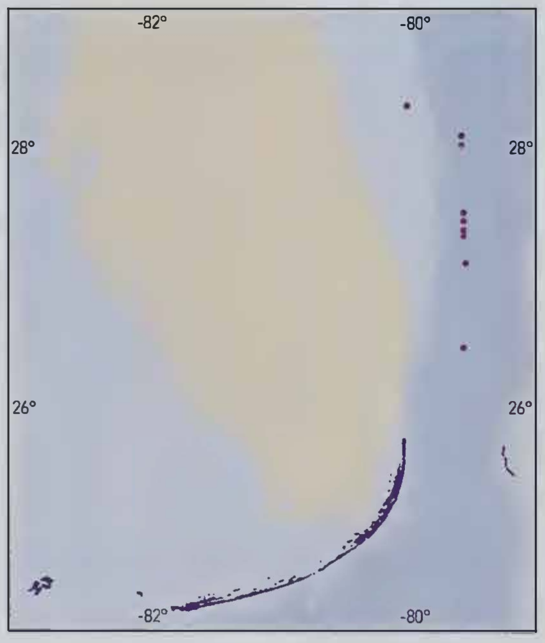


Figure 4: Deep-water *Oculina varicosa* reefs off eastern Florida, with shallow-water corals to the south
UNEP-WCMC, data compiled from Reed, 2002a and Spalding et al., 2001

Madrepora oculata

In contrast to the monospecific genus *Lophelia*, *Madrepora* has developed several species and two of them, *Madrepora oculata* and *Madrepora carolina*, are often associated with cold-water reefs. The branched colonies of *Madrepora* are generally much more fragile than *Lophelia* and tend to break off easily, thus considerably limiting its framework-building capacity. Even in areas where *Madrepora* dominates the coral community, thick reef frameworks do not occur. More often *Madrepora* is associated with reef-building corals such as *L. pertusa* and *Goniocorella dumosa*. Much remains to be learnt on the biological and ecological aspects of this.

Like *Lophelia*, *Madrepora* is a cosmopolitan coral (Figure 2). In the northeast Atlantic and the Mediterranean Sea, *M. oculata* is associated with, or even dominates, the coral community; in the western Atlantic, *M. oculata* overlaps with *M. carolina*. The northernmost recorded occurrence is from the Andfjord, northern Norway, at 69°14'N and 16°41'E (Zibrowius, 1980), and the southernmost from the subantarctic Drake Passage at 59°49'S and 68°52'W (Cairns, 1982). The shallowest live *M. oculata* have been noted off Brazil and from the mid-Norwegian Heltefjord with (unusually shallow) 55 m and 60-120 m, respectively; the deepest occurrences are recorded from the southern Reykjanes Ridge at 1 950 m, and from 1 694 m water depth near the Cape Verde Islands (Zibrowius, 1980).

Goniocorella dumosa

The biology of *Goniocorella dumosa* is poorly known. This coral is restricted to the southern hemisphere, mostly to New Zealand waters and adjacent oceanic banks such as the Campbell Rise and the Chatham Rise (Figure 3; Cairns, 1995). Elsewhere this coral has been recorded from South African, Indonesian and Korean waters. The known bathymetric range is from 88 to 1 488 m with a concentration around 300 and 400 m below sea level.

Oculina varicosa

Oculina varicosa is quite unusual in that it grows both in shallow and deep water (Reed, 1981). The shallow-water variety occurs in the Caribbean Sea, the Gulf of Mexico and the Atlantic from Florida to North Carolina at depths of 2 to 45 m. It appears golden brown because the tissue is packed with light-demanding symbionts. In the surf zone of the waves, *Oculina* produces wave-resistant colonies with stout branches. The colony shape varies from spherical to bushy or dendroid measuring 10 to 150 cm in diameter. The annual growth rate is 1.1 cm on average in shallow waters but increases to 1.6 cm in the

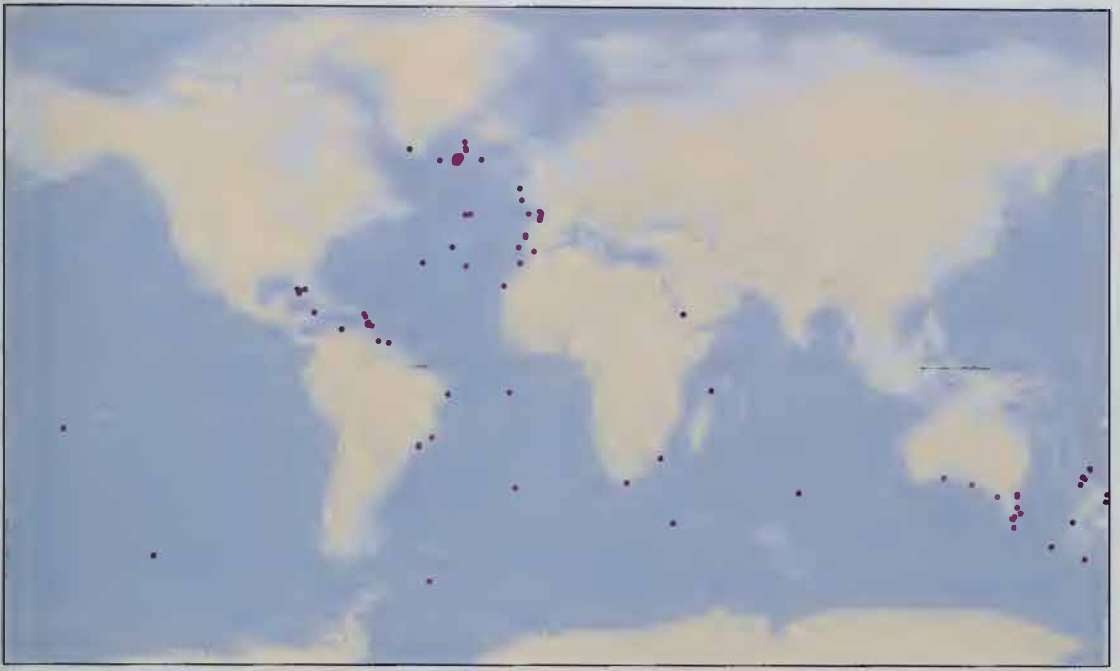


Figure 5: Global distribution of live *Solenosmilia variabilis*

UNEP-WCMC, sourced from A. Freiwald, from various sources

deep (Reed, 2002a). This means that an *Oculina* colony 1.5 m thick is about a century old. The deep-water form of *O. varicosa* occurs from 45 to about 100 m depth, has translucent soft tissue and lacks symbionts. The colonies are much taller and more fragile. Over a distance of 167 km along the eastern Florida Shelf the deep-water *Oculina* is an important reef constructor that produces coral ridges and pinnacles 3 to 35 m high (Figure 4; Reed, 2002a).

Enallopsammia profunda

Enallopsammia contains four valid species with *E. profunda* as the major framework-constructing species (Rogers, 1999). This coral forms massive dendroid colonies, up to 1 m thick. The species is endemic to the western Atlantic and ranges from the Antilles in the Caribbean to off Massachusetts at depths from 146 m to 1 748 m (Cairns, 1979). It is often associated with *L. pertusa*, *M. oculata* and *Solenosmilia variabilis* (Reed, 2002a). It is known from more than 200 banks on the outer eastern edge of the Blake Plateau, off North Carolina, at depths of 640 m to 869 m. Another concentration of *Enallopsammia-Lophelia* reefs has been located nearby along the Florida-Hatteras Slope at depths of 500 to 800 m with a maximum relief of 97 m from Miami to South Carolina (Reed, 2002a).

Solenosmilia variabilis

The biology and ecology of *Solenosmilia variabilis* is unstudied. Like *Lophelia*, it forms densely branched colonies. This species has a generally cosmopolitan distribution, but it has not been found in Antarctic waters nor in the North or east Pacific (Figure 5; Cairns, 1995). *Solenosmilia* occurs between depths of 220 and 2 165 m and is often found associated with *L. pertusa*, *Madrepora* spp. and *E. profunda*. Dense *Solenosmilia* aggregations frequently occur on the summits of the south Tasmanian seamounts in depths of 1 000 to 1 400 m, and prior to fishing. Reports of significant coral bycatch from the early years of the fishery suggest that it probably occurred to depths of 600 m (Koslow et al., 2001). Large quantities have been found in the Heezen Fracture Zone in the South Pacific. *Solenosmilia* also occurs in the Indian Ocean along the slopes of St Paul and Amsterdam (Zibrowius, 1973). In the Atlantic it is known from the northern slope of the Little Bahama Bank at depths of 1 000 to 1 300 m (Mullins et al., 1981) and from the Reykjanes Ridge, south of Iceland, in water 1 000 to 1 900 m deep (Copley et al., 1996).

Cold-water black corals (Antipatharia)

Antipatharians are tree-like or stick-like cnidarians with a solid, dark brown skeleton decorated with small spines or knobs (Opresko, 1974). This rough surface distinguishes

André Freiwald, IPAL

Lophelia pertusa **from the Sula Reef, Norwegian Shelf**

André Freiwald, IPAL

Madrepora oculata **from Santa Maria di Leuca, Ionian Sea**

Stephen Cairns, Smithsonian Institution

Goniocorella dumosa **from the southwest Pacific**

Tom Smoyer, HBOI

The deep-water *Oculina varicosa* with expanded polyps

them from gorgonians and arborescent hydroids. The soft tissue consists of thousands of tiny polyps and the colony structure may be branching (bushy, pinnate or fan-shaped) or whip like. About 250 species are known. Most black corals are anchored with a strong holdfast to the hard substrate but some are adapted to live in soft sediments. Black coral colonies can grow several metres high and are often inhabited by crabs and molluscs.

Cold-water soft corals (Octocorallia)

The soft corals belong to the systematic group of octocorals to which the sea pens (Pennatulacea), blue corals (Helioporacea) and true soft corals (Alcyonacea) are associated. Octocorals are recognized by their polyps, which typically have eight feathered tentacles, and virtually all form colonies. About 2 700 species are scientifically described and most of them belong to the true soft corals. Like the stony corals, true soft corals form large, long-living colonies packed with myriads of tiny polyps that capture food using their tentacles as suspension feeders. Their colonies are the home of specialized fauna, mostly crustaceans and snails that live permanently on or within the coral tissue. This relationship is symbiotic as both the host coral and the associated species benefit.

True soft corals are often closely associated with stony coral reefs, for instance the *Lophelia* reefs off Norway. On seamounts or deep shelves, especially in high latitudes where stony corals are less prominent, true soft corals form the backbone of the coral ecosystem and are usually called octocoral gardens, or forests. Examples of octocoral gardens are found off Nova Scotia and the Aleutians and in many sites along the Pacific coast and on seamounts off Canada and the United States, as well as on Japanese seamounts and in New Zealand waters.

The leather corals (Gorgoniidae) dominate cold-water soft coral ecosystems in terms of spatial coverage. The leather coral group includes precious corals, sea fans and bamboo corals. Many leather corals build large anastomosing colonies that are attached to any kind of hard substrate lying on the seabed. Different species of leather corals show different styles of internal skeletonization consisting of masses of tiny, needle-like, calcareous skeletal elements, the sclerites. These sclerites are glued together by a leathery substance called gorgonin that stiffens the entire colony. The strongest degree of skeletonization is developed in the precious corals.

Precious corals

Precious corals are found in many seas of the world and are heavily exploited through targeted sampling for the coral trade to make beautiful beads, idols and expensive jewelry

(Grigg, 1974; Garrabou and Harmelin, 2002). Such a case is *Corallium*. Its hard calcareous skeleton and the intense red colour unfortunately make it very attractive to the coral trade. A well-known hotspot with a diverse community of precious corals is found along the deep slopes of the Hawaiian Islands and seamounts. Precious corals have recently been discovered in the southwestern Atlantic off Brazil, associated with *L. pertusa* (Castro et al., 2003).

Sea fans

Probably the largest octocoral colonies are found within the sea fans, or gorgonian corals. Sea fans are anchored to the bottom by a holdfast, out of which grows a central flexible trunk that branches up into the water column. Colonies that are several centuries old can be as high as 5 m, and are likened to 'trees' in a cold-water environment (Andrews et al., 2002). Gorgonians produce a protein skeleton which is made up of a wood-like core that is surrounded by a softer layer called the rind. Coral polyps are embedded in this rind and extend their bodies through openings in order to feed. Their huge fan-like colonies are oriented to prevailing currents. Common genera with a cosmopolitan distribution are *Placomus*, *Paragorgia* and *Primnoa*.

Bamboo corals

A third group of octocorals frequently found in deep- and cold-water environments are bamboo corals, which have a peculiar skeletal arrangement strongly resembling bamboo plants. Heavily calcified skeletal elements alternate with proteinaceous gorgonin elements. Bamboo corals develop fragile colonies measuring several tens of centimetres across. Common genera are *Acanella*, *Isidella* and *Keratoisis*.

Cold-water lace corals (Stylasteridae)

Lace corals are hydrozoan corals with a calcified and delicately branched skeleton. In tropical coral reefs lace corals are widely known as fire corals because of the fiercely stinging abilities of *Millepora*. Lace corals are often confused with stony corals but the resemblance is superficial. Like other hydrozoans, lace corals have two types of polyp with distinct functions. The larger feeding polyps remove zooplankton from the water and are surrounded by smaller defensive polyps that contain the stinging cells.

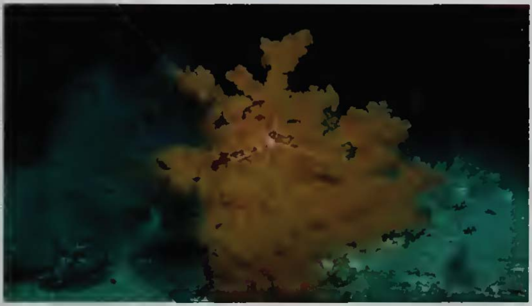
All lace corals living in cold and deep waters belong to the group of Stylasteridae with *Stylaster*, *Distichopora* and *Pliobothrus* as the better-known genera. As a group, the stylasterid lace corals have a worldwide distribution (Cairns, 1983; Cairns and Zibrowius, 1992). *Distichopora* species are found in the Indo-west Pacific, North Pacific, Galapagos Islands and


John Reed, HBOI

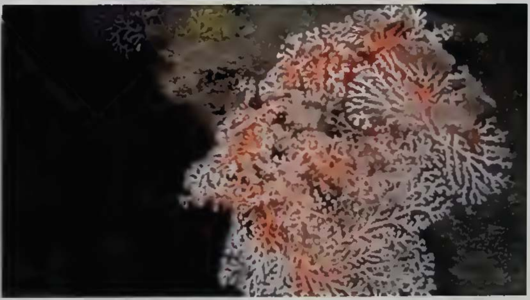
***Enallopsammia profunda*, Stetson's Bank, Blake Plateau**


Tony Koslow, CSIRO

***Solenosmilia variabilis* from a Tasmanian seamount**


IFREMER, CARACOLE, 2001

A 50-cm-high black coral colony (*Antipathes* sp.)


Amy Baco, WHOI

Precious coral (*Corallium secundum*) from off Hawaii


Allan Blacklock, NIWA

Huge trunk of a sea fan from New Zealand waters


The JAGO-Team

***Paragorgia arborea* surrounded by *Primnoa* colonies**


NOAA/MBARI, 2002

A bamboo coral on Davidson Seamount, off California


IFREMER, ARK-19/3a, 2003

A lace coral (*Stylaster* sp.), western Rockall Trough

west Atlantic. *Stylaster* species occur in all major oceans and are known as a dominant component of the octocoral forests along the Aleutian Islands (Heifetz, 2002). In the *Lophelia-Madrepora* systems in the Porcupine Seabight and Rockall Trough, northeast Atlantic, *Stylaster* and *Pliobothrus* frequently colonize stones and dead stony corals. In places, stylasterids occur in great abundance as in the Denmark Strait (between Greenland and Iceland) and along the western slope of the Porcupine Bank at depths of 560 to 900 m (Broch, 1914).

COLD-WATER CORAL ECOSYSTEMS

This section describes characteristic cold-water coral ecosystems and provides information on their structure and subhabitats. Cold-water coral ecosystems are defined as large areas of corals at a given locality. Almost all known coral ecosystems share a number of attributes or environmental factors, and their preferred locations are found in areas where:

- The seasonal storm wave base does not affect the seabed.
- Strong topographically guided bottom currents prevent deposition of sediments, thereby creating current-swept hard substrate that facilitates colonization by habitat-forming corals. Generally, these grounds are pre-existing topographic highs of various scales that form obstacles in the current path: they can be boulder fields, moraine ridges, drumlins, the flanks of oceanic banks, seamounts, sedimentary mounds and occasionally artificial substrates such as wrecks and oil rigs.
- The flow of water is funnelled through narrow passages such as straits (e.g. Florida Strait, Strait of Gibraltar, Cook Strait (New Zealand)) or channels, fjord troughs (e.g. in Scandinavia, New Zealand and Chile) and submerged canyons and gullies.
- Nearby nutrient-rich waters stimulate the development of high phyto- and zooplankton levels, providing a major food source for the coral communities.

Cold-water coral ecosystems on continental shelves

The continental shelf stretches from the coastal zone to the shelf break. The width of the shelf varies from a few kilometres up to several hundreds of kilometres and depends on geological processes such as the activity of plate tectonics and the supply of sediment from the hinterland. Major physical forces affecting the shelf seabed include storm waves that stir up and mobilize huge amounts of sediments. Depending on the latitude and the exposure of the shelf to the path of low-pressure cells, storm waves can affect and disturb substantial portions of the shelf seabed. This explains the relative paucity of coral ecosystems in shelf environments in most parts of the world.

One of the best-known exceptions is the Norwegian Shelf, where coral reefs exist in a broad range of settings. The Norwegian Shelf, however, has some peculiarities that help to explain why the environment is so favourable for cold-water corals. The shelf is characterized by banks (≤ 200 m deep) and troughs (> 300 m deep), the latter oriented perpendicular to or parallel to the coastline. The North Atlantic Current transports relatively warm (6 to 8°C) and saline (> 35‰) water from the southwest along the Norwegian Shelf to the Arctic and provides environmental conditions that are beneficial for the corals in this high latitudinal setting. However, the northward flowing, less saline Norwegian Coastal Current, derived from the North Sea, occupies the shelf and forms a surface water lens approximately 100 m thick. All deeper shelf areas and troughs are filled with the denser North Atlantic Current.

Some of the deep shelf troughs continue eastwards in fjord basins, and oceanic North Atlantic water forms a major component in the deep inflow of Norwegian fjords. The distribution pattern of *Lophelia pertusa* reflects the spread of oceanic Atlantic water on the shelf and within the fjords (Freiwald, 2002), where *Lophelia* reefs can occur at quite shallow depths, the shallowest thriving at 39 m on the Tautra Ridge, mid-Trondheimsfjord, Norway (Fosså et al., 2002). Other fjord regions in the world also have very shallow occurrences of otherwise deep-water corals. The dense populations of *Desmophyllum dianthus* living in only 7 to 25 m on the slopes of a Chilean fjord (Försterra and Häussermann, 2003) are an interesting example.

Cold-water coral ecosystems along continental slopes

The continental slope environment is transitional between the shelf break and the deep-sea plain and is known as the bathyal zone (200 to 2 000 m). Slopes are characteristically inclined seabed, generally covered with mud, although some continental slopes are more heterogeneous and have a wide range of features including canyons. Canyons can act as conduits for sediment and organic matter transported from the shelf to the deep sea. Beyond the shelf break, coral ecosystems commonly occur from about 600 m down to depths where cold and deep-water masses with temperature regimes of less than 4°C prevail. Despite the great depths, many slope environments are prone to a strong current regime driven by tidal motion, internal waves, or episodically by the cascading of dense waters from the shelf. In these bathyal depths, areas of sediment erosion alternate closely with areas of sediment deposition and may lead to the formation of huge sedimentary mounds – the so-called carbonate mounds.

Cold-water coral ecosystems are widespread on continental margins. In the Atlantic, corals occur from the Faroe-Shetland Channel south to central Africa. In many regions, corals are associated with sedimentary mound features, seabed structures several hundred metres high. Except for parts of the upper slope in mid-Norway, the continental margins of the Norwegian and Greenland Seas are not known to host large amounts of coral, as the water temperature of this North Atlantic basin is too low.

The Mediterranean Sea has a relatively warm deep-sea basin with temperatures of 10 to 13°C, close to the upper limit of many cold-water corals occurring in the bathyal zone. Corals are found in the Strait of Gibraltar and along the canyons of the Alboran Sea, Ligurian Sea (Tunesi et al., 2001) and Ionian Sea (Taviani et al., in press). The living coral populations provide a glimpse of the rich and more diverse coral communities of the last glacial period, when temperatures were lower (Delibrias and Taviani, 1985).

In the northwest Atlantic, coral ecosystems are prominent along the continental margin off Nova Scotia, where the Gulf Stream and the polar Labrador Sea Water meet (Gass and Willison, in press; Mortensen and Buhl-Mortensen, in press). In an area called the Stone Fence (Figure 22), a large *Lophelia* reef was documented from a remote operated vehicle (ROV) in 2003 (Sayfy et al., 2003). Another well-known coral hotspot is the continental margin off the southeastern United States, where coral reefs occur in great densities on the Blake Plateau and off eastern Florida (Stetson et al., 1962; Reed, 2002a; Paull et al., 2000).

There is increasing information about cold-water coral ecosystems in the Gulf of Mexico and the Caribbean Sea (Schroeder et al., in press). Coral reefs grow in the De Soto slope off Louisiana (Schroeder, 2002) between 400 and 500 m deep. Rich coral populations including *L. pertusa* occur on the upper slope off Colombia, in the southern Caribbean (Reyes et al., in press). Further south, coral ecosystems living on sedimentary mounds are common in the Campos Basin, off south Brazil (Viana et al., 1998).

There have been few surveys of cold-water coral in the Indian Ocean. The best known octocoral ecosystems in the Pacific Ocean are along the margins and outer shelves of the Gulf of Alaska, the Aleutian Islands and the Bering Sea (Heifetz, 2002). Further south along the Canadian and northwestern American continental margin, as far south as California, octocorals are an important component of the seabed community (Etnoyer and Morgan, 2003).

Cold-water coral ecosystems on oceanic banks

Submerged microcontinents are called oceanic banks, rises or plateaux. They are of considerable size and are characterized by flat, wave-abraded bank areas with or without islands. Their size forces ocean currents to deviate along their flanks thus creating fertile regimes that maintain pelagic plankton communities, which in turn feed cold-water corals. Below the storm wave base, coral ecosystems colonize exposed hard substrates. In the northeast Atlantic, the flanks of the Rockall Bank (Figure 11) from 180 to 950 m have many *Lophelia* and *Madrepora* reef patches (Wilson, 1979a; Kenyon et al., 2003; van Weering et al., 2003). Coral patches are also found on the Galicia Bank, off northwestern Spain. In the southwest Pacific, near New Zealand, the flanks of the Chatham Rise and the Campbell Plateau are particularly rich in coral ecosystems formed by *Goniocorella dumosa*, *Solenosmilia variabilis* and *Enallopsammia rostrata* (Cairns, 1995; Probert et al., 1997; Hoernle et al., 2003).

Cold-water coral ecosystems on seamounts and mid-ocean ridges

Seamounts are submarine, usually extinct volcanoes with a limited summit area; they occur as isolated volcanoes or are grouped in clusters or chains. The mid-ocean ridges are rich in seamounts. Seamounts provide the primary habitat for cold-water corals in the Pacific, where there are an estimated 30 000 seamounts higher than 1 000 m (above the sea floor) compared with fewer than 1 000 seamounts in the North Atlantic (Smith and Jordan, 1988; Epp and Smoot, 1989). Although seamounts in the Pacific were sampled during the *Challenger* expedition of 1872-1876, greater interest in these features developed after the Second World War, during which naval use of newly developed sonar revealed their widespread distribution in the Pacific Ocean (Hess, 1946).

The ichthyologist Carl Hubbs (1959) systematically sampled the fish fauna of seamounts and asked the key questions that have underlain studies ever since:

- ☐ Do seamounts have a distinct fauna?
- ☐ How do species become established on seamounts?
- ☐ Does the isolation of seamounts lead to speciation?
- ☐ Do seamounts play a key role in oceanic biogeography, i.e. do they serve as 'stepping stones' for particular species across the oceanic abyssal plain?
- ☐ What physical and ecological factors are responsible for the abundance of life on seamounts?

Due to their rugged topography, however, seamounts proved difficult to investigate with the nets typically used by biologists to sample the sea floor and so biological studies of seamounts lagged considerably behind physical and geological studies. Amazingly, the close association of cold-water corals with seamounts, which results from their topographically enhanced currents, was established only in the mid-1980s (Genin et al., 1986; Boehlert and Genin, 1987; Grigg et al., 1987).

Although there exist extensive records of the presence of cold-water corals along the slopes of North Atlantic seamounts, dedicated surveys to examine coral ecosystems are scarce. The Reykjanes Ridge south of Iceland is an area where cold-water corals (*L. pertusa*, *M. oculata*, *S. variabilis*) are frequently dredged (Copley et al., 1996). *L. pertusa* populations are present on some of the New England seamounts in the western North Atlantic (Jaques, 1972; Moore et al., 2003). There are unpublished sight records of stony coral, black coral and octocoral populations from several seamounts in the Azores region (Gubbay, 2003).

The Milwaukee Bank and other seamounts in the North Pacific Emperor seamount chain were the primary source of precious corals worldwide, following the discovery there of extensive beds of pink coral (*Corallium secundum*) by Japanese coral fishermen in 1965 (Grigg, 1984; Grigg, 1993; Baco and Shank, in press; Etnoyer and Morgan, 2003). Farrow and Durant (1985) described *L. pertusa* from the Cobb Seamount, Gulf of Alaska; and the Davidson Seamount off central California has rich populations of cold-water octocorals (Andrews et al., in press).

Until recently little was known about seamounts and cold-water coral habitats in the South Pacific. In their comprehensive review, Wilson and Kaufman (1987) listed only 27 coral species recorded from seamounts in the southwest Pacific. However since 1984 French researchers have conducted more than 20 cruises in the region around New Caledonia (Richer de Forges, 1990; Richer de Forges, 1993), and from the mid-1990s Australian and New Zealand researchers have undertaken intensive investigations of the seamount faunas around Tasmania and New Zealand, particularly in areas of orange roughy trawling. The scleractinian coral *Solenosmilia variabilis* is the dominant coral on seamounts at depths of about 1 000 m off Tasmania, forming reefs with a diverse associated benthic community including numerous other hard and soft corals (Koslow et al., 2001). Although *S. variabilis* is also found on seamounts around New Zealand, the scleractinian *Goniocorella dumosa* appears to be the primary reef-forming coral on seamounts there (Probert et al., 1997).

A key finding of recent studies in this region is that seamount faunas are more diverse than previously recognized and also more isolated, with relatively high levels of endemism. Richer de Forges et al. (2000) reported more than 850 macro- and megafauna species from seamounts in the Tasman and Coral Seas, 42 per cent more than Wilson and Kaufman (1987) recorded from all studies of seamounts worldwide to that date. About one third of the species (255) were new to science and potential seamount endemics. Very low levels of overlap in species composition have been found between seamounts from different chains or clusters, even within different sectors of the Tasman sea (Koslow et al., 2001).

Faunas associated with the seamounts and cold-water corals of the Indian Ocean are virtually unknown; even the number of seamounts in the Indian Ocean has yet to be determined. Wilson and Kaufman (1987) recorded only two seamounts and 13 species of corals. Further studies were undertaken by Russian researchers and the Census of Marine Life is funding a project to recover data from those expeditions.

In summary, cold-water coral ecosystems are clearly not randomly distributed on the seabed. Indeed, the probability of finding coral ecosystems is high in areas where topographic constrictions interfere with the current flow, providing colonizable hard substrates and concentrating food particles for coral in the water. Amongst the cold-water corals, the stony corals (order Scleractinia) and the octocorals (order Alcyonacea) can form substantial aggregations on the seabed which are described as (stony) coral reef and octocoral forest habitat.

Cold-water corals on artificial structures

Cold-water corals have been observed to colonize man-made installations and wrecks. *L. pertusa* is relatively abundant on many of the oil platforms surveyed in the northern North Sea. More than a hundred individual colonies were recorded during a single survey of just a small part of one installation (Roberts, 2002). *L. pertusa* colonies have been seen on North Sea oil installations only at sea depths greater than 50 m where there is year-round influence of Atlantic water. These depths correspond with temperatures of 8°C and salinities of 35‰. Coral larvae must have been transported to the northern North Sea in order to have settled onto the oil platforms there, and this provides firm evidence for a dispersive larval phase. In addition to the constraints imposed on distribution from the physical environment, coral colonies may be out-competed for space on the platform surface. These surfaces are often completely covered with soft corals and sea anemones, species not restricted to oceanic water of high salinity. In addition wave action during winter storms may dislodge coral recruits at shallower depths.

Due to a lack of hard substrate in the North Sea, few colonies are found away from installations and wrecks. Since the seabed bed immediately around oil installations is closed to trawling, it is possible that as well as providing a hard settlement substrate, the platform structures have also offered a refuge from trawling where corals and other epifaunal organisms have been able to develop over the last 25 to 30 years. With the decommissioning of oil industry infrastructure, it is likely that both the availability of hard substrates and the protection they offer from trawling will be reduced.

These observations have provided a valuable insight into the growth rates of cold-water coral species (Box 3, page 33).

Table 2: Countries with cold-water corals

Angola
Australia
Brazil
Canada
Cape Verde
Chile
China
Colombia
Cuba
Denmark (Greenland, Faroer)
Dominican Republic
Ecuador
France
Ghana
Guyana
Haiti
Honduras
Iceland
Indonesia
Ireland
Italy
Jamaica
Japan
Madagascar
Mauritania
Mexico
Morocco
New Zealand
Nicaragua
Norway
Portugal
Russia
Seychelles
South Africa
Spain
Surinam
Sweden
United Kingdom
United States of America
Venezuela
Western Sahara

CORAL REEFS

Cold-water coral reefs, like their tropical warm and shallow-water counterparts, are built predominantly by stony corals (Scleractinia, Box 2). Wilson (1979b) found that a typical mature cold-water coral reef structure passes through several evolutionary stages. The availability of hard substrate on the seabed is a prerequisite for the settling of coral larvae and for producing dense stands of bushy colonies. One to two decades later, a thicket of coral has formed. As the colonies continue to grow upward, the basal and oldest parts of the colonies die off and became infested by skeleton-excavating communities such as boring sponges. This establishment of live and dead zones within the coral colonies is crucial for reef habitat development. The degradation of the basal and dead colonies by boring organisms produces the typical coral rubble. More sediment from external sources accumulates between the dead colonies by the trapping effect of the bushy colonies.

Particle-laden water that passes through the colonies is slowed, thus facilitating settling of detritus. This is the point in reef formation where the sensitive balance between constructive processes such as the growth of the corals and sediment accumulation starts. If this interplay of colony growth, larval settlement, skeletal degradation and sediment formation continues over a timespan of a few thousand years, a three-dimensional coral reef structure will develop. Such a structure represents an accumulation of sediment-filled dead corals surrounded by coral rubble aprons with an outer rim of living corals on top.

Cold-water reefs can measure several tens of metres in coral framework thickness and several hundred metres to kilometres across. Their large size and the increasing differentiation between living and dead coral areas influence both the local current regime and the colonization patterns of the associated fauna. Compared with the diverse coral community that contributes to reef building in the tropics, there are only a few reef-building cold-water corals, and reefs at a given location are in most cases made up by one species.

Lophelia reefs

The highest known density of *Lophelia* reefs is in Norwegian waters, generally at depths between 39 and 400 m (Fosså et al., 2000). Some Norwegian reefs have been mapped or described to some extent (Figure 6): the eastern Skagerrak reefs (Pfannkuche, 2004), the Sula Reef (Mortensen et al., 1995; Hovland et al., 1998; Freiwald et al., 2002), the Røst Reef (Fosså and Alvsvåg, 2003) and the Stjernsund Reef (Freiwald et al., 1997). Although the precise number of Norwegian reefs is not yet known, several hundreds of locations have been mapped with an estimated total spatial coverage of about 2 000 km² (Fosså et al., 2000; Mortensen et al., 2001). This is a greater area of coral reef than in some countries with well-known tropical warm-water reef ranges such as Belize, Mozambique or Seychelles.

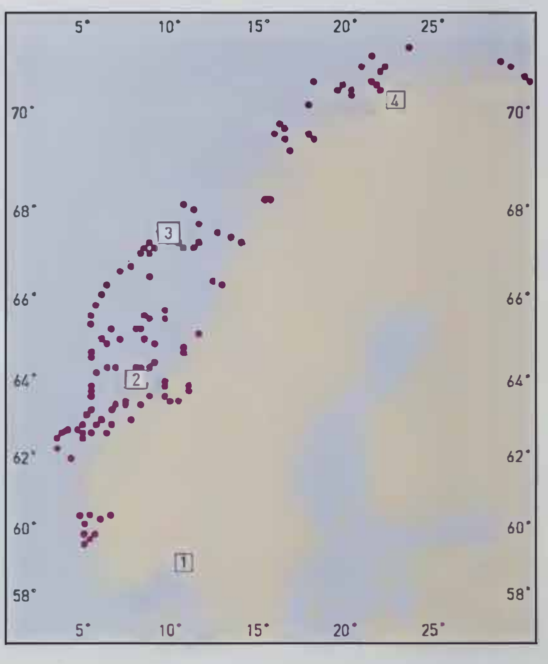


Figure 6: *Lophelia* reefs on the Norwegian continental shelf and fjords. Boxes indicate locations of major reefs described in this report: 1: The eastern Skagerrak reefs. 2: The Sula Reef. 3: The Røst Reef. 4: The Stjernsund Reef Compiled from Fosså et al., 2000

Box 2: Defining reefs

There has been some controversy as to whether or not cold-water corals may be identified as 'reefs'. Originally, a reef was defined by sailors as being a navigational hazard and could be a rock, sand bank or a biogenic build-up. In this respect, cold-water coral reefs hardly form navigational hazards as they usually grow in deeper waters. Otherwise cold-water coral reefs share many attributes with warm-water reefs in that both types produce discrete carbonate structures formed by *in-situ* or bound organic components that develop topographic relief upon the sea floor (Wood, 1999). According to the European Habitats Directive (92/43/EEC, see also EC, 1996), a reef can be a submarine, biogenic concretion which arises from the sea floor and which supports a community of animals. *Lophelia pertusa, Goniocorella dumosa, Oculina varicosa* and *Solenosmilia variabilis* can form reefs according to this definition.

The eastern Skagerrak reefs are confined to elevated fjord sills, such as the recently protected Tisler Reef at 80 to 180 m depth, and the reefs close to the Søster Islands which occur on submerged drumlins (a subglacial bedform) at similar depths. The reefs are exposed to upwelling currents of Atlantic waters that flush through the narrow sounds. In this area, only *L. pertusa* builds reefs. Individual reefs measure tens to several hundreds of metres across and are more than 10 metres thick. Dead reefs or reef portions are colonized by gorgonians (*Paramuricea*), bivalves (*Chlamys*), brachiopods (*Macandrewia*), ascidians (*Polycarpa*) and sponges (*Geodia, Pachastrella*). Redfish (*Sebastes* spp.) and cod (*Gadus morhua*) are plentiful within the reefs.

The Sula Reef is located on a sandstone ridge north of Frøyabank, mid-Norwegian Shelf, at 315 to 240 m depth (Hovland et al., 1998). The ridge was deeply scoured by grounding icebergs at the end of the last ice age. These scour marks form a complex pattern of lineated furrows

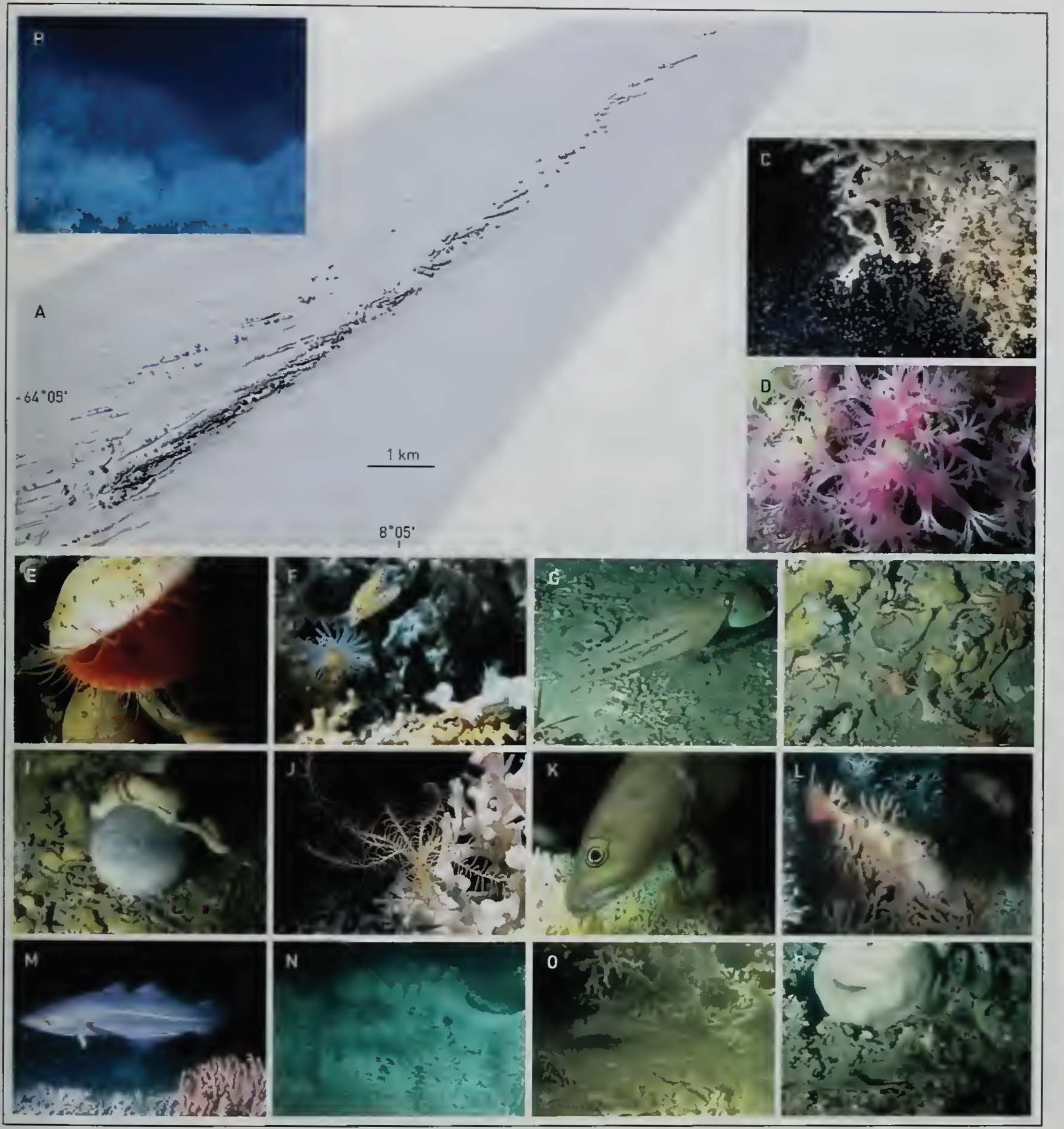


Figure 7: The Sula Reef. (A) Shaded multibeam map of the Sula Reef. The dark spots mark individual reefs superimposed on lineations created by grounding icebergs some thousands of years ago. (B) A gallery of *Lophelia* on the reef top. (C) Zooplankton is a major food source for the corals. (D) *Anthothela grandiflora* (octocoral). (E) *Acesta excavata*, the largest clam in the reef. (F) Escaping *Chlamys sulcata* with *Protanthea simplex* (Actinaria). (G) Escaping octopus. (H) Assemblage of *Munida sarsi* between coral rubble and yellow sponges (*Plakortis simplex*). (I) Starfish grazing upon a rotten *Geodia* sponge. (J) A resting feather star (*Antedon bifida*) on *L. pertusa*. (K) The tusk (*Brosme brosme*) on the reef top. (L) Redfish (*Sebastes marinus*) hiding between the corals. (M) A pollock (*Pollachius virens*) hunting for food. (N) Wolf fish (*Anarhichas lupus*). (O) Rabbit fish (*Chimaera monstrosa*) near the reef base. (P) Ray fish egg cases deposited within the reef corals

Map A from Fosså et al., 2000, photos B-P the JAGO-Team

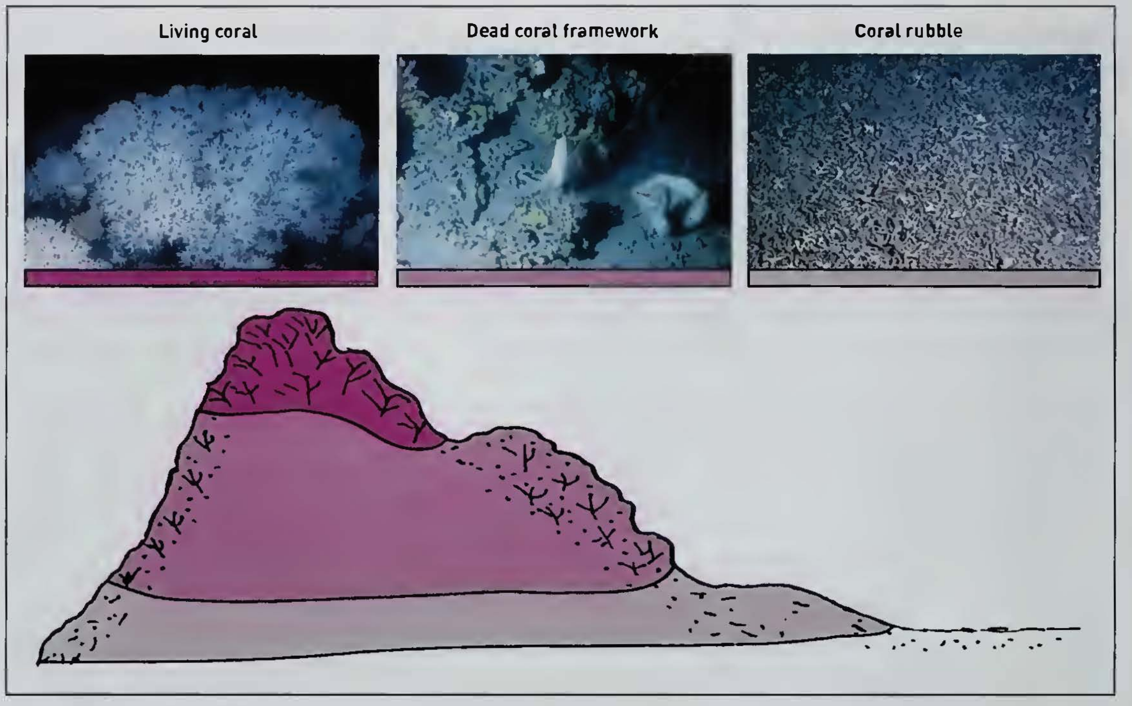
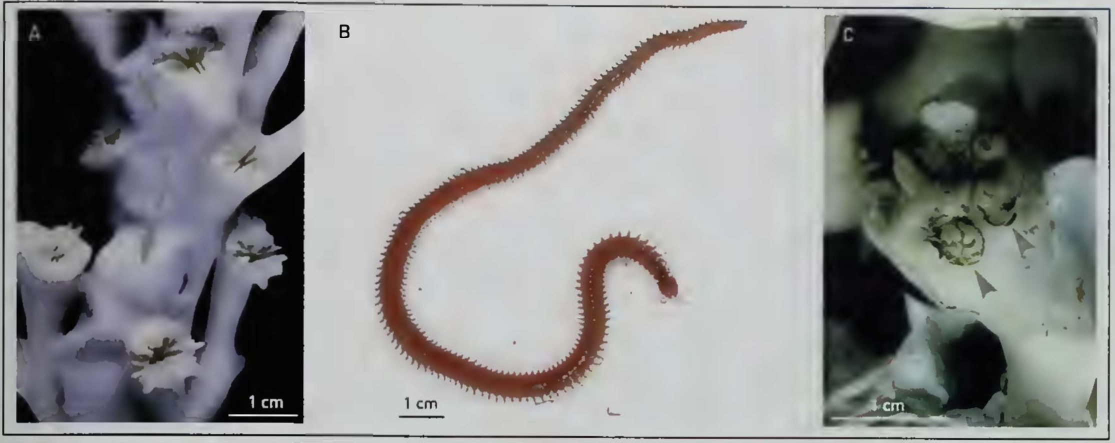


Figure 8: Schematic sketch of the major habitats of a *Lophelia* reef (not to scale)

Photos the JAGO-Team

Living coral	**Dead coral framework**	**Coral rubble**
Densest accumulations of live *Lophelia* found on summit and upper slopes Consists of two reef-building species, *L. pertusa* and to a much lesser degree *Madrepora oculata*; the reef-associated fauna is quite diverse	Prevails down slope and under living corals Highest species richness on the reefs	Forms aprons around the base and outer circumferences of the reef Most degraded state of a cold-water reef
There are few permanently attached organisms, as living coral seem to be very successful in preventing fouling. Amongst the few are: ❏ the carnivorous worm *Eunice norvegica* that lives in symbiosis with the coral (Figure 9A-B); while the worm protects the coral polyps against predators, it stimulates the coral to build a calcareous shelter around the worm's parchment tube (Mortensen, 2001); ❏ the parasitic foraminifer *Hyrrokkin sarcophaga* commonly found attached to the skeletons of living coral polyps (Cedhagen, 1994; Freiwald and Schönfeld, 1996; Figure 9C); ❏ clusters of bivalves (*Delectopecten vitreus, Acesta excavata*), attached by organic threads to the coral skeleton, can be common; ❏ mobile organisms such as sea urchins, brittle stars, gastropods, crustaceans and fishes are most often observed.	Hundreds if not thousands of species of many size classes and taxonomic groups live in this habitat. Amongst the megafauna gorgonian corals, actinians and sponges are conspicuous and abundant. On a smaller scale, hydrozoans, bivalves, brachiopods, bryozoans and barnacles are prevalent. Several decapod species, large gastropods, sea urchins, brittle stars, starfishes and countless worms crawl between the coral framework or rework the fine sediment.	The coral rubble subhabitat is occupied by encrusting sponges. In areas rich in finer sediments, echiurid worms are common. Mortensen et al. (1995) found that the squat lobster *Munida sarsi* was ten times more common in the coral rubble than in the surrounding soft bottom.



Photos: André Freiwald, IPAL

Figure 9: Characteristic organisms found in the living coral subhabitat. (A) Calcareous tube as shelter for the polychaete *Eunice norvegica*. (B) *E. norvegica* taken out of its tube. (C) A cluster of the parasitic foraminifer *Hyrrokkin sarcophaga*

flanked by boulder ridges which provide hard substrate for the corals that colonized around 9 000 years ago (Figure 7). Several hundred individual reefs formed by *L. pertusa* extend more than 14 km along the entire ridge structure measuring 2 to 30 m in height (Mortensen et al., 2001; Freiwald et al., 2002).

A typical *Lophelia* reef consists of three major subhabitats (Figure 8).

One of the most obvious features when diving with a submersible over a cold-water reef is the species richness and abundance of the fish community compared with the off-reef seabed (Costello et al., in press; Husebø

Table 3: Latin and common names of fishes observed on cold-water coral reefs

Latin name	Common name	Market value
Anarhichas lupus	Wolf fish	Highly commercial
Anoplopoma fimbria	Sablefish	Highly commercial
Aphanopus carbo	Black scabbardfish	Commercial
Beryx spp.	Alfonsino	Commercial
Brosme brosme	Tusk	Highly commercial
Chimaera monstrosa	Rabbit fish	Minor commercial
Coryphaenoides rupestris	Roundnose grenadier	Commercial
Epinephelus niveatus	Snowy grouper	Commercial
Gadus macrocephalus	Pacific cod	Highly commercial
Hoplostethus atlanticus	Orange roughy	Highly commercial
Lophius piscatorius	Monkfish	Highly commercial
Microstomus kitt	Lemon sole	Commercial
Molva dypterygia	Blue ling	Commercial
Molva molva	Ling	Highly commercial
Munida sarsi	Squat lobster	No indication found
Pleurogrammus monopterygius	Atka mackerel	Commercial
Pollachius virens	Pollock	Highly commercial
Pseudopentaceros richardsoni	Pelagic armorhead	Highly commercial
Pseudopentaceros wheeleri	Slender armorhead	Commercial
Reinhardtius hippoglossoides	Greenland halibut	Highly commercial
Sebastes marinus	Redfish	Highly commercial
Sebastes spp.	Rockfish	Generally commercial
Theragra chalcogramma	Walleye pollock	Highly commercial

Information on market value sourced on www.fishbase.org species summaries

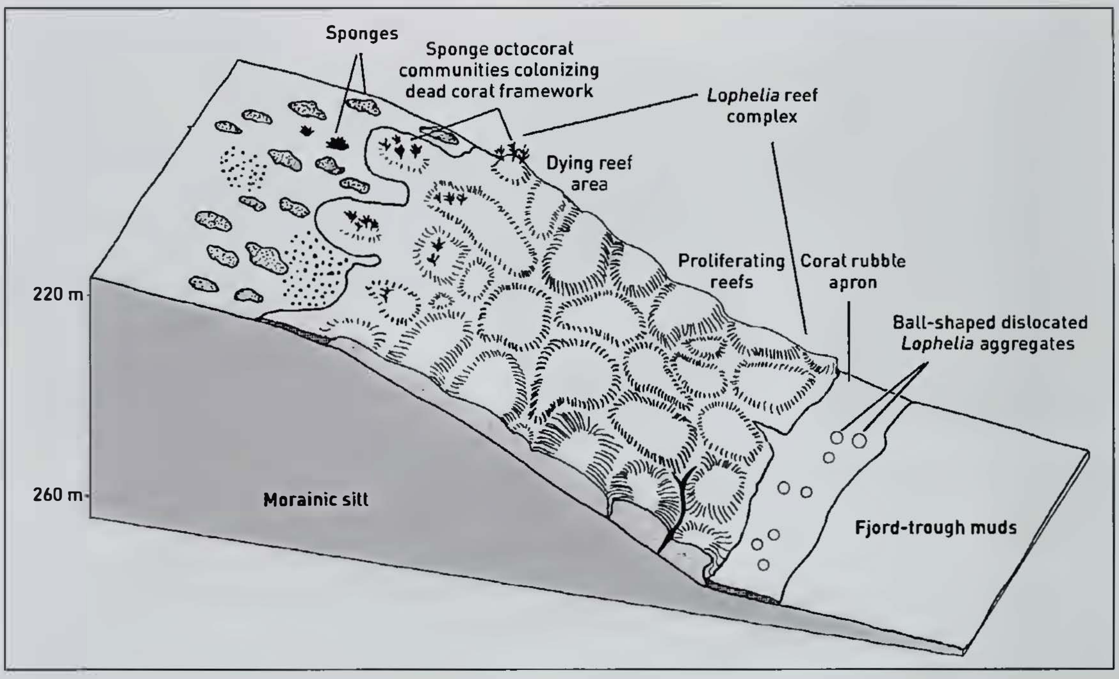


Figure 10: The Stjernsund *Lophelia* reef growing along the flank of a sill Modified from Freiwald et al., 1997

et al., 2002). Table 3 lists the main species that have been observed on cold-water coral reefs, and their commercial significance. Reefs may be attractive for fish in several ways. The complex three-dimensional reef provides enhanced feeding possibilities, hiding places and nursery areas (Fosså et al., 2000).

Based on experience from several submersible dives to the Sula Reef, it seems that some fish species show distinct subhabitat preferences. The current-exposed reef tops generally have schools of redfish and pollock. The fissures and crevices that occur within the dead coral framework subhabitat are frequently occupied by tusk, ling and wolf fish. In the coral rubble lemon sole and monkfish are most often seen. Sharks and chimaera show no preferred habitat as they hunt for prey everywhere. In the reef areas, egg capsules of rays are frequently found entangled between live corals or deposited in the dead coral framework.

Husebø et al. (2002) undertook a quantitative fishing survey using longlines and gillnets in coral and non-coral areas on two sites along the outer shelf off mid-Norway. Redfish, ling and tusk were more abundant and larger within the coral habitat than in non-coral habitats. Stomach analysis showed that redfish fed mostly on zooplankton, whereas ling preferred smaller fish and crustaceans, and tusk preyed upon epibenthic decapods.

Since March 1999, the Norwegian Government has prohibited the use of all fishing gear that is dragged and may make contact with the sea floor in the Sula Reef, which thus became the first protected cold-water reef in the northeast Atlantic.

An ongoing census of life in *Lophelia* reefs from the northeast Atlantic under the Atlantic Coral Ecosystem Study (ACES) project has so far identified about 1 317 species. However, many groups have yet not been processed and reviewed by specialists so the list is likely to grow.

The Røst Reef, discovered in 2002 at the continental margin southwest of the Lofoten Islands, northern Norway, is the largest *Lophelia* reef complex yet found in the northeast Atlantic. Several hundreds of individual reefs extend over a distance of 40 km and are arranged, 2-3 km wide, parallel to the shelf edge at 300 to 400 m depth. At approximately 100 km² in area (roughly the size of Manhattan), the Røst Reef is ten times larger than the Sula Reef.

In Norwegian waters *Lophelia* reefs occur both along the continental shelf and in fjords far from the open sea (Dons, 1944; Fosså et al., 2000). Fjord basins with cold-water reefs are characterized by a seasonal exchange of open-ocean deep water from the Atlantic. Specific circulation patterns inside fjords force the intruded open-ocean water near to the surface and many

Lophelia reefs occur in unusually shallow depths of less than 250 m. The shallowest reef is at only 39 m depth on the Tautra Ridge, middle Trondheimsfjord (Fosså et al., 2002). Typical reef sites in fjords are sills that are kept free from sediment deposition by strong tidal currents. A good example has been described from the Stjernsund at 70°N, northern Norway (Figure 10; Freiwald et al., 1997). *Lophelia* growth is well developed along the current-swept flanks of the sill at 220 to 260 m depth. However, on the shallower sill living sponge-octocoral communities grow on fossil coral rubble.

Elsewhere in the world, *Lophelia* reefs have been described at the base of the Florida-Hatteras Slope at depths of 500 to 800 m, and from the outer eastern edge of Blake Plateau, both off the southeastern United States, at 640 to 869 m depths (Stetson et al., 1962; Reed, 2002a and b). The maximum relief of the pinnacle-shaped *Lophelia* reefs is 97 m. In the Florida Strait-Blake Plateau area, the corals are growing on dead, possibly fossil, coral rubble ridges. As these ridges are often consolidated they are called 'lithoherms'. Paull et al. (2000) estimated the existence of over 40 000 lithoherms in the Florida Strait-Blake Plateau area. The lithoherms show a clear zonation of corals with *L. pertusa* and *Enallopsammia profunda* along the upcurrent slopes and the golden coral *Gerardia* sp. on top of the structure, with downcurrent assemblages of octocorals and stalked crinoids common (Messing et al., 1990).

There are a number of *Lophelia* records from the Gulf of Mexico but only one has been confirmed (Schroeder et al., in press). The reef is located on the upper De Soto Slope, off Louisiana, at a depth of 434 to 510 m, and has a relief of 45 to 90 m (Schroeder, 2002). Individual colonies are as large as 1.5 m in diameter and colony clusters measure 1.5 by 1.5 by 4 m.

Lophelia reefs on carbonate mounds

During the past decade, spectacular mound provinces have been discovered in continental margin environments. In the northeast Atlantic, major sedimentary mound areas exist in the Porcupine Seabight, in the Rockall Trough, off Morocco, off Mauritania and off

Figure 11: (A) Major carbonate mound provinces off Ireland and the United Kingdom: BMP = Belgica Mound Province (shown in B), DM = Darwin Mounds, HMP = Hovland Mound Province, LMP = Logachev Mound Province, PMP = Pelagia Mound Province, WRM = Western Rockall Mounds, WPBM = Western Porcupine Bank Mounds. (B) Shaded multibeam map of the Belgica Mound Province off Ireland

Data Andreas Beyer, AWI

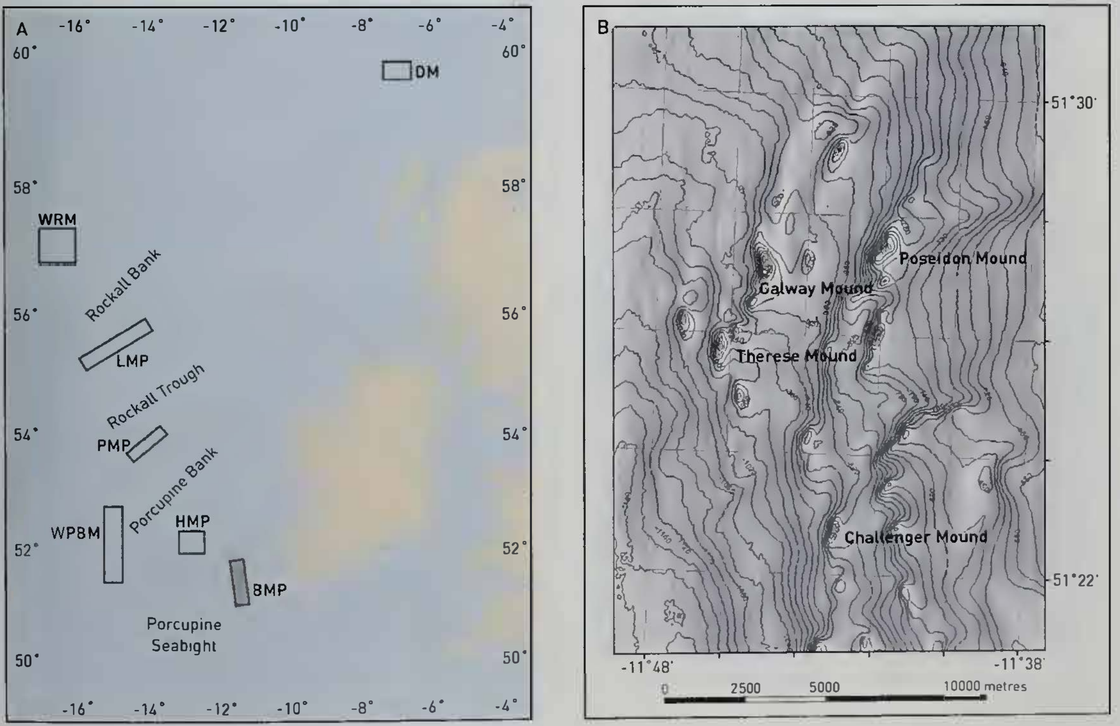


Table 4: Major coral-topped carbonate mound provinces

Mound province	Geographic area	Depth (m)	Framework-constructing corals	References
Belgica Mounds	Eastern Porcupine Seabight, northeast Atlantic	600-900	*Lophelia pertusa* *Madrepora oculata*	De Mol et al., 2002 Van Rooij et al., 2003
Hovland Mounds	Northern Porcupine Seabight, northeast Atlantic	725-900	*Lophelia pertusa* *Madrepora oculata*	Hovland et al., 1994 De Mol et al., 2002
Pelagia Mounds	Southeastern Rockall Trough, northeast Atlantic	650-950	*Lophelia pertusa* *Madrepora oculata*	Kenyon et al., 2003 van Weering et al., 2003
Logachev Mounds	Southwestern Rockall Trough, northeast Atlantic	550-1 200	*Lophelia pertusa* *Madrepora oculata*	Kenyon et al., 2003 van Weering et al., 2003
Darwin Mounds	Northern Rockall Trough, northeast Atlantic	950-1 000	*Lophelia pertusa* *Madrepora oculata*	Masson et al., 2003
Chinguetti Oilfield	Off Mauritania, central northeast Atlantic	450-550	*Lophelia pertusa* *Madrepora oculata* *Solenosmilia variabilis*	Colman et al., in press
Campos Basin Mounds	Off southeast Brazil	570-850	*Lophelia pertusa*	Viana et al., 1998

southeast Brazil (Table 4). The mounds form isolated or clustered seabed elevations measuring up to 350 m in height in the depth interval of 600 to 900 m corresponding to the mid-slope of the continental margin (Figure 11). Mound formation started several million years ago but the causes remain unclear.

Almost all these giant mounds are draped with coral reef patches of *L. pertusa* and *M. oculata*; the reef patches form a low-relief framework approximately 1 m thick. Locally dense populations of the stony coral *Desmophyllum dianthus* occur, and between the coral patches are areas rich in gorgonians and stylasterid lace corals. The rate at which new discoveries of coral-covered carbonate mounds have been made indicate that they are widespread in continental margin settings and there are likely to be many more waiting to be found.

Oculina reefs

The ivory tree coral *Oculina varicosa* builds reefs that are similar in structure to those of *Lophelia*. Their geographic occurrence is restricted to a relatively small strip off central eastern Florida at 70 to 100 m depth, underneath the flow of the Gulf Stream (Reed, 2002b). The reefs form pinnacles and ridges that are up to 35 m in height and provide habitat for a great diversity of invertebrates and fish. In 1984, a 315 km² area was designated the *Oculina* Habitat of Particular Concern in order to protect the coral from bottom trawling and anchoring; the area was expanded to 1 029 km² in 2000.

Enallopsammia reefs

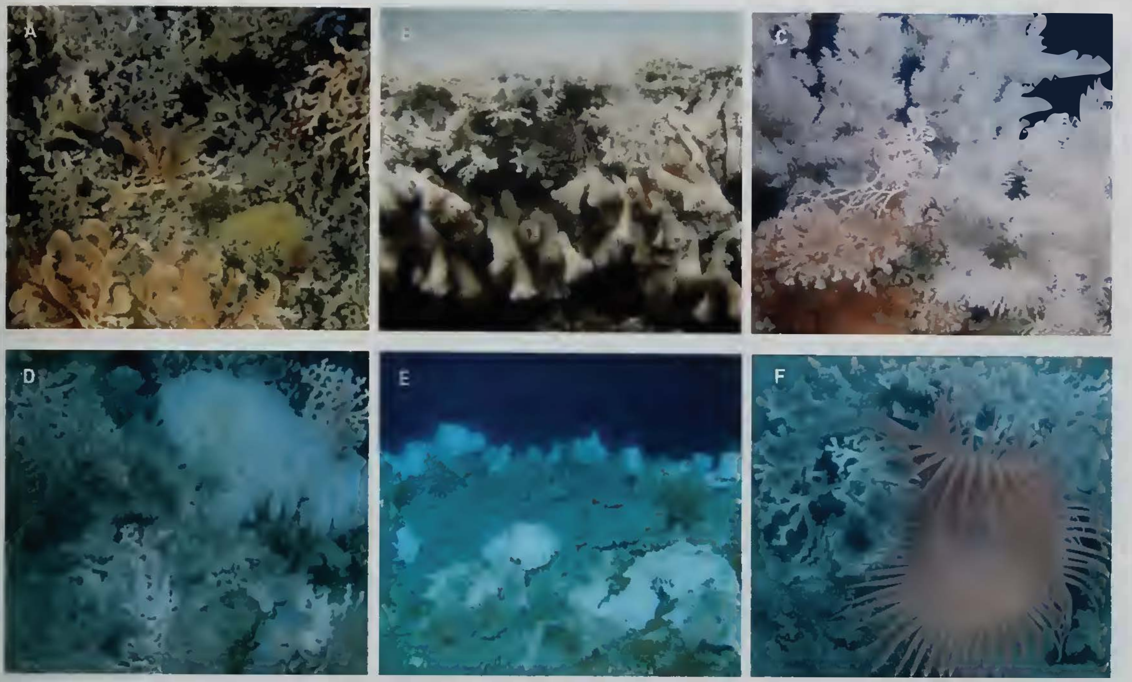
Little information on reefs formed by *Enallopsammia* species exists. *E. profunda* builds extensive frameworks with *L. pertusa* as associate on the outer edge of the

John Reed, HBOI

A school of groupers in a deep-water *Oculina* reef off eastern Florida

Tony Koslow, CSIRO

***Solenosmilia variabilis* framework matrix from a south Tasmanian seamount, with associated faunal community**



Coral patch reefs from carbonate mounds: (A) *Lophelia* patch reef visited by swimming crinoids (*Koehlerometra porrecta*). (B) 'Hanging garden' with *Desmophyllum dianthus* and *L. pertusa* underneath a consolidated seabed crust. (C) Black coral colony (white bush) with a medusa-head (*Gorgonocephalus* sp.) above a *L. pertusa* colony. The dead coral framework is plastered with hormatiid anemones. (D) *Lophelia* patch reef with bizarre glass sponges (*Aphrocallistes bocagei*). (E) Lace coral (*Stylaster* sp.) colonies (white) growing on dead coral framework. (F) The anemone *Phelliactis hertwigi* next to *L. pertusa*

Photos A, C, D and F IFREMER, CARACOLE, 2001, B, E. IFREMER, ARK 19/3a, 2003

Blake Plateau off the coast of North Carolina, United States, at 640 to 869 m depth (Stetson et al., 1962; Reed, 2002a). More than 200 steep-sloped coral mounds up to 146 m high occur in an area measuring 6 174 km². *E. rostrata* forms reefs along the edges of some southwest Pacific oceanic banks such as the Chatham Rise (Probert et al., 1997). Although there has been no targeted survey of *E. rostrata* reefs in the Pacific, there is a high likelihood that extensive reef areas will be present.

Goniocorella reefs

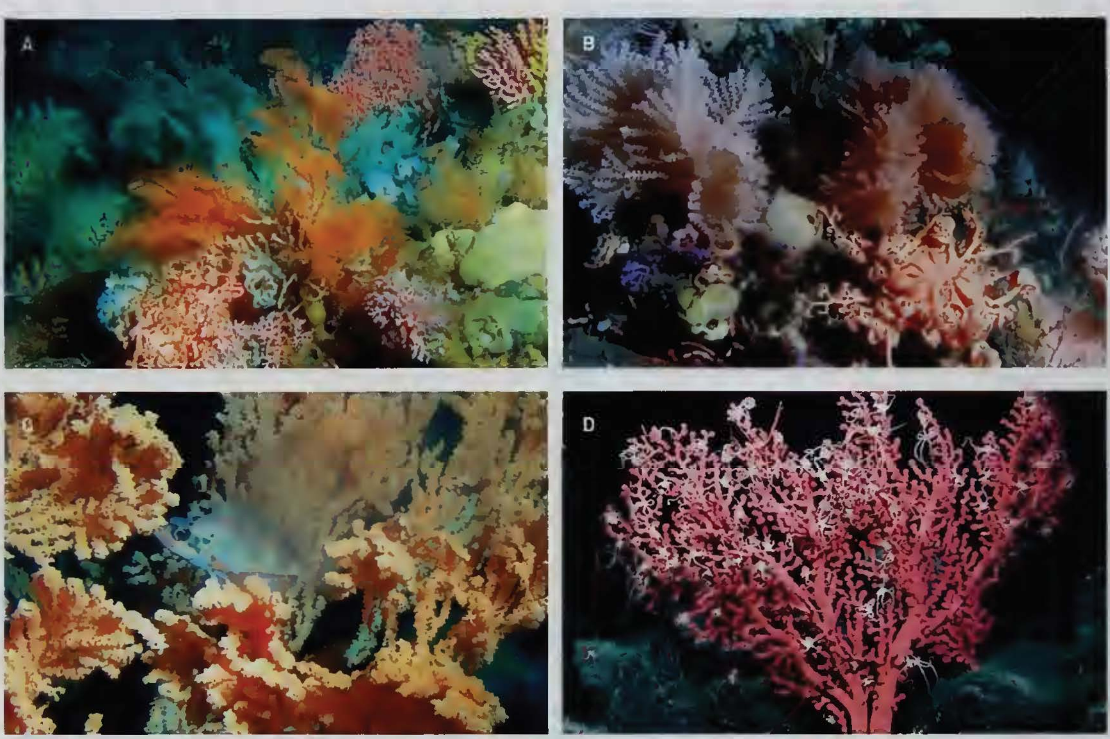
Goniocorella reefs are restricted to the southern hemisphere with the main distribution in New Zealand waters. Dense, low-relief patch reefs of *G. dumosa* have been photographed on the Chatham Plateau (Dawson, 1984), or have been trawled up, especially from the northern slope of the plateau (Probert et al., 1997). Squires (1965) described a mound 40 m high and covered with *G. dumosa* from this plateau. However, attempts to revisit this mound using Squires' navigation data failed during a recent German expedition (Hoernle et al., 2003). Instead, scientists found an 11-km-long ridge structure packed with *G. dumosa* patch reefs to the south of Chatham Island on the continental slope at 450 to 700 m depth.

Solenosmilia reefs

Although *Solenosmilia* has a cosmopolitan distribution, reefs formed by *S. variabilis* have been documented only on the south Tasmanian seamounts area at depths of around 1 000 m (Koslow et al., 2001). The corals support a rich associated fauna including gorgonian and black corals, hydrozoans, sponges, echinoderms and fishes, especially orange roughy (*Hoplostethus atlanticus*).

Octocoral ecosystems

In cold waters swept by currents and rich in nutrients, gorgonian octocorals are common members of the seabed communities, often closely associated with stony cold-water coral reefs. Their large colonies form distinct habitats either within or adjacent to stony coral ecosystems. Analysis of the lifespan of octocorals indicates that some of the large colony-forming species



NMFS

Rebecca Reuter, NMFS

Victoria O'Connell

NOAA Ocean Explorer

(A) Coral garden off Adak Island (Aleutians) containing black corals (*Antipathes* sp.), gorgonian octocorals, sponges and a basket star. (B) Octocorals from Adak Canyon (Aleutians) with brittle stars. (C) Juvenile sharpchin rockfish between *Primnoa resedaeformis* from the Gulf of Alaska. (D) *Paragorgia arborea*, the home of associated shrimp and crabs, Gulf of Alaska

such as *Primnoa resedaeformis* can live for centuries (Risk et al., 2002; Andrews et al., 2002).

An increase in the number of studies of deep and cold-water habitats being carried out has led to the discovery of a growing number of octocoral-dominated ecosystems, which are being described as octocoral gardens or forests. The region that probably harbours the highest abundance and diversity of octocorals is the thousand-mile-long Aleutian Island chain between Alaska and Russia, in the northern Pacific (Stone and Malecha, 2003). Rich octocoral communities are also found in the neighbouring Bering Sea and Gulf of Alaska (Heifetz, 2002). In these areas, the deep shelf and continental slope is punctuated with volcanic seamounts and island archipelagos that act as sieves for nutrient-rich water flows.

The octocoral gardens are rich in rockfish (*Sebastes*), with six species that seek protection within and between the coral colonies (Krieger and Wing, 2002). Other common protection seekers are shrimp and crustaceans. The associated suspension feeders consist of feather stars (crinoids), basket stars (*Gorgonocephalus*) and sponges. Some species have been identified as polyp feeders on the corals, and these include sea stars (*Hippasteria heathi*), nudibranchs (*Tritonia exulsans*) and snails (Krieger and Wing, 2002).

Another octocoral hotspot is the Gully, off Nova Scotia, Canada (Figure 22). The Gully is the largest submarine canyon of the eastern Canadian continental margin and is more than 70 km long and 20 km wide (Harrison and Fenton, 1998). The main canyon axis is 150 to 2 700 m deep. The Gully is a major habitat for coral communities such as Alcyonacea (five species), Gorgonacea (six species) and Scleractinia (five species). An analysis of the associated fauna of *Paragorgia arborea* yielded 97 species while 47 species were identified associated with *Primnoa resedaeformis* (Buhl-Mortensen and Mortensen, in press; Buhl-Mortensen and Mortensen, 2004). These observations underline the importance of octocoral colonies as major habitat-formers and providers. Undoubtedly, there must be many more regions in deep and cold water where octocoral ecosystems await discovery.

3. Ecology

Several important biological and ecological aspects of cold-water corals and of their habitats and where they occur have already been highlighted. Here additional information on the productivity and resilience of cold-water corals is presented with a focus on:

❑ depth range
❑ temperature and salinity limits
❑ nutrition and food source
❑ growth rates and longevity
❑ reproductive and molecular ecology
❑ predation and parasitism of corals
❑ coral bioerosion.

DEPTH RANGE

Cold-water corals are frequently referred to as 'deep-water' corals, as most findings and observations of these organisms come from deeper water. However, the term 'deep-water corals' can be misleading, as *Lophelia* has been found in Norwegian fjords as shallow as 39 metres, and other cold-water coral groups have been observed in waters less than 200 metres deep (Figure 12). This indicates that hydrographic conditions and the geomorphology of the seabed, combined with environmental parameters such as temperature, salinity and nutrient supply (see below), are more important factors determining and limiting the distribution and growth of cold-water corals than depth (i.e. hydrostatic pressure). In high latitudes, these physical and environmental factors, and cold-water corals, can be found in relatively shallow areas, whereas in the tropics and subtropics these conditions generally occur at greater depths underneath warm-water masses.

TEMPERATURE AND SALINITY LIMITS

Knowledge of temperature and salinity limits for cold-water corals is incomplete. Historically, few relevant measurements have been made at coral sites, or they remain unpublished, and as yet the effects of temperature and salinity changes on coral ecosystems are not well understood. *Lophelia pertusa* tolerates temperatures between 4 and 13°C (Freiwald, 2002). Studies from the Faroe-Shetland Channel, northeast Atlantic, provide evidence that colder temperatures – even reaching subzero values for a short period of time – can be tolerated by this species (Bett, 2001). However, when records of *L. pertusa* are related to depth in the Faroe-Shetland Channel, it is clear that this species is not present in the deeper waters derived from the Arctic (Roberts et al., 2003). At the other extreme, live *L. pertusa* and *Madrepora oculata* from mounds off Santa Maria di Leuca, Ionian Sea, thrive at temperatures of 13.8°C at 550 to 1 100 m depth (Taviani et al., in press).

The Mediterranean Sea provides a unique example of a natural global change laboratory. Since the end of the last glacial period, the waters of the Mediterranean deep-sea basins have warmed up considerably. During the cooler climatic periods, cold-water corals were widely distributed on the Mediterranean's continental margins and seamounts (Delibrias and Taviani, 1985). Since then, the diversity of cold-water corals and associated fauna

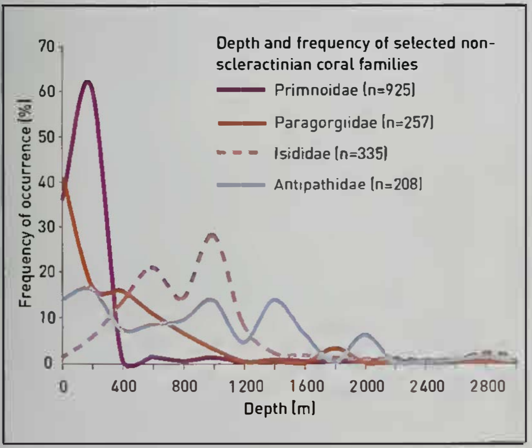
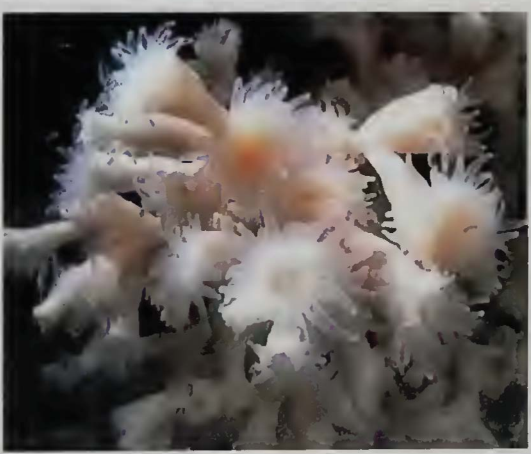


Figure 12: Coral families in the northeast Pacific

Modified after Etnoyer and Morgan, in press


The JAGO-Team

***L. pertusa* with expanded tentacles ready to capture zooplankton**

Figure 13: (A) View of the outer living zone and inner dead coral framework zone of *L. pertusa* from the Sula Reef. (B) Cross-section of *L. pertusa* skeleton showing the presumed annually deposited incremental layers

Photo A the JAGO-Team, B Kai Kaszemeik, IPAL

has decreased considerably until the present (Di Geronimo et al., in press).

The spread of *Lophelia* northwards in the northeast Atlantic during the climatic warming that followed the last glacial period can be reconstructed by radiocarbon dating of fossil corals. During the last glacial maximum, 18 000 years ago, *Lophelia* occurred in the central northeast Atlantic on the seamounts off Gibraltar and off northwest Africa, between 33 and 35°N (Schröder-Ritzrau et al., in press). Around 12 000 to 10 000 years ago, the coral began recolonizing the carbonate mounds found in the Porcupine Seabight and Rockall Trough at 51 to 55°N (Frank et al., in press). The oldest radiocarbon ages obtained from *Lophelia* in Norwegian waters (from 60 to 64°N) cluster around 8 600 years ago (Mikkelsen et al., 1982; Hovland et al., 2002). This postglacial northward movement of *Lophelia* from the central northeast Atlantic to the mid-Norwegian Shelf took place within 10 000 years and represented a northwards change in limit of 3 500 km. During the same period, the Mediterranean coral ecosystems were in decline due to sea warming.

Lophelia pertusa tolerates salinity values from as low as 32‰ in Scandinavian fjords to at least 38.78‰ in the Ionian Sea (Strømgren, 1971; Taviani et al., in press). Geographic regions where coral ecosystems may be vulnerable either to an increase or to a decrease in salinity are the Mediterranean Sea and the Scandinavian fjords. In the latter case, such as in the Swedish Kosterfjord, *Lophelia* lives only a few metres below a permanent brackish surface water lens (Wisshak et al., in press). Similarly, where *Lophelia* has colonized oil installations in the North Sea, it is found only at water depths where there is year-round influence of Atlantic water masses, reflecting this species' predominant association with salinities of 35‰ and temperatures of 7 to 8°C (Roberts, 2002).

The temperature and salinity limits of *L. pertusa* indicate that areas providing stable environmental conditions are the preferred sites of coral growth. Changes in these fundamental factors may cause local extinction or geographic expansion of communities. However, changes in seawater temperature and salinity are beyond any regional management influence but are related to global change affecting all environments. Therefore, defining environmental boundary conditions for corals is essential for:

- the assessment of coral habitats living at biogeographic boundaries
- conducting probability studies of potential coral habitats in yet unexplored regions of the oceans (for example remote seamounts and oceanic banks).

NUTRITION AND FOOD SOURCES

Little information on the nutrition and food sources of cold-water corals is available. It is most likely the corals feed on live plankton and suspended particulate organic matter that is captured by the polyp tentacles. Visual observations carried out with boreoscope cameras mounted on the manipulator (robotic arm) of a manned submersible next to a living colony, and in aquaria experiments, showed that the polyps of *L. pertusa* prey upon zooplankton up to 2 cm in size (Freiwald, 2002; Mortensen, 2001). It has been suggested that the coral may acquire nutrients from bacteria associated with hydrocarbon seeps (Hovland et al., 1997). A preliminary biochemical study of the soft tissue of *L. pertusa* and *M. oculata*, however, yielded no evidence to support this supposition (Kiriakoulakis et al., in press). We also have little or no information on what prey items different species of coral utilize, or how significant the input of resuspended material could be (Frederiksen et al., 1992).

Unlike tropical coral reef habitats, where almost all nutrients and food are generated and subsequently utilized within the system through photosymbiosis, cold-water habitats depend on pelagic production. The quality and availability of nutrients and food particles determine the fitness of coral habitats. To improve understanding of

Box 3: *Lophelia* growth rates from colonization of man-made structures

L. pertusa has been reported to have colonized man-made structures such as submarine cables (Duncan, 1877; Wilson, 1979a) and shipwrecks (Roberts et al., 2003) as well as the Brent Spar oil storage buoy (Bell and Smith, 1999) and other oil platforms in the North Sea (Roberts, 2002; and see Chapter 4). Since these colonization events must have happened after the hard substrate was introduced, the maximum time that coral growth could have taken place is known.

This information, summarized in Table 5, gives estimates of the rate of skeletal linear extension of between 5 and 26 mm per year. Clearly these estimates are based on the assumption that the coral settled as soon as the structure was in place, and as such they are minimum extension rates. If a coral larva settled several years later, its extension rate must have been significantly higher than estimated. This could explain the discrepancy in estimates between the Beryl and Brent Field corals (Table 5).

Additional evidence on the rate of skeletal linear extension of *L. pertusa* has come from analysis of carbon and oxygen stable isotopes. These estimates vary from 5 mm per year (Mortensen and Rapp, 1998) to 25 mm per year (Mikkelsen et al., 1982; Freiwald et al., 1997; Spiro et al., 2000) and so support linear extension rate estimates from colonization data.

Table 5: Summary of data on *Lophelia pertusa* colonization of man-made structures

Location (depth, m)	Substrate	Maximum growth time (years)	Maximum linear extension (mm)	Linear extension rate (mm/year)	Reference
Northwest Spain (955-1 006)	Cable	6	45	8	Duncan, 1877
Bay of Biscay (800)	Cable	38	230	6	Wilson, 1979b
West of Shetland (400)	Shipwreck	82	~1 000	12	Roberts et al., 2003
North Sea (60)	Brent Spar storage buoy	20	540	26	Bell and Smith, 1999
North Sea (100)	Beryl Alpha SPM2	23	120	5	Roberts, 2002

coral habitat function and longevity, assessment studies should study trophic relationships including pelagic production.

GROWTH RATES AND LONGEVITY

Rates of annual skeletal extension in habitat-forming cold-water stony corals have been variously estimated for *L. pertusa* and *Oculina varicosa* as 4 to 25 mm and 11 to 16 mm, respectively (Rogers, 1999; Reed, 1981). Such growth rates are a magnitude lower than those of branching tropical symbiotic corals which grow at a rate of 100 to 200 mm per year (Buddemeier and Kinzie, 1976) but are about the same as most massive tropical corals.

The lifespan of *Lophelia* colonies is not yet known. Mature *Lophelia* colonies can be divided into an upper living zone and a lower dead coral framework zone (Figure 13A; Freiwald and Wilson, 1998). Counts of the number of polyp generations in the living zone from various *Lophelia* locations in the northeast Atlantic reveal a consistent number rarely exceeding 20 polyps within sequentially grown colony branches. After each formation of a new daughter polyp the growth rate of the parental polyp decreases considerably, whereas the newly formed daughter polyp continues to grow at a high rate. It seems that each new polyp generation coincides with the formation of a new incremental calcareous layer that is secreted around the skeleton of the older polyps belonging to the living zone only. In cross-sections, these incremental layers resemble the formation of 'tree rings' (Figure 13B).

Assuming that under ideal conditions one polyp is generated per year, the lifespan of the living zone of *L. pertusa* colonies does not exceed 20 years. Depending on various environmental factors, 20 living polyp generations can attain a colony height of up to 35 cm in the mid-Norwegian Sula Reef, but only 20 cm or less on the carbonate mounds off western Ireland (Kaszemeik and Freiwald, 2003). It is clear that species such as *L. pertusa* are highly variable in their gross morphology and that this variability probably reflects differing environmental, ecological and competitive conditions.

More is known about growth rates and lifespans of some gorgonian corals such as *Paragorgia* sp., *Primnoa resedaeformis*, *Keratoisis* spp. and *Corallium* spp. (Andrews et al., 2002; Andrews et al., in press; Grigg, 1974; Risk et al., 2002). All studies point to lifespans of 100 to 200 years for mature colonies. The low growth rates and extended longevity clearly highlight the vulnerability of cold-water corals. Once the coral grounds are disrupted, for example by trawling, and providing that recolonization does take place, it would be many decades or even centuries before the former habitat complexity of mature reefs or giant gorgonian trees were restored.

REPRODUCTIVE AND MOLECULAR ECOLOGY

Knowledge about reproductive seasonality, gamete quality, fecundity and larval supply of habitat-forming species, supplemented by molecular genetic methodologies, is essential for understanding ecosystem functions and recovery potential following a disruptive event, and for making recommendations for conservation and management practices.

However, little is known of the basic reproductive biology of habitat-forming cold-water corals (Waller, in press). Preliminary information on reproductive biology is available for *L. pertusa*, *M. oculata*, *O. varicosa*, *Enallopsammia rostrata*, *Solenosmilia variabilis* and *Goniocorella dumosa* (Brooke and Young, 2003; Burgess and Babcock, in press; Waller, in press). While the majority of warm-water stony corals are hermaphroditic, the habitat-forming cold-water corals studied have separate sexes and spawn their gametes into the water column for external fertilization.

Gametogenesis occurs continuously in *E. rostrata* (Burgess and Babcock, in press) whereas in other species it is seasonally controlled (Brooke and Young, 2003; Waller, in press). In the absence of light and below the permanent thermocline, deep tidal currents and annually occurring changes in the physical properties of water masses, e.g. winter water cascading events from the continental shelf down to the continental slope, may be factors in the synchronization of reproductive processes. Free-swimming larval stages are known only from *O. varicosa* (Brooke and Young, 2003) but must occur in other species. *Oculina* larvae are small (160 µm), ciliated and have been observed swimming actively in an aquarium for one to two weeks before commencing benthic settlement behaviour.

Investigation of the genetic structure of a species in a locality will determine whether the population is made up of one or a number of smaller local populations. In the latter case, the degree of gene flow occurring sheds light on how isolated these local populations are from each other. When the species is genetically uniform, the loss of a local population theoretically can be compensated for over time because the gene pool has not been affected, and gene flow will eventually permit natural recolonization. In contrast, losses from genetically diverse species will have much more serious consequences.

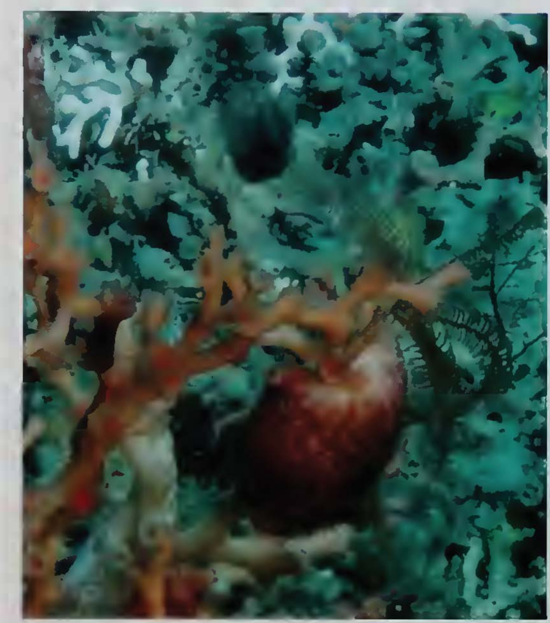
The genetic structure of *L. pertusa* populations was studied by Le Goff and Rogers (2002), Le Goff-Vitry et al. (2004) and Le Goff-Vitry and Rogers (in press). In the northeast Atlantic, *L. pertusa* does not form one panmictic population. Instead, there is a high genetic differentiation between subpopulations in fjords and those offshore. Along the continental margin, the genetic differentiation can be regarded as moderate, suggesting sporadic, but not continuous, gene flow through larval dispersal over long periods of time. Significant degrees of inbreeding were detected at several sites indicating substantial proportions of self-recruitment within these subpopulations.

For instance, the Darwin Mounds subpopulation at 950 m depth in the northern Rockall Trough revealed a high proportion of clones and low gene diversity. This observation supports histological data by Waller and Tyler (in press) who could not detect any reproductive coral in this area. The Darwin Mounds area (Figure 19) has been intensely trawled and damage to corals has been documented. Further trawling will have a severe effect on the survival of this subpopulation. Fortunately, the Darwin Mounds area has recently been protected under a European Fisheries Regulation that prohibits the use of bottom trawl and will also become a special area of conservation under the European Habitats Directive (92/43/EEC).

A comparative molecular genetic study has been performed on the common precious coral *Corallium lauuense* in the Hawaiian Archipelago, Pacific Ocean (Baco and Shank, in press). Genetic structure from widely distributed populations within and among eight Hawaiian seamounts was analysed. Little population differentiation was found between seamount and island populations but significant levels of inbreeding were detected, suggesting that *C. lauuense* populations are primarily self-recruiting.

PREDATION AND PARASITISM OF CORALS

Mass occurrences of predatory species that graze upon the tissue and skeleton of corals play a vital role in ecosystem functioning. In shallow-water ecosystems such events include outbreaks of the crown-of-thorn starfish (*Acanthaster planci*) in the Australian Great Barrier Reef (van der Laan and Hogeweg, 1992). Although all groups of echinoderms are present in almost all cold-water coral ecosystems, a distinct predatory echinoderm-coral relationship has only been reported from the Aleutian Islands octocorals (Krieger and Wing, 2002), where the starfish *Hippasteria heathi* appeared to be grazing selectively on *Primnoa resedaeformis*. In *L. pertusa* and *M. oculata* patch reefs on carbonate mounds in the Porcupine Seabight and Rockall Trough, the starfish *Porania* sp. is commonly found within the living polyp zone. Despite the large number of fish species that aggregate in the various cold-water coral reefs and reef patches, no coral-grazing fish, such as parrotfish, have been observed. Although some gastropods and crustaceans are known as coral tissue and mucus grazers, they hardly form a threat either to stony corals or to octocorals.


IFREMER, CARACOLE, 2001

A starfish curled around and apparently grazing on *Lophelia pertusa*, southwestern Rockall Trough, northeast Atlantic

The occurrence of parasites can reduce the fitness of the host organism. Documentation of parasitic organisms in cold-water corals is plentiful. Stony corals, octocorals and stylasterid corals are parasitized by several groups of organisms such as ascothoracid crustaceans (Grygier, 1985; Grygier, 1990; Grygier and Cairns, 1996), copepod crustaceans (Zibrowius, 1981; Buhl-Mortensen and Mortensen, in press; Buhl-Mortensen and Mortensen, 2004) and the foraminifer *Hyrrokkin sarcophaga* (Cedhagen, 1994; Freiwald and Schönfeld, 1996). There are no studies of the impact of parasites on the fitness of host corals, however.

REEF FRAMEWORK GROWTH AND CORAL BIOEROSION

Growth of the reef framework depends on a number of variables and cannot be extrapolated from the growth rate of corals. Factors that need to be considered are: local temperature regimes and currents, the inclination of the seabed, the frequency and degree of physical disturbances such as storms, and the frequency and degree of biological disturbances. All these factors exert a strong influence on vertical growth potential. It is known that tropical coral reefs grow vertically less than 1 cm per year.

A natural destructive process affecting stony coral

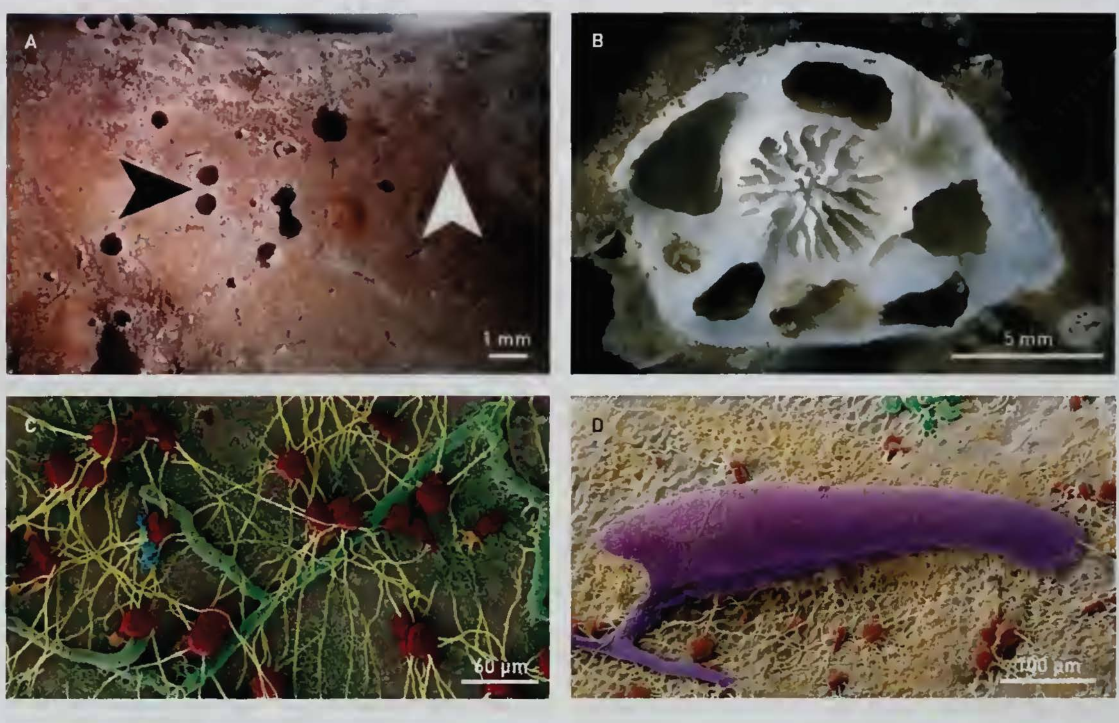


Figure 14: Bioerosion, a major destructive process in the degradation of cold-water coral reefs: (A) External view of a bioeroded *Lophelia* skeleton with circular apertures of boring sponges (black arrow) and comma-shaped apertures of boring bryozoans (white arrow). (B) Broken *Lophelia* skeleton showing the boring sponge cavities. (C) SEM image of a resin cast of *L. pertusa* containing a boring fungi consortium. (D) SEM image of a resin-casted boring bryozoan that produces the comma-shaped apertures (see A)

Lydia Beuck, IPAL

reef growth both in warm and cold water is related to the biological degradation of the calcareous framework known as 'bioerosion'.

Bioerosion results in the disintegration of calcareous skeletons through the activity of organisms (Neumann, 1966). This may be caused by the mechanical removal of skeletal carbonates (bioabrasion), or chemical dissolution (biocorrosion), or a combination of both (Golubic and Schneider, 1979). The different bioerosion processes result in the alteration of calcareous skeletons to smaller-sized grains and in the collapse of reef frameworks (MacIntyre, 1984; Günther, 1990; Wood, 1995).

In cold-water reefs, bioerosion is one of the key factors that weakens the stability and thus the longevity of old coral colonies (Boerbom et al., 1998; Freiwald and Wilson, 1998). In contrast to tropical coral reefs, light-dependent boring organisms such as cyanobacteria and algae are not present in cold-water reefs. Here, the boring bioeroder community consists of fungi, sponges, foraminiferans, bryozoans and phoronid worms (Figure 14; Beuck and Freiwald, in press; Wisshak et al., in press). The most vulnerable zone with the most intense infestation and diversity of bioeroders in coral skeletons is the dead coral framework just underneath the zone of the living polyps. The composition and abundance of the bioeroder community seems to vary in different *Lophelia* locations from both sides of the North Atlantic, as does the framework stability and structural complexity of coral habitats.

The rate of bioerosion and the taxonomic composition of the bioeroder community in cold-water reefs has yet to be studied and correlated with local environmental factors. Preliminary data already indicate the potential to use the 'bioerosion impact' on cold-water corals as a means to decipher biological fitness.

Some promising initial research has shed light on several important ecological factors and environmental influences affecting cold-water corals. It has also identified gaps in our knowledge and suggests that more research is required to better inform the development of conservation and management strategies.

4. Threats

Since about the mid-1980s, the deeper parts of the world's oceans have come increasingly under pressure from human activities to exploit their biological and mineral resources. In the 1990s the exploration of deep-water ecosystems with sophisticated camera systems showed damage and habitat losses in most oceans of the world. This raised concern among academia as demonstrated by the call for action from more than 1 000 scientists and 69 countries at the annual meeting of the American Association for the Advancement of Science in Seattle, United States, in February 2004. Documented and potential sources of threats to cold-water corals are:

- commercial bottom trawling and other bottom fishing
- hydrocarbon exploration and production
- cable and pipeline placement
- bioprospecting and destructive scientific sampling
- other pollution
- waste disposal and dumping
- coral exploitation and trade
- upcoming threats: sequestration of CO_2, other mineral exploration and increased atmospheric CO_2.

COMMERCIAL BOTTOM TRAWLING AND OTHER BOTTOM FISHING

There is growing concern among scientists, fisheries managers and the fishing industry about the wider effects of fishing on marine ecosystems (Turner et al., 1999). Open-access policies and subsidy-driven over-capitalization have helped put marine fisheries in a global crisis (Pauly et al., 1998; Pauly et al., 2003). The collapse of fish stocks and subsequently fisheries is generally attributed to overfishing, but other effects on the ecosystem have become more apparent recently. One such effect is unintentional or incidental damage to marine organisms (including bycatch) or sea-floor habitats by bottom-fishing activities (Morgan and Chuenpagdee, 2003). The ambivalent relationship between coral occurrences and fishery interests is not a new phenomenon. In 1915 the French biologist Joubin published a paper entitled: 'Les coraux de mer profonde nuisibles aux chalutiers' (Deep-water corals, a nuisance for trawlers). Fishing gear can be described as active (physically dragged along the bottom) or passive (positioned and then gathered after a period of time). Active gear that comes into contact with the sea floor is

Figure 15: Sketch showing the design and impact of a bottom trawl equipped with rollers and heavy doors

Joe Shoulak, MCBI

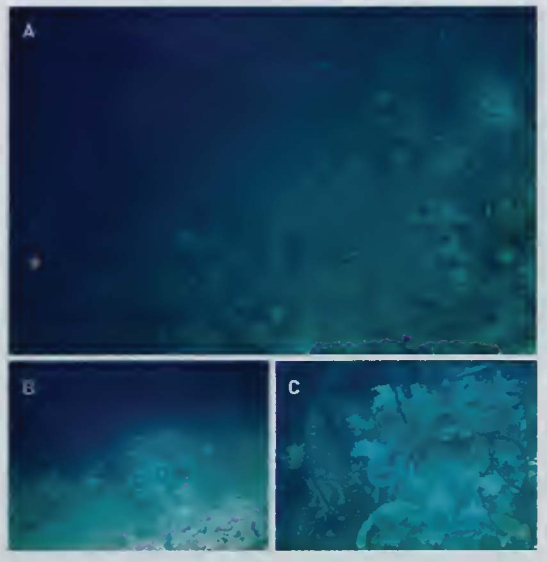


Figure 16: Lost gillnets and their impact on the coral ecosystem with examples from coral-covered carbonate mounds off western Ireland: (A) A ghost-fishing gillnet continues actively fishing for a long time. (B) Failed recovery of a gillnet that was supposedly lost when dragged through the corals during a recovery attempt. (C) Close-up of (B) showing the unselective bycatch of live and dead corals. Scavenging crabs are attracted by the smashed corals

Photo A IFREMER, CARACOLE, 2001, B-C IFREMER, ARK-19/3a, 2003

considered the greatest threat to cold-water coral reefs and includes bottom trawls and dredges.

Bottom trawls are mobile fishing gear towed behind a vessel. A cone-shaped, bag-like net is held open by a solid beam or by vanes (known as doors) made of wood or steel. Large trawl doors can weigh as much as 6 tonnes. During the towing, the doors are in contact with the seabed and keep the net open by the force of water pressure. To secure contact between the seabed and the net, the groundline can be weighted by chains or cables with heavy discs or rollers, and this enables the trawl to fish over rough seabed with rocks and boulders or coral-rich grounds (Figure 15). Usually the bottom of the net is reinforced or protected to prevent it tearing; the nets can be as large as 55 m across and 12 m high. Bottom trawls are used to catch crustaceans, gadoids, flatfish, rockfish and other bottom-living fishes.

Due to their widespread use, bottom trawls have the largest disruptive impact of any fishing gear on the seabed in general and especially on coral ecosystems (Morgan and Chuenpagdee, 2003). Bottom trawling on deep shelves and along the continental margins down to 1 500 m depth and beyond increased dramatically in the late 1980s (Gordon, 2003; Roberts, 2002; Fosså et al., 2002). On a typical 15-day trip in the Rockall Trough, northeast Atlantic, a trawler sweeps approximately 33 km² of seabed (Hall-Spencer et al., 2002). The detrimental effects of bottom trawling to coral ecosystems are well documented from various locations: the *Oculina* reefs off eastern Florida (Reed et al., in press); *Solenosmilia* reefs on the summits of some south Tasmanian seamounts (Koslow et al., 2001); the oceanic banks in New Zealand waters (Probert et al., 1997); the octocoral gardens in Alaskan waters (Shester and Ayers, in press) and coral grounds off Nova Scotia (Gass and Willison, in press); and *Lophelia* reefs in Scandinavian waters (Fosså et al., 2002), off western Ireland (Hall-Spencer et al., 2002) and in the northern Rockall Trough (ICES, 2002; ICES, 2003).

Although fishermen try to avoid trawling over large coral reefs and coral-topped carbonate mounds, as these form seabed obstacles too rough to be swept over, there is a great deal of direct and collateral damage to coral grounds of low relief. Visual observations provide clear evidence that trawl doors plough through the seabed and smash or disrupt corals. Groundline rollers that keep the net close to the seabed also flatten corals and coral-covered boulders, while the strengthened base of the trawl net can tear or break coral further.

The effects of bottom trawling include a reduction in the structural complexity of coral grounds. Structural complexity is positively correlated with species diversity and enhances survivorship of species. For this reason bottom trawling has been compared by Norse and Watling (1999) to forest clear-cutting: it is converting productive and species-rich large areas into much less productive flattened seabed. The habitat-forming corals and many of the fishes living there are long-lived species. Pauly et al. (1998) demonstrated that a reduction of stocks of long-lived species, characterized by low growth and reproduction rates, through trawling alters the trophic levels within an ecosystem as long-lived species are replaced by short-lived ones.

The northern North Sea has been trawled for demersal fish since the early 1900s (Jennings and Kaiser, 1998). Trawling is particularly damaging to sessile (attached to the substrate) benthic communities such as corals, sponges and bryozoans, and is now known to have scarred the seabed to the west of Scotland since the late 1980s (Roberts et al., 2000). Anecdotal reports from North Sea fishermen and the distribution described by Wilson (1979a) both refer to *L. pertusa* occurrence in the North Sea. Trawling coral bycatch data are scarce but the few available are terrifying. For example, the Aleutian Islands in Alaska contain some of the most abundant, diverse and pristine cold-water coral and sponge ecosystems. From 1990 to 2002, US federal fishery observer data indicate approximately 2 176 648 kg of coral and sponge bycatch occurred in the Aleutian Islands, equivalent to 52 per cent of all coral and sponge bycatch in Alaska (Shester and Ayers, in press).

Further damage caused by bottom trawling may come from sediment resuspension. The effect of sedimentation on corals is not simple but overall there is a negative trend between coral growth rate and sedimentation (Dodge et al., 1974; Dodge and Vaisnys, 1977; Hudson et al., 1982; Dodge and Lang, 1983). There are few published studies on the sensitivity of cold-water corals to sedimentation stress. Shelton (1980) showed that *L. pertusa* was able to clear graphite particles from its oral surface using ciliary currents. More recently Mortensen (2001) examined colonies of *L. pertusa* held in an aquarium for just over a year. Coral growth was reduced in areas of the aquarium where there was highest background sedimentation. However, the results need further verification.

Dredges are also mobile fishing gear that is towed behind vessels. A dredge consists of a frame made of steel with a mounted net behind. Large dredges can weigh 1 tonne and are used to catch clams, scallops and oysters. Dredges reduce the habitat complexity considerably as they take away all organisms, rocks and sediments that are in the gear's track. Bycatch of non-targeted species is high. Dredging over soft substrates stirs up sediment which can smother the communities living in the direction of the sediment-laden current flow.

Bottom-set gillnets are used to catch benthic fish species such as the gadoids (e.g. cod, pollock), flatfish, skates and rays. The nets can measure 100 m in length and often 10 to 20 nets are tied together in a line. Anchors and weights are used in order to hold position and to bring the net close to the seabed. When placed within a coral ecosystem, physical damage derives from the anchors and weights. ROV observations from coral-covered carbonate mounds in the Porcupine Seabight and Rockall Trough at 700 to 900 m depth frequently documented the severe effects of gillnets that were placed within the coral reef patches. Ghost fishing is a well-known problem related to lost gillnets which continue to catch fish (Figure 16A). In some areas, including Norway, lost nets are collected in order to reduce ghost fishing, but the equipment used to collect the nets is destructive to corals and thus not suitable for use in coral reef areas. If gillnets become entangled during recovery, they may be dragged some distance through the coral patches causing further disruption (Figure 16B-C).

Bottom-set longlines consist of a stationary line constructed from a thick monofilament or steel to which shorter lines with baited hooks (up to 12 000 per line) are mounted. Weights are used to sink the gear to the seabed. Bottom-set longlines are used to catch redfish, tusk, ling, sablefish and groupers. Placed in a coral habitat, the line can touch the coral heads and break them off during hauling (see picture below); trails of snagged-off corals are left behind on the seabed. Both *Lophelia* reefs off Norway (Fosså et al., 2002; Husebø et al., 2002) and gorgonian forests off Alaska (Witherell and Coon, 2001) are considered good longline fishing grounds.

Pots and traps consist of frames made of wood, aluminium, steel or vinyl-covered wire which are set out in lines connected by a rope. They are used to catch crabs, lobster, prawns or whelks. Pot and trap fisheries occur in the coral-covered carbonate mounds of Ireland (Freiwald, pers. observation) and, as small fishing boats can be used, are also found in fjord and inshore coral habitats. Although some harm, from impact or snagging, may occur when the pots are launched and hauled, the degree of damage is much lower than that caused by the other fishing gear described above.

Longline fishing gear wrapped around a colony of *Oculina varicosa*, Sebastian Pinnacles, 80 m depth

John Reed, HBOI

HYDROCARBON EXPLORATION AND PRODUCTION

There are a number of regions where the exploration and production of hydrocarbons takes place in cold-water coral areas, such as in the northern North Sea on the Norwegian Shelf, off northwestern Scotland, in the United Kingdom, off Mauritania, and in the Campos Basin off southeast Brazil. Exploration and production of oil and gas could have a severe effect on coral habitats: physical impact from the placement of structures (oil platforms, anchors, pipelines), or impact from discharges of rock cuttings, drilling fluids and chemicals (Davies and Kingston, 1992; Olsgard and Gray, 1995) or discharges from the wells.

There are currently no published studies on the effect of exposure to drilling mud on *L. pertusa* or other habitat-forming cold-water corals. The exposure of warm-water corals to drilling fluids may result in reduced viability (Raimondi et al., 1997), morphological changes (Foster, 1980), altered feeding behaviour (Szmant-Froelich et al., 1981), altered physiology (Krone and Biggs, 1980) or disruption to the pattern of polyp expansion (Thompson and Bright, 1980). The effect of drilling fluids on corals seems to vary between species, within species and with the type and amount of drilling fluid examined (Dodge and Szmant-Froelich, 1985). A laboratory study by Raimondi et al. (1997) indicated that environmentally realistic concentrations of a drilling mud used on the southern Californian shelf edge reduced both the survivorship and viability of the brown cup coral *Paracyathus stearnsii*, but further substantiation of the results is needed.

Some observations show that certain cold-water coral species could be adversely affected by drilling activity. The abundance of *Caryophyllia* species was reduced following drilling on the outer continental shelf and slope off the coast of southern California. The impact detected was associated both with the dose of cuttings received and the time of exposure, and was attributed to the physical effects of increased sediment loading and not to toxic effects (Hyland et al., 1994).

Recent surveys have shown that coral colonies can be found in close proximity to substantial piles of drill cuttings and visual evidence suggests that some colonies have been directly exposed to drilling mud discharges (Roberts, 2000a). Indeed coral colonies recently collected from some platforms have dead polyps on their upper surface where cuttings have accumulated, but living polyps are present beneath the surface exposed to cuttings (Gass, unpublished observations). While this suggests that *L. pertusa* may tolerate some discharge exposure, further work is needed to examine in detail the effect of drilling discharges on coral growth and reproduction (Roberts, 2000b). The occurrence of *L. pertusa* colonies on North Sea oil installations represents an interesting natural experiment, since some colonies show evidence of exposure to drilling discharges while others do not. It is therefore possible to design studies to examine the effect of drilling discharges on the growth and development of an important framework-constructing cold-water coral (Gass and Roberts, 2003).

In many areas, such as European waters, oil companies are required to conduct environmental impact assessments before carrying out most activities (Colman et al., in press). As a result, oil companies have financed much survey work that has discovered cold-water coral reefs, and activities that would have affected these sites has been avoided. Well-regulated exploration for hydrocarbons, including several layers of environmental impact assessment, should reduce the risks to cold-water coral ecosystems. The challenge is to ensure that such regulation occurs everywhere and that the industry works to the highest possible environmental standards. The effects of oil spills and oil spill dispersion techniques on cold-water coral ecosystems are not yet known.

CABLE AND PIPELINE PLACEMENT

Cables for telecommunication and electricity and pipelines for oil and gas are laid across seas and oceans. In shallower seas, these cables and pipelines have to withstand a number of stresses related to geological instability, corrosion and accidental trawling by fishermen, and so are buried within the seabed. With fishing activity moving into deeper waters since the 1980s, cables can nowadays be buried in water depths of 1 500 m. There are no known examples of cables cutting through coral areas, but equally there has been little examination of this possibility. Burying cables will also resuspend sediment which could in turn smother corals living nearby. Ships normally use several heavy anchors which are moved forward during the placement or repair of pipelines and cables. This can physically damge corals in a much larger area than the area eventually damaged by the pipeline or cable itself. Dynamic positioning of the operating ships will eliminate this risk, but is more expensive. The homepage of Kingfisher Information Service and Cable Awareness (www.kisca.org.uk) provides information about cables around the British Isles, some of which pass near coral locations. In Norway pipelines and cables are placed avoiding coral reef areas as far as possible; however there are some cases where this is economically impossible and some kind of guidance is required to assist contractors and authorities in managing these situations.

BIOPROSPECTING AND SCIENTIFIC RESEARCH

During the past decade the research efforts of scientists, biotechnology and pharmaceutical companies have increasingly shifted from shallow-water to deep-water ecosystems, including cold-water corals and sponges. The search for beneficial substances and genes offers a new field of economic importance. The physical impact on the ecosystem can be relatively small or quite large, depending on the gear used to harvest and select organisms. Nowadays, ROVs and manned submersibles are used for sampling in order to retrieve uncontaminated and unharmed organisms, and the use of such high-technology equipment reduces the impact on the environment considerably. If sampling gear which is dragged along the bottom or on the coral reefs is used, then the impact remains high.

The same statement holds for scientific research, where the use of minimally damaging equipment such as ROVs is now common, again limiting the impact on the environment. Formerly, scientific dredging was widely used to obtain samples from deeper water environments including corals.

OTHER POLLUTION

The impact on cold-water corals of other pollution of the seas, such as environmental toxicants, contamination with radioactive substances and sewage is even more uncertain. However, the scientific community is very concerned that chronic pollution of the ocean will result in the depletion of marine ecosystems and biodiversity.

WASTE DISPOSAL AND DUMPING

The oceans have long been regarded as a place where wastes may be disposed of or dumped. Deployed rope and fishing equipment are frequently found on cold-water coral reefs, most of which occurs through accidental loss. The deliberate dumping or disposal of material (such as dredged sediments) on coral reef ecosystems is likely to physically harm corals and reefs by covering them or damaging their structure. This matter should be given serious consideration.

CORAL EXPLOITATION AND TRADE

A total of 140 species of stony coral are traded worldwide, with the best estimate of annual global trade ranging between 11 and 12 million pieces (Wabnitz et al., 2003). With a few exceptions, this coral trade concentrates on tropical corals. Grigg (1989) notes that about 20 species of precious corals are exploited for trade and they belong to three orders: the Gorgonacea, the Zoanthidae (gold corals) and the Antipatharia (black corals), especially from Hawaiian seamounts and the Mediterranean Sea. Drags are used to harvest precious coral grounds off Hawaii (Grigg, 1993), while in the Mediterranean a special coral dragger called the St Andrews Cross, consisting of an iron bar hung with chains, was invented to harvest *Corallium rubrum*. This gear is unselective and damages the habitat as the precious corals are harvested.

UPCOMING THREATS

Sequestration of CO_2

The capture and sequestration of greenhouse gases, mostly CO_2, from the atmosphere into deep waters has been proposed and is being tested as a way of reducing global warming through 'environmental engineering'. A basic assumption is that ocean CO_2 disposal would reduce atmospheric CO_2 (Herzog et al., 1997), but this is not certain and there are concerns about the consequences, including the risk of lowering the alkalinity (pH) of seawater and therefore impairing the ability of corals to lay down calcium carbonate framework structures.

Other mineral exploration

Although no major exploration for non-hydrocarbon minerals has occurred in deep water yet, this may become relevant – especially for nodules of metals in the tectonically active areas of the sea floor. If such exploration occurs, it will be important that all adverse impacts on corals (e.g. direct impact and resuspension of sediments) are assessed and avoided.

Increased atmospheric CO_2

One possible scenario of how present and future CO_2 increases will negatively affect coral reef ecosystems in the next 60 years is briefly summarized below.

Levels of CO_2 in the atmosphere are increasing rapidly. The Intergovernmental Panel on Climate Change (IPCC) has provided several projections of atmospheric CO_2 and sea surface temperature (SST) changes into the next century, of which the most widely accepted is a doubling of pre-industrial concentrations of CO_2 and a consequent SST increase of 1 to 2°C by the year 2065 (Houghton et al., 1996). This rise in CO_2 will also increase levels in seawater that will probably result in a drop in alkalinity and in calcium carbonate saturation of surface seawater by about 30 per cent (Kleypas et al., 1999). This will lead to a sharp decrease in warm-water reef calcification rates (coral carbonate production), in the range of 9 to 30 per cent compared with pre-industrial levels (Gattuso et al., 1999). How these dramatic effects may influence cold-water reefs in deeper zones has yet to be studied; however, a drop in the saturation state affecting deeper water masses will not be beneficial to any calcium carbonate-driven ecosystem.

5. Current state

The sophisticated tools required to examine cold-water coral ecosystems in their natural deep-water surroundings are expensive and only became available to scientists in the past decade, so information on the state of cold-water coral reefs remains incomplete and is also geographically biased. There is still a lot to learn about these ecosystems, especially in areas where spot investigations have revealed the presence of reefs and cold-water coral associations, but where no mapping or more detailed studies have yet been undertaken.

This chapter provides information on the current state of cold-water coral reefs on the basis of case examples from the Atlantic, Indian and Pacific Oceans. Where appropriate, actions taken by national governments to protect, manage and conserve these habitats are referred to.

ATLANTIC OCEAN

Most of the continental shelves of the northeastern and northwestern parts of the Atlantic Ocean provide suitable environmental conditions for cold-water corals to grow. Some of the reefs found in these regions, especially on the eastern seaboard stretching from Norway as far south as West Africa, are among the best studied so far and have provided most of our knowledge on the state of cold-water coral reefs. However, even in these relatively well-known areas of the Atlantic Ocean, new reefs are being discovered on nearly every expedition. The largest *Lophelia* reef (about 100 km²) was found as recently as 2002 (see below).

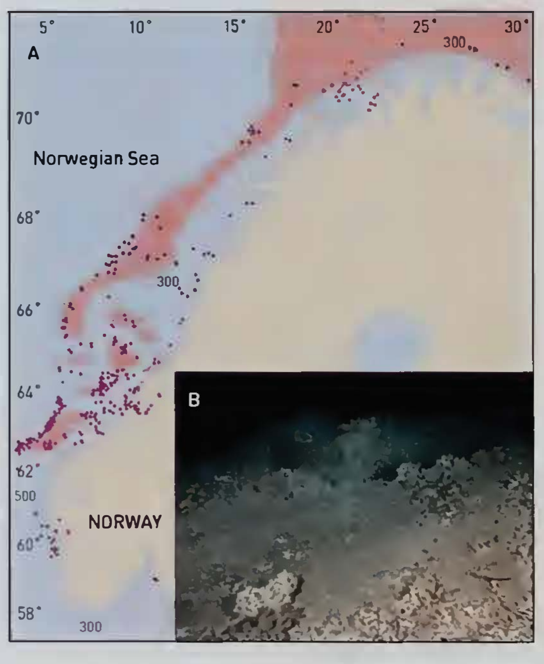


Figure 17: (A) Map of the Norwegian Shelf showing the trawl fields (pink) in relation to major coral occurrences (dots). (B) A trawled coral reef near Iverryggen on the Norwegian continental shelf at 190 m depth

Map A Jan Helge Fosså, IMR, photo B from Fosså et al., 2002

Norwegian Shelf, northeast Atlantic

On the Norwegian Shelf, a large number of cold-water coral reefs have been found along the shelf break and the edges of deep shelf-cutting troughs, including the largest and the shallowest *Lophelia* reefs discovered so far: Røst Reef, southwest of the Lofoten Islands, and Selligrunnen Reefs in the Trondheimsfjord, respectively. There are relatively few records from level shelf seabed. Compilations of coral records collected from scientific cruises and fishing reports indicate that the mid-Norwegian shelf sector between 62°30'N and 65°30'N and the shelf break between 62°30'N and 63°50'N contain the densest occurrence of corals, at 200 to 400 m depth (Fosså et al., 2002).

Since the mid-1980s trawling has taken place along the continental shelf break and on the shelf banks. The more robust rock-hopper trawls appeared at the end of the 1980s and allow larger vessels to fish in rougher and previously inaccessible areas. These fisheries are targeted at Greenland halibut (*Reinhardtius hippoglossoides*), redfish (mostly *Sebastes marinus*) and pollock (*Pollachius virens*). The major trawling grounds are indicated in Figure 17A and show the geographical overlap with coral. In places, the outcome is the complete destruction of a coral reef (Figure 17B).

Norway is the first country to have implemented protection measures for cold-water corals in European waters. Attention was drawn to the need to protect these coral reefs after the Norwegian Institute of Marine Research estimated that probably between 30 and 50 per cent of the cold-water coral reefs then known or expected to be found in Norwegian waters had been partially or totally damaged by bottom-trawling activities (see Chapter 4). In 1999, Norwegian fisheries authorities established a regulation for the protection of cold-water coral reefs against damage due to fisheries through the Sea-water Fisheries Act and the Act related to Norway's exclusive economic zone (EEZ). This national regulation prohibits intentional destruction of coral reefs and requires precaution when fishing in the vicinity of known

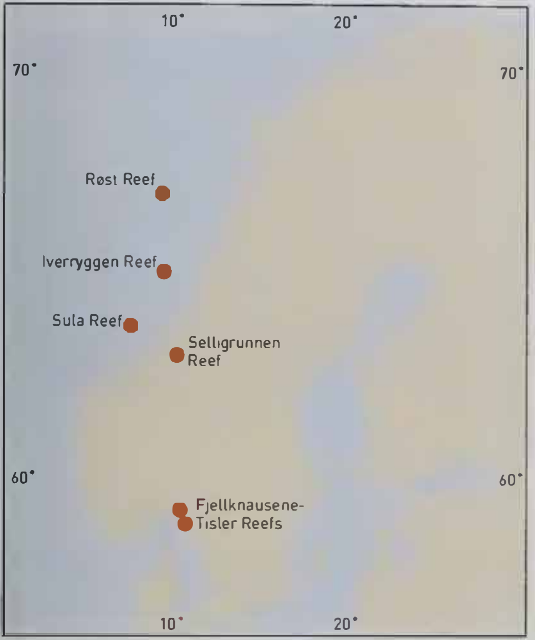


Figure 18: Norwegian coral habitat marine protected areas A Freiwald, using GEBCO bathymetry

reefs. Further, the regulation gives special protection to specified, particularly valuable coral reefs by totally banning the use of fishing gear which is dragged along the bottom and may come in contact with the reefs. So far five reefs have received this special protection: the Sula Reef, Iverryggen Reef, Røst Reef, Tisler and Fjellknausene Reefs (Figure 18). In addition, the Selligrunnen *Lophelia* reef has been temporarily conserved by the environmental authorities through the Norwegian Nature Conservation Act (Table 6).

In the Government's Report No 12 to the Storting (2001-2002), 'Protecting the Riches of our Seas', further measures to protect the cold-water coral reefs are outlined, including a proposal to protect a selection of reefs against all threats as part of a national representative network of marine protected areas (MPAs). Selligrunnen, which rises to 39 m below the sea surface and is the world's shallowest *Lophelia* reef, will probably be amongst the reefs which are permanently protected. The process of establishing a network of MPAs was started in 2001 and is due to end in 2006-2007. The Government has also established a working group to advise on further measures needed to protect cold-water coral reefs. The group's 2003 report dealt with the need for further mapping of the reefs, for improved legislation and for further protection of the reefs against fisheries and other threats.

Protection of cold-water coral reefs will also be considered in the preparations which have recently started in Norway for revising legislation on biological diversity and on fisheries.

Rockall Trough, Darwin Mounds and Porcupine Seabight, northeast Atlantic

Knowledge of coral occurrence in the Rockall Trough, Darwin Mounds and Porcupine Seabight area to the west of Ireland and the UK has increased considerably recently through targeted studies such as those funded by the Atlantic Frontier Environmental Network (AFEN), by the Natural Environment Research Council (NERC) and industrial consortia of the UK (Managing Impacts on the Marine Environment (MIME)), and by the European Commission (EC) (Atlantic Coral Ecosystem Study (ACES) and Environmental Controls on Mound Formation along the European Margin (ECOMOUND) projects).

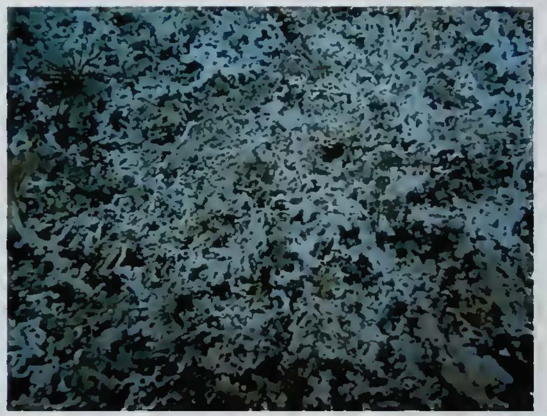
Habitat-forming *L. pertusa* occurs along the relatively shallow flanks of the Rockall Bank and to a lesser degree on Porcupine Bank, at 180 to 300 m depth (Wilson, 1979a; Roberts et al., 2003). Along the slopes flanking the Rockall Trough and the northern and eastern parts of the Porcupine Seabight, coral-covered carbonate mounds have developed at 500 to 1 200 m depth. The *L. pertusa* reefs are found in association with provinces (clusters) of giant carbonate mounds such as the Logachev, Pelagia, Hovland-Magellan and Belgica mounds (Figure 20) which rise 10 to 300 m above the

Table 6: *Lophelia* reefs protected by the Norwegian Government

Reef site	Implementation date	Restrictions	Centre coordinate
Sula Reef	11 March 1999	Trawling	64°09'N 08°00'E
Iverryggen Reef	6 January 2000	Trawling	65°00'N 09°20'E
Selligrunnen (Tr.fj.)	8 June 2000	Human activities	63°36'N 10°30.5'E
Røst Reef	4 January 2003	Trawling	67°25'N 09°00'E
Tisler Reef	18 December 2003	Trawling	58°59.7'N 10°58.5'E
Fjellknausene	18 December 2003	Trawling	59°03.5'N 10°44.5'E

IFREMER, ARK-19/3a, 2003

Trawl mark along a coral-covered carbonate mound, eastern Rockall Trough



IFREMER, ARK-19/3a, 2003

Close-up of a trawled coral area in the Rockall Trough with smashed *L. pertusa*

sea floor. The densest living coral cover is on the summits of mounds where current flow is generally highest. The reefs are home to a rich associated invertebrate and fish fauna.

As on the Norwegian Shelf, the entire area is subjected to deep-sea fishery activities, including intense demersal trawling since 1989 (Gordon, 2003). The main target species are blue ling (*Molva dypterygia*), roundnose grenadier (*Coryphaenoides rupestris*), black scabbardfish (*Aphanopus carbo*) and orange roughy (*Hoplostethus atlanticus*), and some deep-water sharks.

Although no quantitative analysis of the state of coral ecosystems in the wider Rockall-Porcupine area has yet been undertaken, damage created by trawls and

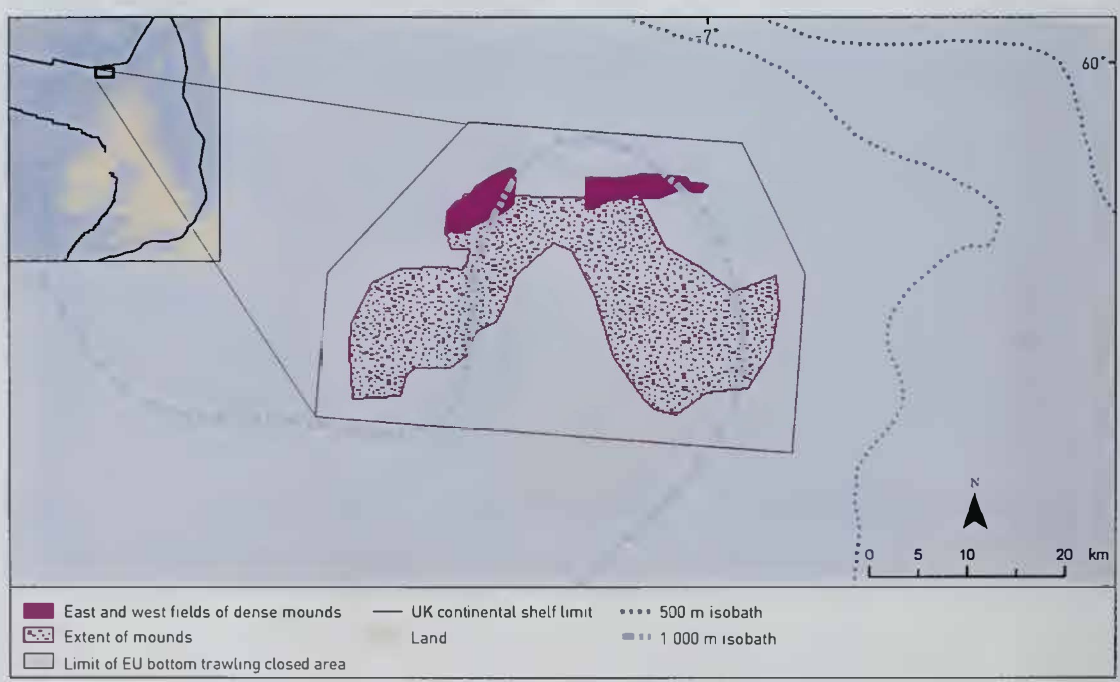


Figure 19: The Darwin Mounds area, which is within the UK 200 nautical mile fisheries limit off northwestern Scotland, and is closed to bottom trawling under European Council Regulation No 602/2004

JNCC

other fishing activities is frequently documented during visual inspections. Some of the carbonate mounds appear too steeply inclined for current trawling gear, but low-relief mounds are much more vulnerable to trawling. Such an area of concern is the Darwin Mounds, a territory of approximately 100 km² in the northern Rockall Trough about 185 km off northwest Scotland (Figure 19). This area is characterized by a series of mounds in almost 1 000 m water depth, and was discovered in 1998 through an environmental survey commissioned by a consortium of oil companies and UK government agencies. The mounds, measuring up to 5 m in height and 75 m in diameter, are most probably 'sand volcanoes' formed by fluid release, and are colonized by *L. pertusa* and a rich associated community. Two years after their discovery, direct evidence that the mounds had been trawled was recorded by Masson et al. (2003).

Following a formal request by the UK Government, in August 2003 the European Commission imposed an emergency measure under Council Regulation (EC) No 2371/2002 on the conservation and sustainable exploitation of fisheries resources under the common fisheries policy. The emergency measure prohibited bottom trawling or the use of similar towed nets operating in contact with the seabed within the Darwin Mounds area. In March 2004 the European Council adopted Regulation (EC) No 602/2004, which will permanently prohibit such fishing methods from 23 August 2004 onwards, covering an area of approximately 1 300 km² (EC, 2004 and Figure 19).

The UK is intending to designate the Darwin Mounds as a special area of conservation (SAC) in accordance with Annex 1 of the Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (92/43/EEC) (Habitats Directive). There is no national legislation which specifically protects cold-water coral species in UK waters, but *L. pertusa* reefs feature in the non-statutory UK Biodiversity Action Plan, which recommends conservation actions, including research on their distribution in UK waters and designation of marine protected areas (e.g. SACs). *L. pertusa* reefs are also on the current draft list of nationally important features which are being identified as part of the Review of Marine Nature Conservation (RMNC) being carried out by the UK Department for Environment, Food and Rural Affairs (Defra).

Evidence of fishing impact (Grehan et al., in press) prompted the establishment in 2001 of an ad hoc group in Ireland to advise policy makers on the need to conserve cold-water corals. This group included representatives from government departments and government agencies, industry, academia and the legal profession. In June 2003, the Irish Government announced its intention to designate a number of offshore sites as cold-water coral SACs under the EU Habitats Directive. The Department of the Environment, Heritage and Local Government, the competent authority, is currently engaged in a process of identifying suitable sites. Formal designation of SACs under the Habitats Directive will take place after a consultative process including stakeholders. Long and Grehan (2002) reviewed the legal instruments available for the conservation of cold-water corals in waters under Irish jurisdiction. They concluded that, in addition to SAC designation, specific technical conservation measures in the EU common fisheries policy would need to be adopted at Community level.

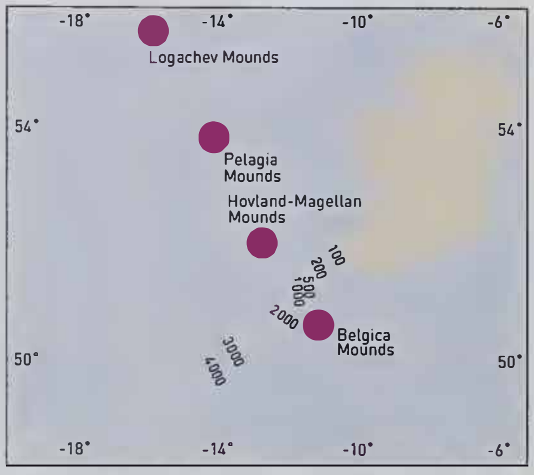


Figure 20: The location of the principal carbonate mound clusters off the west coast of Ireland

A. Freiwald, using GEBCO bathymetry

Azores, Madeira and Canary Islands

Lophelia reefs have been recorded off the Canary Islands and in several sites at depths mostly greater than 1 000 m around the Atlantic islands of Madeira and the Azores. These reefs belong to the belt of cold-water coral reefs stretching from Norway to West Africa.

In light of the increasing threat of mechanical erosion by fishing gear, the EC presented in February 2004 a proposal to amend Regulation (EC) No 850/98 in order to protect vulnerable deep-water coral reefs from the effects of trawling in certain areas of the Atlantic Ocean around the Azores, Madeira and Canary Islands (Figure 21). These areas are currently protected from trawling by a special access regime defined in Council Regulation (EC) No 2027/95, which will cease to apply in 2004. The new regulation will guarantee continuity of protection for these areas as part of European Community legislation.

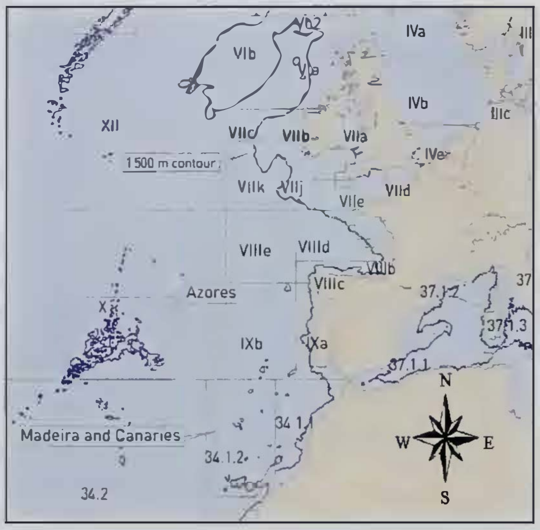


Figure 21: Map of proposed areas in the Atlantic Ocean where the European Commission plans to ban bottom trawling

EC

Cold-water coral reefs in Atlantic Canada

Corals have long been known to exist in Atlantic Canada because they frequently appear as bycatch from bottom-tending fishing gear such as trawls, longlines and gillnets. The Department of Fisheries and Oceans (DFO) at the Bedford Institute of Oceanography (BIO) began studies of cold-water corals in 1997. Interviews with fishers and records of observers on commercial fishing vessels were complemented by video footage, photographs and samples of cold-water corals collected on research cruises throughout Atlantic Canada using DFO research vessels, primarily the CCGS *Hudson*. Corals were found to be widespread off Nova Scotia, Newfoundland and Labrador, and to extend at least as far north as the Davis Straits.

So far, a total of 19 taxa of cold-water corals have been recorded in Atlantic waters off the coast of Canada, belonging to five different taxonomic groups (soft corals, horny corals, stony corals, black corals and sea pens). The Environmental Studies Research Fund (established in 2001 and funded by the oil and gas industry) is providing funding for a major three-year research project to obtain

Figure 22: Proposed and already functioning cold-water coral marine protected areas off Atlantic Canada

A. Freiwald, using GEBCO bathymetry

new information on the distribution, abundance, habitat and biology of cold-water corals and their associated species in Atlantic Canada.

Scotian Shelf, northwest Atlantic

The Scotian Shelf off Nova Scotia provides habitat for octocoral ecosystems, with *Primnoa resedaeformis*, *Paragorgia arborea* and *Acanthogorgia armata* occurring predominantly at depths between 190 and 500 m. These corals are frequently caught as bycatch by bottom-tending fishing gear such as trawls, longlines and gillnets. In 1997, a review of the distribution and status of corals off Nova Scotia was published by the Ecology Action Centre (Breeze et al., 1997). Three major areas on the outer continental shelf and slope are currently under research by the Canadian DFO and Dalhousie University: the Gully, a large submarine canyon on the Scotian Shelf that supports the highest diversity of coral species found in Atlantic Canada (Mortensen and Buhl-Mortensen, in press); the Northeast Channel, with a high density of gorgonian corals; and the Stone Fence, which harbours the first documented *L. pertusa* reef in Atlantic Canada (Figure 22).

The Gully Marine Protected Area (2004)

The DFO is in the final regulatory stages of designating the Gully as the first marine protected area in Atlantic Canada under the Oceans Act (1997) and this process is due to be concluded by mid-2004. Draft regulations were released for public comment in December 2003. The MPA will include general prohibitions against all damaging activities in order to protect every species in this ecosystem, including deep-sea corals. All activities, including research, will be strictly controlled in the canyon. To date, few indications of fisheries damage to corals have been observed. The halibut longline fishery will be permitted to continue within a portion of the MPA.

Northeast Channel Conservation Area, 2002

ROV surveys carried out in 2000 and 2001 in the Northeast Channel confirmed that octocorals are restricted to areas with cobbles and boulders, with 4.8 colonies per 100 m^2 for *Primnoa* and 0.6 to 3.1 colonies per 100 m^2 for *Paragorgia*. About 29 per cent of all transects showed broken or tilted colonies due to longline and trawling activities. The major target fish is redfish (*Sebastes*) and coral bycatch is a common phenomenon.

In 2001 the DFO, working jointly with a fishing industry working group, developed a proposal for a conservation area in the Northeast Channel with the highest density of gorgonian corals. A 424 km^2 conservation area, centred around Romey's Peak, was implemented in June 2002. About 90 per cent of the area is a 'restricted bottom fisheries zone', closed to all bottom fishing gear used for groundfish or invertebrate fisheries (longline, gillnet, trap, mobile). Roughly 10 per cent of the area is a 'limited bottom fisheries zone' and is only open to authorized fishing (Figure 22), and at present only to longline gear and no other bottom fishing gear. An observation programme is required to provide information on the level of fishing activity and on any impact the fishing has on deep-sea corals.

Jim Reid, DFO-Canada

Paragorgia arborea **colony as accidental bycatch from the Scotian Shelf**

Stone Fence Fisheries Closure (2004)

The first documented *L. pertusa* reef in Atlantic Canada was found off the Stone Fence at the mouth of the Laurentian Channel in September 2003. The reef is small, approximately 1 km long and several hundred metres wide. Fishing damage was observed to be heavy: live *Lophelia* colonies were either small or clearly broken in an unnatural manner. Consultations are currently under way with the fishing industry and other interests over a fisheries closure to protect the newly discovered *Lophelia* reef and provide it with an opportunity to recover. A closure under the Fisheries Act for all bottom fishing gear is being put in place in 2004.

US ATLANTIC AND PACIFIC WATERS

Cold-water coral ecosystems and habitats are known from both the Atlantic and the Pacific coasts of the United States, ranging from precious cold-water corals found in the waters of US territories in the western Pacific to cold-water coral and sponge associations in the Gulf of Alaska, the Bering Sea and around the Aleutian Islands, and to the *Oculina* reefs off Florida (see below).

The conservation of cold-water corals in US EEZ waters from 3 to 200 nautical miles (nm) offshore falls under the remit of the National Oceanic and Atmospheric Administration (NOAA), as part of the US Department of Commerce, and eight Regional Fishery Management Councils, which develop and maintain fishery management plans for the areas under their responsibility. These plans require the identification and description of essential fish habitats (EFHs) and within this process provide the means to designate habitat areas of particular concern (HAPCs), in which special conservation and management regulations apply, such as the prohibition of trawling. Although primarily established for the purpose of fishery management, these fishery management plans and the HAPCs provide a varying degree of protection for coral areas. However, a distinction is not always made between cold-water coral reefs and other coral habitats (e.g. warm-water corals).

In terms of new legislative measures, two congressional Acts adopted in 2003 are of particular relevance for the protection of cold-water coral reefs (Hirshfield et al., in press). The Ocean Habitat Protection Act (HR 1690) aims to mitigate the habitat damage caused by rock-hopper trawl gear by banning such gear from structurally complex habitat and controlling both roller size and the areas where such gear may be used. This Act provides funds for mapping areas of complex habitat and gives fishers economic incentives to switch to less destructive fishing gear.

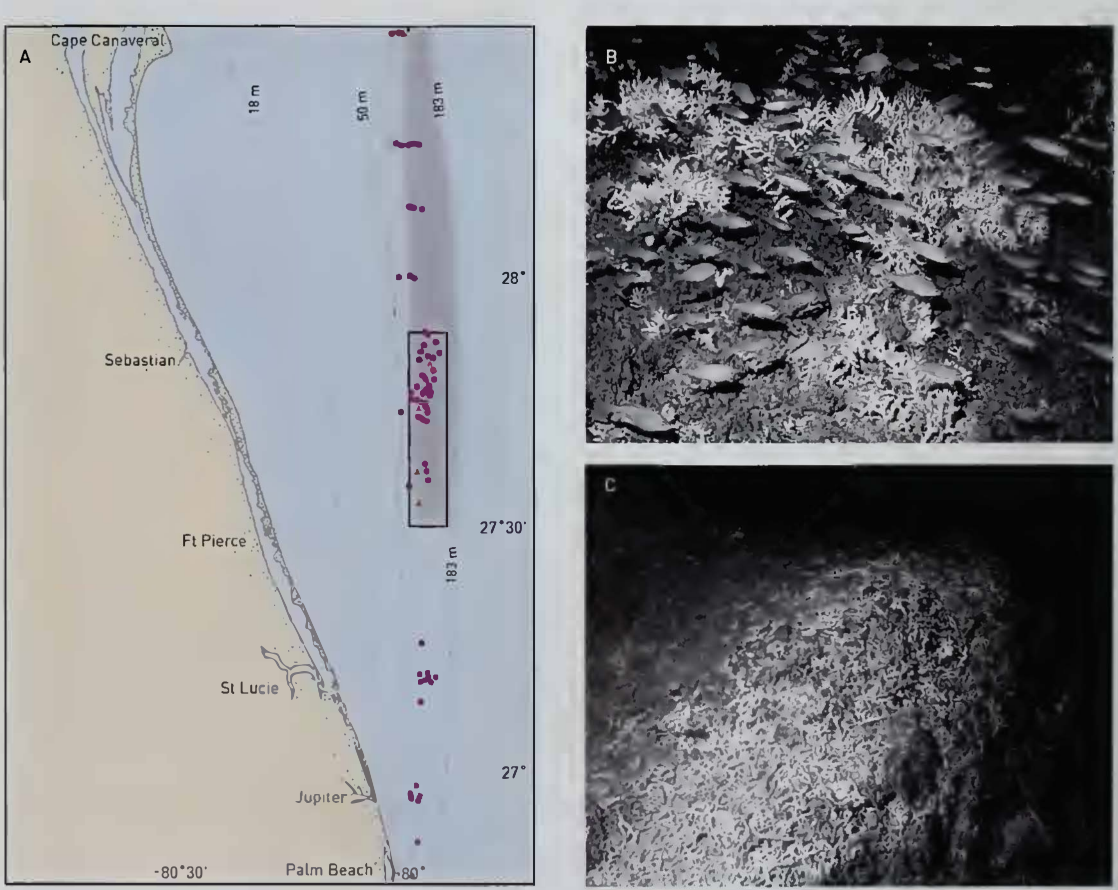


Figure 23: (A) The *Oculina* protected area off the Florida coast with the 1984 315 km² limits (solid rectangle) and the 2000 extension to 1 029 km². Dots indicate *Oculina* coral reefs and triangles mark the reef study sites. (B) Healthy *Oculina varicosa* corals with a school of anthiid fish. (C) *Oculina* reef degraded to coral rubble John Reed, HBOI

The Deep-Sea Coral Protection Act (S 1953) includes the following statement under section 3 (Policy): 'It is the policy of the United States to protect deep-sea corals and sponges, including protecting such organisms that are found in the continental margins, canyons, seamounts, and ridges of the world's oceans, and the habitats of such organisms from damage from gear and equipment used in commercial fishing, particularly mobile bottom-tending gear.' Section 6 (Coral Management Areas) of this Act specifically designates several known and mapped deep-sea coral and sponge locations as coral management areas, in which mobile bottom-tending fishing gear may not be used. These are the Alaska Deep Sea Gardens, the Oceanographer Canyon, the Lydonia Canyon, the *Oculina* reefs off Atlantic Florida, the *Lophelia/Enallopsammia* reefs off the east coast and the Bear Seamount. Non-governmental organizations in the United States are currently working to gather support for these pieces of legislation in both chambers of Congress.

In addition, the National Marine Sanctuaries Act authorizes the Secretary of Commerce to designate and manage areas of the marine environment with special national significance due to their conservation, ecological, historical, scientific, cultural, archaeological, educational or aesthetic qualities. Ten of the 13 sanctuaries designated so far are believed to contain deep-sea corals and/or sponges.

Florida Strait, western North Atlantic

Since the first scientific documentation in the 1960s, the status of the *Oculina* reefs exclusively found 60-100 m deep off eastern Florida has deteriorated (Reed et al., in press). The narrow reef area stretches some 167 km along the shelf break about 32 to 68 km offshore. Submersible dives sponsored by NOAA in the 1970s showed large pristine coral reefs rich in shrimp and fish such as groupers (*Epinephelus niveatus*, *Mycteroperca phenax*), which became a target for commercial and recreational fishery in the following years. This geographically restricted reef area is one of the first known examples where cold-water coral reefs live in close proximity, but in greater depths and further offshore, to warm-water corals.

In 1984, a substantial portion (315 km^2) of this *Oculina* reef ecosystem became the first cold-water coral MPA in US waters. This important decision was prompted by the South Atlantic Fishery Management Council (SAFMC), and trawling, dredging and other disruptive activities such as anchoring are banned within this *Oculina* HAPC (OHAPC). In order to reduce the impact of overfishing of grouper populations, in 1994 the SAFMC closed the OHAPC to bottom hook-and-line fishing for a period of ten years as a precautionary measure to test the effectiveness of a fishery reserve for the restoration of fish stocks. In 2003 this measure was extended indefinitely. The OHAPC was enlarged to 1 029 km^2 in 2000 (Figure 23A).

Despite the great efforts to protect the *Oculina* reefs off eastern Florida, recent ROV and submersible surveys have yielded evidence that illegal trawling is still occurring and that in some places the reef has been converted to coral rubble by these fishing activities (Figure 23B-C). The latest scientific explorations have also discovered *Oculina* reefs outside the OHAPC that are vulnerable to legal fishing impact (Reed et al., in press).

Aleutian Islands

Validated information on fishing impacts on coral grounds is available from the Aleutian Islands (Figure 24; Shester and Ayers, in press). From 1990 to 2002, US federal fishery observer data indicate approximately 2 176 648 kg of coral and sponge bycatch occurred in the Aleutian Islands, equivalent to 52 per cent of all coral and sponge bycatch in Alaska (Shester and Ayers, in press). The targeted fish species are walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), Atka mackerel (*Pleurogrammus monopterygius*), rockfish (*Sebastes* spp.) and sablefish (*Anoplopoma fimbria*) (Heifetz, 2002).

PACIFIC OCEAN AND INDIAN OCEAN

Little is known about the state of cold-water corals in the Pacific and Indian Oceans. Cold-water corals are presumably widely dispersed on the tens of thousands of seamounts found in these oceans, as well as on portions of the continental slopes of islands and continents. Only a small number of these sites have been visually surveyed. Such studies have generally found coral densities declining at depths greater than about 1 000 and 1 500 m (Grigg et al., 1987; Boehlert and Genin, 1987; Koslow et al., 2001). Precious coral densities in the North Pacific have usually been greatest at depths of 100 to 400 m and 1 000 to 1 500 m (Grigg, 1984). Coral abundance also seems to depend upon the productivity of overlying waters (Boehlert and Genin, 1987).

Many seamounts within about 1 500 m of the sea surface have now been commercially exploited for fish and mineral resources. Rogers (1994) lists more than 70 species of fishes commercially exploited on seamounts, and Grigg (1984) notes that about 20 species of precious corals are exploited for global trade, and include the Gorgonacea (the pink, red, gold and bamboo corals), the Zoanthidae (gold corals) and the Antipatharia (black corals).

Since the mid-1960s when extensive coral and fish

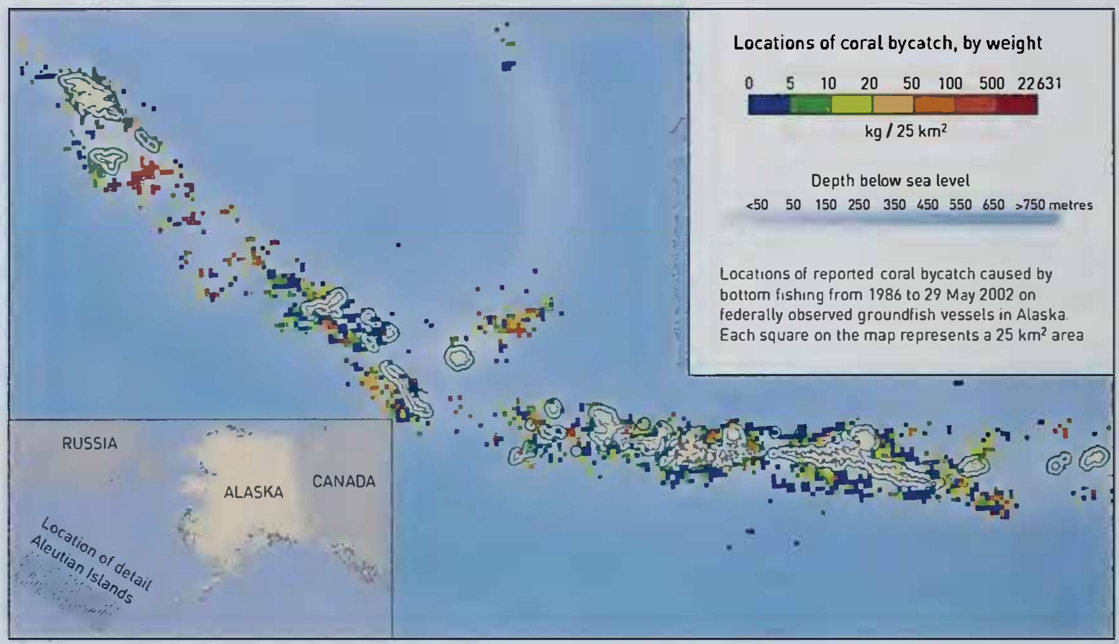


Figure 24: Coral bycatch data based on US federal fishery observation in the Aleutian Islands

Oceana and Conservation GIS Support Center, Anchorage, AK

resources were discovered on seamounts in the North Pacific, successive waves of fisheries have swept across seamounts in the North and South Pacific, Atlantic and Indian Oceans (Koslow et al., 2000). Fishing effort has often been massive: in the years 1969 to 1975 some 18 000 trawler days were spent by the former Soviet Union fleet trawling for pelagic armorhead (*Pseudopentaceros richardsoni*) on a few seamounts in the southeast Emperor-northern Hawaiian Ridge system (Borets, 1975), and more than 100 Japanese and Taiwanese vessels were involved in a second wave of coral fishing on central North Pacific seamounts in 1981 for a newly discovered species of *Corallium* (Grigg, 1993).

Seamount fisheries are particularly vulnerable to overexploitation due to their fixed and limited topographic location, and the species exploited are often particularly long lived and exhibit infrequent recruitment. As a result these fisheries are characterized by a 'boom and bust' cycle. After the end of the 1970s when the pelagic armorhead fishery collapsed, the locus of seamount fisheries shifted first to the southwest Pacific for orange roughy around New Zealand and Tasmania and subsequently to the Indian Ocean, North Atlantic Ridge and the southeast Atlantic off Namibia. Seamounts at tropical/subtropical latitudes have been exploited for alfonsino (*Beryx* spp.) (Koslow et al., 2000). The precise locations of these fisheries are often not recorded, particularly when they occur in international waters (e.g. the central Indian Ocean) or when they involve poaching on seamounts in another nation's EEZ.

There are few observations of the impact of these fishing activities on benthic communities. However, coral bycatch from orange roughy fisheries around New Zealand and Tasmania has been substantial, particularly in the initial years of fishery development, with 1-15 tonnes of coral bycatch per trawl often being recorded (Probert et al., 1997; Anderson and Clark, 2003). In fact the estimated coral bycatch from one year of the Tasman Rise fishery was greater than the recorded landings of oreo species (*Pseudocyttus* sp.), the most valuable commercial species after orange roughy (Anderson and Clark, 2003). Based on photographic evidence, Koslow et al. (2001) found virtually no coral cover, living or dead, on heavily fished seamounts off Tasmania, in marked contrast to unfished or lightly fished seamounts.

Richer de Forges et al. (2000) observed little overlap in species composition between groups of seamounts. The mean percentage similarity in species composition was only 4 per cent between seamounts situated on parallel ridges at the same latitude and only 1 000 km apart. No species were found in common between seamounts south of Tasmania and those on the

Norfolk Ridge or Lord Howe Rise in the northern Tasman Sea and southern Coral Sea. In contrast, some 60 per cent of non-mesopelagic decapod crustaceans found on the continental slope off southeastern Australia are also found in the Indo-west Pacific.

Richer de Forges et al. (2000) speculated that the apparently localized distribution of many seamount species, in marked contrast to species distribution patterns in the deep sea generally, arises from topographic rectification of deep-water currents, such that they tend to follow the contours of the seamounts and seamount chains; many seamount species also have a limited larval phase in the plankton. This localization, combined with the presence of many apparently rare species, greatly increases the risk of extinction of biodiversity through the large-scale removal of benthic fauna from exploited seamounts.

So far, only a small number of seamounts in the Pacific and Indian Ocean have been protected. Only a few countries have adopted national legislation and measures to conserve some of the seamount habitats and ecosystems in their territorial or EEZ waters.

Seamounts in the Australian EEZ

Scientific exploration of the benthic macrofauna and the associated fish community on the seamounts south of Tasmania and within the EEZ of Australia showed that the summits of these seamounts are rich in *Solenosmilia variabilis* (see Chapter 2) that provides a substrate for a diverse associated fauna (Koslow et al., 2001). On 16 May 1999, the Australian Government declared the Tasmanian Seamounts Marine Reserve under the National Parks and Wildlife Conservation Act 1975 (Figure 25).

The management plan for the reserve came into effect under the Environment Protection and Biodiversity Conservation Act 1999 on 26 June 2002. The key objectives are:

- To add a representative sample of this unique seamount region to the National Representative System of Marine Protected Areas (NRSMPA).
- To protect the high biodiversity values of the seamount benthic communities from human-induced disturbance.

The reserve is divided into two management zones with different objectives allowing different activities. A highly protected zone runs from a depth of 500 m to 100 m below the seabed and is managed to protect the integrity of the benthic ecosystem. This means that no method of fishing nor petroleum or mineral exploration is permitted in this zone. A managed resource zone stretches from the ocean surface to a depth of 500 m. Its aim is to ensure long-term

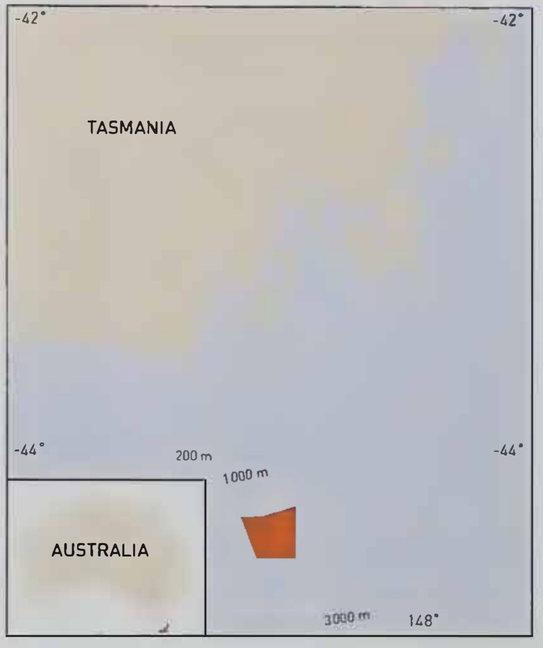


Figure 25: The Tasmanian Seamounts Marine Reserve as a marine protected area protecting cold-water corals and fish from trawling activities

A. Freiwald, using GEBCO bathymetry

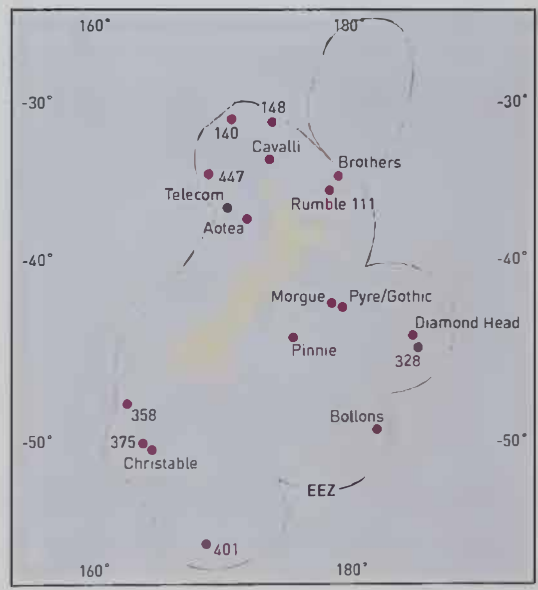


Figure 26: Seamounts closed for fisheries within the exclusive economic zone of New Zealand

Modified after Clark and O'Driscoll, 2003

Table 7: Seamounts closed for fisheries within the New Zealand EEZ

Seamount	Depth (m)	Elevation (m)	Area (km²)	Region
148	677	2 600	190	Northern North Island
Cavalli	538	1 050	125	Northern North Island
140	1 750	2 900	590	Northern North Island
Brothers	1 197	1 300	35	Northeast North Island
Rumble 111	200	3 200	300	Northeast North Island
Aotea	900	1 200	500	Western North Island
Telecom	1 500	250	20	Western North Island
447	615	650	120	Western North Island
Pinnie	600	200	5	Southern Chatham Rise
Morgue	890	310	3	Northern Chatham Rise
Pyre	1 004	200	1	Northern Chatham Rise
Gothic	987	170	2	Northern Chatham Rise
Diamond Head	603	500	3	Eastern Chatham Rise
328	1 750	1 200	600	Eastern Chatham Rise
358	1 652	2 400	2 000	Southwest South Island
Bollons	800	3 600	35 000	Southeast New Zealand
375	684	570	460	Southern South Island
Christable	910	2 400	2 170	Southern South Island
401	1 159	340	200	Southern New Zealand

After Clark and O'Driscoll, 2003

protection and maintenance of biological diversity while allowing the tuna longline industry access to the surface waters.

Seamounts in the New Zealand EEZ

Maintenance of biodiversity and productive ecosystems on seamounts within the New Zealand EEZ are key goals of several government departments. In May 2001, the Ministry of Fisheries protected from bottom trawling and dredging 19 representative seamounts under a Seamounts Management Strategy (Anon., 2001). The seamounts are distributed around New Zealand's EEZ, including the Chatham Rise, subantarctic waters, and the east and west coasts of the northern part of North Island (Figure 26). The protected seamounts vary in size from the very large Bollons Seamount in the subantarctic to the tiny seamounts on the Chatham Rise (Table 7). Although little is known about their fauna, it is hoped this precautionary measure will protect representative faunas from a variety of habitat types. They are all unfished except for Morgue, which was included so that recolonization and regeneration could be monitored once fishing is removed (Clark and O'Driscoll 2003).

Although we do not know exactly how many coral reefs and octocoral gardens exist in the oceans, current information obtained from all areas, though limited, clearly indicates severe impact from disruptive bottom fisheries. In many areas, cold-water coral ecosystems even in deep water are under serious threat.

A school of crinoids (*Koehlerometra*) sitting on coral colonies, southeastern Rockall Bank, 850 m depth

IFREMER, CARACOLE, 2001

6. Socio-economic considerations

Cold-water coral ecosystems have been known as features in the deeper marine environment for centuries, attracting the attention only of local fishermen and a small global community of biologists and geologists. However, increased interest in the economic exploitation of these deeper water environments for living and non-living resources since the mid-1980s has raised concern about possible environmental effects. This chapter discusses some socio-economic considerations related to cold-water coral ecosystems as a resource for:

- ❑ fisheries and bioprospecting
- ❑ stimulating the development of new technologies
- ❑ education and outreach.

CORAL ECOSYSTEMS AS A BIOLOGICAL AND ECONOMIC RESOURCE

Cold-water coral ecosystems are biological hotspots and provide resources for fisheries, bioprospecting, science and education. The structural complexity of the coral ecosystem attracts a yet unknown number of different species. Although none of the species so far recorded occurs exclusively in the coral habitat, many are present in greater abundance within coral habitats than in the surrounding seabed. This includes species of economic importance to fisheries such as crabs, ling and rockfish.

Fish resources in cold-water coral ecosystems

It is too early to evaluate the importance of coral ecosystems as essential habitats for fish or crustaceans as mating, feeding, shelter or nursery grounds (Auster, in press; Costello et al., in press) as long-term observations have yet to be carried out. Husebø et al. (2002) provided clear evidence that economically targeted fishes in Norwegian coral habitats from the outer continental shelf are larger and more abundant than in non-coral habitats. However, there is no information on the proportions of fish populations that use the coral ecosystems and it is therefore not known whether cold-water coral ecosystems are essential for the survival of fish populations or fish stocks. The indication that coral reefs are preferred habitats could mean that reef habitats are high-quality areas that may become important if fish stocks are declining due to fisheries or unfavourable environmental conditions.

Despite significant coral bycatch (Shester and Ayers, in press; Probert et al., 1997; Koslow et al., 2001), in general seamounts are important for fish, but a full assessment has not yet been made. Are fish found there because of the food-rich seamount environment, or because of the presence of corals, or both? There is considerable risk that these coral habitats will be lost before scientists have had an opportunity to study their ecological role and socio-economic importance. However, there is an increasing body of scientific literature and *in-situ* observations that fish occur at high densities in reef areas using the complex structural habitats they provide.

The effect of closing bottom fisheries on cold-water coral reefs

The harm that bottom trawling does to coral reefs has led to the closure of reef areas to bottom trawling. Existing closures are so recent that there are yet no data or information available to evaluate their effect on the fishing industry. It is possible, however, to create both positive and negative hypotheses.

Positive

A high-quality fish habitat is maintained which may lead to higher survival and growth of individual fish, which in turn may have a positive effect on individual fecundity, and hence on fish populations or stocks. It is known that some species are very long lived with slow reproductive rates and therefore the effects of fisheries closures might take some time to be seen.

It is expected that in the long term there would be potential spillover recruitment effects of increased catches and increased fish size into the adjacent areas. Where closed areas have a rugged topography, the closure would flag areas that might cause damage to fishing gear.

Negative

Closures in traditionally important trawling grounds may affect fishing, leading to higher costs for the fleet to achieve the same income per unit time as before closure. However, at present areas closed for the protection of cold-water coral reefs make up only a small fraction of trawling grounds. Although proposed closures are bound to have a significant effect on the livelihoods of those engaged in bottom fishing, this activity represents only a small segment of the overall fishing industry. It should be recognized that due to closures fishing efforts might be displaced into other cold-water areas. Existing closures are so recent that it is too early to assess possible effects.

Bioprospecting

There is increasing interest from scientists, biotechnology and pharmaceutical companies in screening coral

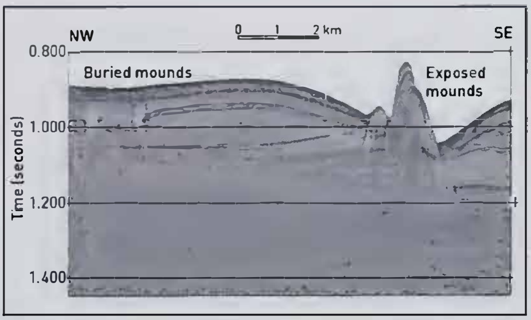


Figure 27: A very-high-resolution reflection seismic profile over buried carbonate mounds (left) and some large surface mounds (right), Porcupine Seabight, west of Ireland. The buried mounds are up to 70 m high, the surface ones up to 150 m

RCMG, Ghent University

habitats and the associated fauna for species which produce potentially beneficial substances and genes. The search, for example, for antibacterial and antivirus substances produced by living organisms offers a new field of great economic value. Baker et al. (2001) pointed to fouling-resistant substances in corals that might be used as an environmentally safer alternative to heavy metal compounds currently used in ship bottom painting.

Bioprospecting has typically been located in high-diversity ecosystems in the tropics, e.g. rainforests and coral reefs. In recent years attention has also turned to high-latitude cold-water systems, and the fauna of coral ecosystems in Norway have already been the target of bioprospecting.

In the majority of cases, only small samples of biological material are necessary in the search for useful substances and genes. When larger-scale harvesting is planned for screening and development of marine biotechnology products, particularly of rare or endemic species in vulnerable ecosystems, regulatory measures, such as a code of conduct, will be needed to ensure that potential impacts are assessed in advance and that the resources are used sustainably.

Monkfish (*Lophius* sp.)

A Freiwald

Industry

In some places, such as the Gulf of Mexico and the European continental shelf, there is a high degree of overlap between the occurrence of cold-water corals and oil and gas exploration activities. Oil and gas exploration has been identified as one of the possible threats for cold-water reefs because of pollution and the placing of infrastructure and pipelines in coral areas. Data and information on the former is lacking but the latter is known to be relevant. On the Norwegian continental shelf and break, for example, there are many areas where the oil industry works in close proximity to cold-water corals. There is now an obligation to map all coral reefs in intended drill areas as part of the application procedure for new licences in the Norwegian EEZ. The oil industry must therefore use extra resources to map reefs and include the information in their obligatory environmental impact assessment.

In many parts of the oceans, cold-water corals are associated with carbonate mounds which can be as high as 300 m and several millions of years old (De Mol et al., 2002; Van Rooij et al., 2003). The oil and gas industry has taken an interest in carbonate mounds as hydrocarbon prospecting targets (Figure 27). Mounds and buried reefs have high porosity and therefore the potential to hold fossil fuel. Understanding reef and mound development may thus be important in terms of reservoir building, and in that respect modern reefs and mounds are seen as outstanding models for fossil carbonate reservoirs.

STIMULATING THE DEVELOPMENT OF NEW TECHNOLOGIES

A major reason for the recent progress in scientific research and greater public awareness of cold-water coral ecosystems is due to technological advances in the field of acoustic mapping and improvements in remote operated vehicle technology both in industry and academia. Backed up by global positioning system (GPS) navigation, the development of multibeam echo-sounding technology (which measures the sea floor depth by transmitting a downward-looking fan-shaped beam and can accurately map depth contours) has allowed mapping of larger seabed areas at high precision and within a reasonably short time.

Multibeam technology has opened new avenues for better understanding of seabed topography and the sedimentary environment. National authorities and industry have used this technology both to search for resources of economic interest and to document environmental hazards. This mapping tool is now used to detect cold-water coral reefs that can be recognized by characteristic physical backscatter properties and morphological characteristics (Figure 28 and Figure 7A). However, to differentiate reefs from rocks and other seabed features, ground truthing through visual inspection using towed or mobile camera system carriers is necessary to properly calibrate and interpret multibeam datasets.

A number of companies and research groups are developing software tools to support identification of seabed features such as coral reefs (Huvenne et al., 2002). The integration of multibeam data into ROV navigational systems is another challenge. Such systems make it possible to navigate the ROV on the multibeam map in real time. The future application of such combined systems will be a great step forward in enabling the mapping of the full extent and distribution of coral reefs at reasonable costs.

EDUCATION AND OUTREACH

The new discoveries of cold-water coral ecosystems made by interdisciplinary teams of scientists using state-of-the-art sampling and observation technologies, coupled with the real-time capabilities of the Internet, offer rich opportunities to capture the interest of the general public. In order to stimulate interest in the Earth's nature and our responsibility for the environment, it is important to improve and increase the dissemination of science to schools and undergraduate students. This is especially so for cold-water coral ecosystems as they are generally located several hundred metres deep – and therefore out of sight. Obtaining good quality photographic images and seabed maps is particularly valuable to show the general public, policy makers and scientists the fantastic range and diversity of corals and other animals on cold-water coral reefs, as well as the devastating effects of damaging activities on these reefs.

Education

An excellent example of how the cold-water coral issue can be used in education is the NOAA programme Island in the Stream: Exploring Underwater Oases (http://oceanexplorer.noaa.gov). Educators and scientists working with NOAA developed web-based curricula and lesson plans with features such as focus questions, background information for teachers and links to relevant websites (see page 79). Web presentations document the latest discoveries from current expeditions, which provide compelling images and video clips in the form of daily logs.

The Intergovernmental Oceanographic Commission (IOC) of UNESCO focuses on promoting marine scientific investigations and related ocean services, with a view to learning more about the nature and resources of the oceans. For this purpose, the Training-through-Research (TTR) Programme became operational in 1991. The benefits of the TTR Programme extend beyond the achievement of its double purpose of training young marine scientists in the field and conducting marine scientific research. The TTR Programme enhances the capacity of the scientific community by bringing people from diverse backgrounds and geographically distant universities into contact with each other in a collaborative effort. The data and knowledge gathered during the cruises are analysed in multiple laboratories around the globe; their consequences are discussed in each lab as well as at annual TTR research conferences, and their conclusions drafted in scientific journals and papers (www.ioc.unesco.org/ttr). One of the TTR objectives is related to the better understanding of cold-water corals and carbonate mounds in the North Atlantic and the Mediterranean Sea (Kenyon et al., 2003; Van Rooij et al., 2003).

Outreach

Public outreach activities that reflect the increasing number of international and multidisciplinary research efforts related to cold-water corals have increased during the past five years. Media coverage has included numerous popular scientific newspaper articles, radio

Figure 28: Mapping and ROV navigation of *Lophelia* reefs on the northern Norwegian continental shelf: cluster of elongated reef ridges

Photo: Jan Helge Fosså, IMR

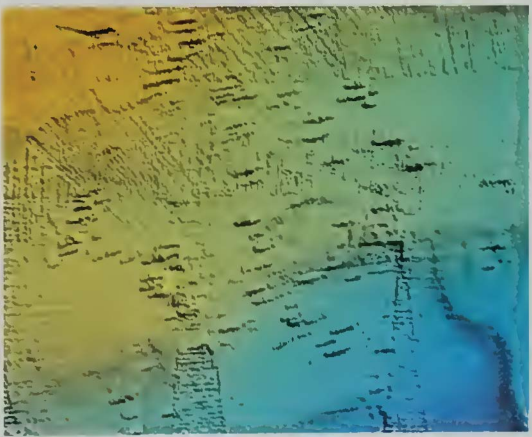


Table 8: A selection of downloadable information brochures related to cold-water corals and their environment

Subject	Hosting organization	Web link
Guide to northeast Atlantic fishes observed in *Lophelia* reefs	Ecoserve Ltd, Dublin, Ireland	www.ecoserve.ie/projects/aces/introduction.html
Seamount report	WWF	www.ngo.grida.no/wwfneap/Projects/Reports/Seamount_Report.pdf
Deep Sea Corals: Oceana report	Oceana	www.oceana.org/uploads/oceana_coral_report_final.pdf
Deep Sea Corals, Atlantic Canada	WWF Canada	http://www.wwf.ca/NewsAndFacts/Supplemental/CoralReport.pdf
Islands in the Stream 2002	NOAA	http://oceanexplorer.noaa.gov/explorations/02sab/welcome.html

interviews and TV documentaries. Environmental organizations such as UNEP, WWF and Oceana have prepared free and easily readable reports, leaflets and posters providing information on cold-water corals, their environments and status (Table 8). The high-quality video images of reefs in Norway, circulated amongst the scientific and government policy communities in Europe, have rapidly increased appreciation of the importance of cold-water coral reefs. Open events provide the general public with the opportunity to learn about the modern technologies used in cold-water coral research and become familiar with this exciting ecosystem by talking to leading experts.

However, perhaps the most attractive way of introducing the public to the fascinating world of cold-water corals is to show living cold-water coral ecosystems. Aquarium displays are still problematic because of the practical problems of cultivating deep-water species. However, US facilities, such as the South Carolina Aquarium and the Monterey Bay Aquarium, provide insights into the world of cold-water corals. In Europe live coral displays have featured in public aquaria in Ireland, Norway and Scotland. In addition to aquarium displays there are a number of places where cold-water coral ecosystems exist in relatively shallow water such as in fjords. In some Norwegian fjords small companies offer guided boat trips with a towed camera system to show the reefs in their natural environment. Similar facilities exist in New Zealand fjords. In the Fjordland National Park a public underwater observatory, the Milford Deep Underwater Observatory, was installed in 1995 (www.milforddeep.co.nz/observatory.htm). Here, beneath a thin freshwater cover, deep-water ecosystems including corals are present at a depth of only 15 m.

A major subhabitat, the coral rubble aprons

A Freiwald

A *Phakellia* sponge safeguarded by squat lobsters

A Freiwald

7. Gaps in scientific knowledge

The previous chapters briefly summarized our current knowledge of cold-water coral ecosystems and also highlighted gaps in scientific understanding. Filling these gaps is of crucial importance, in particular:

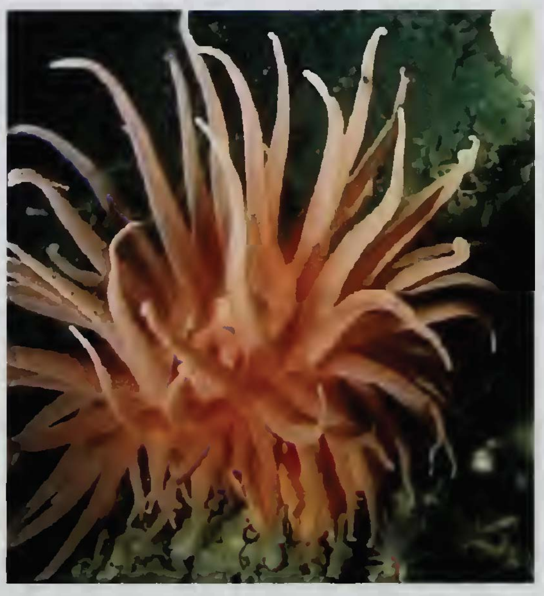
- ❑ Understanding the biological and ecological processes and interactions of cold-water corals, the associated species diversity and environmental regulating factors.
- ❑ Ensuring that cold-water corals are not damaged or destroyed accidentally, and enabling society to make choices on conservation and exploitation.

When cold-water corals became a major international research topic in the past decade, scientists needed a forum to discuss their results within the steadily growing community interested in cold-water corals, including political bodies and environmental associations. The International Deep Sea Coral Symposium series starting in 2000 in Halifax, Canada, and continuing in 2003 in Erlangen, Germany, has helped to meet this need. The third symposium is to be held in the United States in 2005. These symposia are supplemented by thematic workshops and the publication of their proceedings (Willison et al., 2001; Watling and Risk, 2002; Freiwald and Roberts, in press). In addition, interim workshops organized by NOAA and the Irish Marine Institute have brought together leading scientists from the United States and Europe to identify scientific research needs (McDonough and Puglise, 2003). Based upon these expert meetings, scientists have identified broad areas of work, which require multidisciplinary efforts, to improve the understanding of the ecosystem.

- ❑ Mapping: Using multibeam and other technologies to develop low-resolution maps covering large areas for identifying potential locations of cold-water corals, and to develop high-resolution maps for areas where corals are known to exist. Using still cameras and voucher specimens to ground-truth the bathymetric data and to develop habitat characterization maps.
- ❑ Oceanographic data: Collecting high-quality oceanographic data in order to improve knowledge of the physical factors that affect the distribution and extent of cold-water coral habitats.
- ❑ Geology and geomorphology: Collecting data on the underlying geology of cold-water coral habitats, as well as on their morphology. Using this information to enhance understanding of colonization, reef succession, recolonization after physical damage, and for better understanding the habitat preferences of selected species.
- ❑ Biology and physiology: Collecting and analysing specimens in order to better understand coral species and their genetics, to better characterize symbiotic relationships, and to understand more about their life history.
- ❑ Ecology: Collecting data on use made by other species of cold-water coral habitats in order to understand their wider importance.
- ❑ Human activities: Collecting information on human activities that may harm cold-water coral habitats in order to be able to better manage those activities.
- ❑ Socio-economic data: Collecting information to understand the interconnectedness of cold-water corals and human livelihoods.
- ❑ Time-series data: Collecting standardized data over long periods to help identify changes in habitat over time.

It is clear that there is a significant need to build an information base on the growing body of research into cold-water corals. A basic task is to locate and map further areas of cold-water coral habitat to complement existing information on their distribution, to understand patterns of occurrence around the world, and to provide location and extent information towards protection of reef areas from damaging activities. The integration of data sets into a GIS environment is essential to synthesize this information. We already have some information on the physico-chemical requirements for cold-water coral reefs to develop, as a start to looking at where they are likely to occur worldwide (water temperature 4-13°C, some elevation or increased current, availability of nutrients).

As research and surveying in deep and often distant waters is very expensive, a modelling approach to narrow down the areas to target with more detailed mapping will be essential, particularly for high seas areas and areas far from land. Such target areas could then be surveyed using low-resolution multibeam survey to cover larger seabed areas. High-resolution mapping with sonar can then be undertaken for potential coral habitats, together with optical tools such as towed or mobile camera systems (ROVs, autonomous underwater vehicles (AUVs), manned submersibles) to confirm the presence and nature of the reefs identified. These data would not only provide information on the presence or absence of corals and associated megafauna, but also on the seabed


A Freiwald

The large anemone ***Bolocera tuediae*****, commonly found in cold-water coral reef environments**

structures and sediment types within and adjacent to coral habitats. The methods used will be non-destructive.

Oceanographic datasets focus on water mass properties (physical, chemical and to a lesser extent biological), current regimes and particle concentration. To date, limited information exists covering longer timespans to better understand the hydrodynamic changes in coral habitats over annual cycles (White, 2003; White et al., in press). These information needs can be addressed using anchored moorings deployed at coral habitats, equipped with temperature, salinity and particle sensors, sediment traps and with current meter arrays. Benthic lander systems equipped with acoustic Doppler current profilers (ADCPs) and optical backscatter devices to estimate particle resuspension can be used to provide information on the bottom current flow and particle dynamics at the level of the corals (Roberts et al., in press).

As shown by geological records, some of the coral habitats have persisted for thousands if not millions of years; underlying geological information is needed to better understand the response of coral habitats to global change, such as the shift from glacial to interglacial climatic conditions (Van Rooij et al., 2003; Schröder-Ritzrau et al., in press). Geophysical seismic surveys reveal information on the underlying geology of cold-water coral habitats (Figure 27). Sediment coring or drilling in areas where living corals are no longer found is necessary to decipher the time constraints and preserved species compositions back through time. Many coral habitats occur and occurred in seas that were strongly affected by glacial cooling at high latitudes, which would have suppressed coral growth. The estimation of the time lag of postglacial coral recolonization patterns provides essential information on the environmental evolution of the corals' fundamental niche. In other words, a good understanding of the growth and development of cold-water coral reefs in geological time, linked to good estimates of the prevailing oceanographic conditions, will improve our ability to understand the resilience of these ecosystems to predicted levels of climate change.

Coral ecosystem functioning is still poorly known and improving basic knowledge of cold-water coral physiological ecology is necessary. To date, scientists cannot answer fundamental questions such as 'what controls the growth and development of corals?' Research is needed to improve knowledge in coral biology as it relates to feeding and behaviour. In turn such understanding will refine our estimate of carbon and energy flux through the cold-water coral ecosystem. Reproductive biology and larval dispersal, considered jointly with molecular genetics, are exciting emerging fields of research. But we do not know the biotic and abiotic factors that influence reproduction and dispersal.

Future research should focus on both conducting *in-situ* experiments as well as developing aquarium-based research to gain insights into the sensitivities and tolerance of cold-water corals to environmental changes. Cold-water coral habitats support a diverse array of fish and invertebrate species. It is important to assess reef biodiversity, food web relationships, and the role of coral habitats as habitat for fish and invertebrates to spawn, breed, feed and grow to maturity. Many cold-water coral and associated species are still unknown. Taxonomic expertise needs to be fostered and developed.

Finally, scientists have collectively stated concern about the unsustainable exploitation of marine ecosystems.

8. International actions on cold-water coral reefs

The conservation, protection and sustainable management of the natural resources of the oceans is a matter which has been and is being addressed by a large number of events, organizations and stakeholders at national, regional and global levels.

Until 1999, there was little consideration of the protection of cold-water coral reefs. However, due to the increasing amount of information on their distribution, state and threats, summarized in the previous chapters, cold-water corals have received greater attention and are emerging on political agendas. Cold-water coral reef ecosystems occur in waters under national responsibility (territorial waters and EEZs), as well as in international waters (high seas) beyond the jurisdiction of any country, which are subject to control by the relevant international bodies and conventions. Examples of actions taken and measures adopted by national governments and the European Community to protect some of the better known cold-water coral reefs in the territorial or EEZ waters under their jurisdiction have been given in Chapter 5. Further work and discussions are ongoing at the national and international levels, both in terms of preventing deliberate or accidental damage to this unique habitat and as a case study in the more general context of conserving, protecting and managing high seas environments and resources sustainably.

This chapter is intended to provide an overview of some of the statements/agreements made, and actions taken, in recent years at the international level in relation to cold-water corals. It should be noted that this list is not exhaustive, and it is hoped that more international bodies will take up the UN's invitation (see below) and consider incorporating cold-water coral ecosystems into their programmes of activities in the near future.

Academia

Scientists have collectively stated concern about the unsustainable exploitation of marine ecosystems in a call for urgent action which was signed by 1 136 scientists from 69 countries at the annual meeting of the American Association for the Advancement of Science in February 2004 (see www.mcbi.org). *Inter alia*, it alerted governments to the need to act urgently to protect imperilled cold-water coral and sponge ecosystems, urged the United Nations to establish a moratorium on bottom trawling on the high seas, and further urged governments to support research and mapping, and to establish effective, representative networks of marine protected areas that include cold-water coral and sponge communities.

Non-governmental organizations and initiatives

World Wide Fund for Nature (WWF)

The World Wide Fund for Nature (WWF) has several international and regional campaigns and initiatives on the urgent need to conserve, protect and manage cold-water coral reefs and other vulnerable marine ecosystems in both national and international waters. Information, documentation and fact sheets are available at www.panda.org and www.ngo.grida.no/wwfneap. The latter contains a number of articles, maps, fact sheets and links on cold-water coral reefs in the northeast Atlantic.

IUCN–The World Conservation Union

The Global Marine Programme of IUCN–The World Conservation Union, individually or with partners, has published a large number of books, analyses, guidelines, occasional papers and other documents related to conservation, management and sustainable use of marine resources and ecosystems, including reports on the biology, ecology and vulnerability of cold-water coral reefs and other high-seas ecosystems, as well as on the legal considerations/ requirements to protect these habitats in international waters and the high seas (see www.iucn.org/themes/marine/pubs/pubs.htm).

Oceana

The programme of Oceana to protect and restore our oceans includes campaigns on fisheries and destructive trawling and protecting the high-seas environment. In 2003, Oceana produced a report 'Deep-sea Corals: Out of sight, but no longer out of mind', which is available together with a wide range of information on cold-water coral reefs and ongoing Oceana activities at www.oceana.org/index.cfm.

Regional intergovernmental organizations

Council of the European Union and the European Commission

The Council of the European Union and the European Commission were given powers by member states to regulate the conservation and sustainable exploitation of fisheries resources under the common fisheries policy (Council Regulation (EC) No 2371/2002) and the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms (Council Regulation (EC) No 850/98). This competence applies in the EEZs of member states outside the 12 nm border demarcating the territorial water under national legislation. Council Regulation (EC) No 2371/2002 sets out, *inter alia*, that:

> '...the Community shall apply the precautionary approach* in taking measures designed to protect and conserve living aquatic resources, to provide for their sustainable exploitation and to minimise the impact of fishing activities on marine ecosystems...'
> (extract from Article 2 Objectives)

> 'If there is evidence of a serious threat to the conservation of living aquatic resources, or to the marine eco-system resulting from fishing activities and requiring immediate action, the Commission, at the substantiated request of a Member State or on its own initiative, may decide on emergency measures which shall last not more than six months. The Commission may take a new decision to extend the emergency measures for no more than six months.'
> (Article 7 Commission Emergency Measures)

Both these provisions were applied by the Commission and the Council in the prohibition of the use of bottom-trawl and similar towed nets operating in contact with the bottom of the sea in the Darwin Mounds area northwest of Scotland falling within the jurisdiction of the United Kingdom (see Chapter 5).

Furthermore, the Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (92/43/EEC) (Habitats Directive), which is legally binding on all European Union member states, lists 'reefs' in Annex 1 as a natural habitat type of community interest whose conservation requires the designation of special areas of conservation.

In addition to regulatory legislation, the EC is also supporting scientific research programmes on cold-water coral reefs, such as the Atlantic Coral Ecosystem Study (ACES) under the Fifth Framework Programme, and the new Hotspot Ecosystem Research on the Margins of European Seas (HERMES) programme, which is planned to start in November 2005.

OSPAR Convention for the Protection of the Marine Environment of the North East Atlantic

Under the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic (1992), *Lophelia pertusa* reefs are included on the Initial OSPAR List of Threatened and/or Declining Species and Habitats. The Bremen Statement adopted at the OSPAR Ministerial Meeting in 2003 states:

> 'We are particularly concerned about the status of vulnerable cold-water coral reefs, many of which are threatened with destruction. Bearing in mind the ecological importance of these reefs and the practical irreversibility of their damage, we shall take immediate measures to protect coral reefs from further damage due to use of active fishing gear on the reefs. Furthermore, we shall ensure that steps are taken by 2005 to identify additional threats to the cold-water reefs and that measures are taken to protect the reefs against these threats.'

International Council for the Exploration of the Sea

The International Council for the Exploration of the Sea (ICES) promotes and encourages research and investigation of the marine environment and its living resources in the North Atlantic and adjacent seas, and publishes/disseminates the results of this research. Following a request from the European Commission, in 2001 ICES established the Study Group on Cold-water Corals (SGCOR) to identify areas where cold-water corals may be affected by fishing. The reports of this group, together with further information on coral reefs in the North Atlantic, is available at www.ices.dk/marineworld/deepseacoral.asp.

Global conventions and partnerships

Convention on Biological Diversity

The Seventh Conference of Parties to the Convention on Biological Diversity (CBD) in 2004 adopted Decision VII/5 (Marine and Coastal Biological Diversity) which states, *inter alia*,

> 'Agrees that there is an urgent need for international cooperation and action to improve conservation and sustainable use of biodiversity in marine areas beyond the limits of national jurisdiction, including the establishment of further marine protected areas consistent with international law, and based on scientific information,

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*Defined in Article 3 of this regulation as follows: '"precautionary approach to fisheries management" means that the absence of adequate scientific information should not be used as a reason for postponing or failing to take management measures to conserve target species, associated or dependent species and non-target species and their environment.'

> including areas such as seamounts, hydrothermal vents, cold-water corals and other vulnerable ecosystems;'
>
> 'Concerned about the serious threats to the biological diversity, stresses the need for rapid action to address these threats on the basis of the precautionary approach and the ecosystem approach, in marine areas beyond the limits of national jurisdiction, in particular areas with seamounts, hydrothermal vents, and cold-water corals, other vulnerable ecosystems and certain other underwater features, resulting from processes and activities in such areas;'
>
> 'Calls upon the UNGA and other relevant international and regional organizations, within their mandate, according to their rules of procedure, to urgently take the necessary short-term, medium-term and long-term measures to eliminate or avoid destructive practices, consistent with international law, on a scientific basis, including the application of precaution, for example, on a case by case basis, interim prohibition of destructive practices adversely impacting the marine biological diversity associated with the areas identified above, and recommends that Parties also urgently take such measures to respond to the loss of biodiversity in such areas (Dec VII/5 paras 61-62).'

Furthermore, cold-water coral reefs are mentioned in or under the following operational objectives contained in this decision:

> 'Operational objective 2.3: To gather and assimilate information on, build capacity to mitigate the effects of, and to promote policy development, implementation strategies and actions to address: (i) the biological and socio-economic consequences of physical degradation and destruction of key marine and coastal habitats including mangrove ecosystems, tropical and cold-water coral-reef ecosystems, seamount ecosystems and seagrass ecosystems including identification and promotion of management practices, methodologies and policies to reduce and mitigate impacts upon marine and coastal biological diversity and to restore mangrove forests and rehabilitate damaged coral reef...'
>
> 'Operational objective 2.4: To enhance the conservation and sustainable use of biological diversity of marine living resources in areas beyond the limits of national jurisdiction.'

Appendix 2 of this decision sets out elements of a work plan on physical degradation and destruction of coral reefs, including cold-water corals, under five headings: assessments and indicators, management, capacity-building, financing, and education and public awareness.

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) lists black corals (Antipatharia), stony corals (Scleractinia) and lace corals (Stylasteridae) under Appendix II. This means that international trade in most cold-water coral reef species is closely controlled and requires export permits/certificates to be granted by the relevant authorities.

International Coral Reef Initiative (ICRI)

The International Coral Reef Initiative (ICRI) addressed cold-water coral reefs at its Coordination and Planning Committee meeting in November 2003 and *inter alia*:

- ☐ Agreed to establish an ad hoc committee to assess ICRI's potential role in the international collaboration on cold-water coral reefs.
- ☐ Invited the committee to identify ICRI's potential in the protection and sustainable management of cold-water coral reefs, the implications for ICRI's current work and what implementation modalities, if any, might be needed.
- ☐ Agreed to consider the report (of the committee) and decide what contribution ICRI might make at the next ICRI CPC meeting in Okinawa (3-4 July 2004).

UN bodies, conventions and affiliated instruments and organizations

United Nations General Assembly/UNCLOS

The United Nations General Assembly (UNGA) is the main decision-making body for a number of UN agencies, conventions (e.g. the United Nations Convention on the Law of the Sea – UNCLOS (United Nations, 1982)) and affiliated instruments and organizations with a mandate for regulating aspects of the resources of the sea and uses of the ocean, including the protection of cold-water coral reefs and other vulnerable marine ecosystems, especially in international waters.

The fourth meeting of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea (UNICPOLOS) proposed in 2003 that the UN General Assembly:

> 'Reiterate its call for urgent consideration of ways to integrate and improve, on a scientific basis, the management of risks to marine biodiversity of seamounts, cold water coral reefs and certain other underwater features'
>
> 'Invite ICRI and other relevant bodies to consider incorporating cold water coral ecosystems into their programme of activities.'

The 58th session of the United Nations General Assembly took account of these proposals from UNICPOLOS and invited in Resolution 58/240 (Oceans and the Law of the Sea):

> 'the relevant global and regional bodies, in accordance with their mandates, to investigate urgently how to better address, on a scientific basis, including the application of precaution, the threats and risks to vulnerable and threatened marine ecosystems and biodiversity in areas beyond national jurisdiction; how existing treaties and other relevant instruments can be used in this process consistent with international law, in particular with the Convention, and with the principles of an integrated ecosystem-based approach to management, including the identification of those marine ecosystem types that warrant priority attention; and to explore a range of potential approaches and tools for their protection and management and requests the Secretary-General to cooperate and liaise with those bodies and to submit an addendum to his annual report to the General Assembly at its fifty-ninth session, describing the threats and risks to such marine ecosystems and biodiversity in areas beyond national jurisdiction as well as details on any conservation and management measures in place at the global, regional, subregional or national levels addressing these issues'.

The 58th session of the UN General Assembly also adopted Resolution 58/14 (Sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and related instruments), which under section IX (Responsible fisheries in the marine ecosystem):

> 'Requests the Secretary-General, in close cooperation with the Food and Agriculture Organization of the United Nations, and in consultation with States, regional and subregional fisheries management organizations and arrangements and other relevant organizations, in his next report concerning fisheries to include a section outlining current risks to the marine biodiversity of vulnerable marine ecosystems including, but not limited to, seamounts, coral reefs, including cold water reefs and certain other sensitive underwater features, related to fishing activities, as well as detailing any conservation and management measures in place at the global, regional, subregional or national levels addressing these issues'.

Other international events

Vth World Parks Congress

Marine participants at the Vth World Parks Congress agreed in 2003 on Recommendation 5.23 (Protecting marine biodiversity and ecosystem processes through marine protected areas beyond national jurisdiction), which:

> 'Strongly recommend the international community as a whole to... establish a global system of effectively managed, representative networks of marine protected areas by:
>
> a. Taking immediate and urgent action to protect the biodiversity and productivity of seamounts, cold-water coral communities and other vulnerable high seas features and ecosystems and especially to safeguard species and habitats at immediate risk of irrevocable damage or loss'.

In addition, marine theme participants at the congress, in endorsing this recommendation, considered the following recommendation as being of significant importance meriting recognition as an emerging issue:

> 'Call on the United Nations General Assembly to consider a resolution on an immediate moratorium on deep sea trawling in high seas areas with seamounts, cold water coral reef communities until legally binding international conservation measures to protect the areas are in place.'

(www.iucn.org/themes/wcpa/wpc2003/pdfs/outputs/wpc/emergingissues.doc)

9. Recommendations for the sustainable management of cold-water coral ecosystems

The previous chapters have demonstrated that cold-water coral ecosystems are biodiversity hotspots and resources which may be as important as their counterparts in tropical, warm waters. However, our understanding of cold-water coral ecosystems is still fragmented and incomplete. We do know that these corals are widely – probably globally – distributed, slow growing and long lived, and that they form fragile reefs*. We also know that they are under serious threat from increasing resource exploitation in the deeper areas of the oceans, particularly by commercial deep-water fisheries.

In order that cold-water coral ecosystems do not disappear before we even begin to appreciate their role, function and value, urgent actions and measures are needed. Both cold- and warm-water corals form unique marine ecosystems. Their conservation, protection and sustainable management requires a concerted, dedicated approach and an increase in national and international efforts and commitments.

The following recommendations are intended to provide all cold-water coral reef stakeholders – ranging from academia, non-governmental and intergovernmental organizations, national and international policy/decision makers from developed and developing countries to business and industry – with a choice or 'toolbox' of options for actions and measures to be considered for the effective conservation, protection and management of cold-water coral ecosystems. They are not intended to divert attention or resources from actions to reverse the degradation of other marine environments, such as warm-water coral reefs. The recommendations have been numbered for ease of reference – numbers do not reflect priority.

Recommendations have been grouped under the following headings:

- ☐ Information management and research
- ☐ Monitoring and assessment
- ☐ Regulations and measures
- ☐ International coordination and awareness.

Although some of these recommendations are interrelated and linked, together they constitute a flexible framework which can be adapted to existing knowledge and particular circumstances, enabling every stakeholder to consider and choose the most appropriate recommendation(s).

INFORMATION MANAGEMENT AND RESEARCH

The distribution of cold-water corals and reefs (especially in the tropical and subtropical deep-water areas of developing countries and small island developing states) is still poorly known. Most location records are held by individual experts and scientific institutions, or by companies exploring the deep waters for commercial purposes. There is a need to combine, maintain and present this information from the various sources in a way that allows all stakeholders easy access.

Recommendation 1

Encourage the mapping, establishment and mainenance of a global internet-based database of locations where cold-water coral reefs occur, or are absent.

Recommendation 2

Develop a dialogue with industries operating in areas of the oceans where cold-water corals may occur, so that cold-water coral reef data and information, especially those originating from fishing activities and oil and gas exploration and production, are made available to the scientific community, managers and decision makers.

Investigations using the latest deep-sea technology and instruments are time consuming and costly, so their deployment has to be as effective as possible. Modelling the potential distribution of cold-water coral reefs will focus further research and habitat mapping, especially in the tropical and subtropical areas where *in-situ* observations are so far limited. The results of modelling

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*For the purpose of this report 'reefs' are defined as submarine, biogenic concretions which arise from the sea floor and which support a community of animals (Box 2).

activities should be verified with existing records/ observations (where possible) and should be made widely available.

Recommendation 3
Support the modelling of the potential distribution of cold-water coral reefs globally and regionally on the basis of their environmental preferences and the requirements of reef-building species.

Knowledge of cold-water coral biology and the genetic relationship between populations is poor. Much of the structure and function of cold-water coral ecosystems in relation to biodiversity in the marine environment remains to be studied. There is also little understanding of the effects of different human activities, such as physical damage and pollution, on these reefs and their capability to regenerate. Furthermore, cold-water coral field research (including bioprospecting) is expensive, and potentially an impacting activity in itself. Good international coordination of marine research programmes can help to focus research efforts with a view to achieving cost efficiency and minimizing damage to the coral habitats.

Recommendation 4
Strengthen cold-water coral research through increased activity and coordination at the global, regional and national levels, with a view *inter alia* to countries with expertise and modern deep-sea research, exploration and habitat mapping facilities (vessels with multibeam equipment, remote operated vehicles, submersibles) assisting or cooperating with countries that lack such expertise and tools.

Recommendation 5
Develop and implement a code of practice for *in-situ* research (and bioprospecting) on cold-water coral reefs.

MONITORING AND ASSESSMENT

Most regulations and measures to protect cold-water coral reefs have been established only recently, and little information exists concerning their efficacy in achieving conservation objectives (Reed et al., in press). With more regulations and measures to be established, it will become increasingly important to compile and share information about the range of management strategies adopted by various countries and organizations, and to develop monitoring and assessment tools to evaluate and redefine, as necessary, the approaches taken to protect the reefs. This will help to guide countries in their efforts to manage cold-water coral reefs, especially those countries with fewer resources for basic research.

Recommendation 6
Collate the range of existing and new regulations and measures to conserve, protect and manage cold-water coral reefs, and assess their performance and effectiveness with a view to establishing and disseminating 'lessons learned' and 'better practices'.

Appropriate monitoring is vital for the conservation, protection and sustainable management of ecosystems. The monitoring of remote and deep-water habitats is still challenging and requires the development of methods and equipment which are robust, practicable, flexible and cost efficient, so that they can be customized to local conditions and applied in waters of both developed and developing countries. Monitoring efforts should be able to describe the status of undisturbed reefs, and the state and recovery of damaged reefs, as well as the environmental and socio-economic effects of conservation and management regulations and measures.

Recommendation 7
Initiate the development of practical strategies and guidelines for *in-situ* monitoring of cold-water coral reef habitats.

Recommendation 8
Initiate the development of practical strategies and guidelines to assess the socio-economic costs and benefits of cold-water coral reef management actions.

In the light of the increasing amount of data and information becoming available from various sources, there is a need to consider establishing and maintaining database facilities and regular publications on the health and status of cold-water coral reefs, similar to those in place for warm-water tropical reefs, which are able to assist resource managers in coral reef conservation.

Recommendation 9
Establish and maintain a global cold-water coral database for storing and providing access to information and monitoring data on the health, management and conservation efforts of cold-water coral reefs, *inter alia*, as a basis for the production of periodic regional status reports and the compilation of regular global conservation status reports.

REGULATIONS AND MEASURES

Cold-water coral reefs are of ecological and socio-economic importance. Without urgent measures for their conservation, protection and sustainable management, the goods and services these reefs supply might be lost forever. Any regulations and measures should be precautionary and designed to prevent deliberate or accidental damage to cold-water coral reefs, as the restoration of adversely affected reefs, if possible at all, will take generations and require considerably more costs, resources and efforts than precautionary, preventative measures.

> **Recommendation 10**
>
> Develop and adopt precautionary regulations and measures to protect, conserve and sustainably manage cold-water coral ecosystems and reefs to prevent deliberate or accidental damage caused by human activities. This should include consideration of interim prohibitions to reduce or eliminate human activities which adversely impact upon cold-water coral ecosystems within and beyond the limits of national jurisdiction.

Types of regulations and measures

Various countries and regional bodies have adopted, or are in the process of establishing, regulations and measures for the protection and management of vulnerable marine habitats, including cold-water coral reefs. Depending on the specific threat, state and location of the cold-water coral reefs, these regulations and measures vary considerably, ranging from a requirement for an environmental impact assessment, the prohibition of an expansion of operations and bottom trawling on cold-water coral reef areas, to specific management plans and regulations, such as a ban on all or certain types of fishing gear (especially those which are dragged over or can come into contact with the sea floor) on known cold-water coral reefs.

> **Recommendation 11**
>
> Consider the establishment of requirements and procedures for environmental impact assessments to be carried out prior to licensing of activities which affect the sea floor in potential cold-water coral reef areas. This would benefit from a cumulative assessment of all on-going and projected activities in a spatially framed assessment process, with a view to avoiding any damage to coral sites.

A number of known cold-water coral reef locations have been designated by national or international agreements as 'habitats of particular concern', 'special areas of conservation' or 'marine protected areas'. Marine protected areas (MPAs) have long been used by countries in their territorial and EEZ waters as a tool to protect sensitive or valuable marine species and habitats against harmful human activities. MPAs can vary in size and the level/duration of protection, from reserves totally closed to all activities to multiple-use areas that allow human uses compatible with the specific MPA conservation objective(s). In 2002, the international community at the World Summit

Bycatch of a live *Madrepora oculata* colony from Santa Maria di Leuca, off Apulia, Ionian Sea

A. Freiwald

Huge stem and holdfast of the bubblegum coral *Paragorgia*

A. Freiwald

on Sustainable Development (WSSD) agreed on the establishment of marine protected areas consistent with international law and based on scientific information, including representative networks, by 2012. The specific goals and targets to ensure practical and timely implementation of this commitment (including the need to designate cold-water coral reef locations as MPAs) are being discussed in various global and regional fora (Chapter 8).

> **Recommendation 12**
> Include an adequate representation of cold-water coral ecosystems in national and regional networks of marine protected areas.

Cold-water coral reefs also occur in the international waters of the high seas which are beyond national jurisdiction. The protection of these reefs forms part of international efforts to protect vulnerable high-seas habitats and to create a legal basis for this protection consistent with existing law. This is currently being discussed at the international level, including meetings of the UN General Assembly (including the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea), the UN Convention on the Law of the Sea, the UN Fish Stocks Agreement, the Code of Conduct for Responsible Fisheries of the Food and Agriculture Organization of the United Nations and the Convention on Biological Diversity.

> **Recommendation 13**
> Support at the global and regional levels the establishment of urgent and precautionary international measures designed to conserve, protect and manage sustainably vulnerable marine habitats such as cold-water coral ecosystems in the high seas.

> **Recommendation 14**
> Support the establishment of legal regime(s) and framework(s) to conserve, protect and manage sustainably cold-water coral reefs in the high seas under and/or consistent with UNCLOS and existing international agreements and conventions.

Stakeholder involvement

In order to be effective and achieve their goals, regulations and measures will need to be balanced, taking into account the concerns and interests of all relevant stakeholders, including those from industry and business.

> **Recommendation 15**
> Inform the relevant industry associations and sectors of the distribution, importance and vulnerability of cold-water coral reefs and encourage their active involvement and support in the process of developing and implementing management regulations and measures.

Fisheries, especially those carried out with bottom gear, the exploration and production of oil and gas, and the placement of pipelines and cables pose the greatest threats to cold-water coral reefs. Actions to reduce these threats will have to be considered both at international and national levels.

> **Recommendation 16**
> Engage global and regional organizations (both regulatory and non-regulatory), especially global and regional fishery bodies, international oil and gas industry associations, as well as pipeline and cable-placement companies, in the development of international and national work plans on cold-water coral reefs.

> **Recommendation 17**
> Encourage the fishing industry and fishing fleets to comply with the Code of Conduct for Responsible Fisheries of the Food and Agriculture Organization (FAO) of the United Nations* and to avoid the use of destructive fishing methods and gear in known or potential cold-water coral reef areas.

> **Recommendation 18**
> Encourage the oil and gas industries and the pipeline/cable-laying placement industries to avoid and mitigate damage to cold-water corals due to their activities and avoid operations and the placement of pipelines or cables in known or potential cold-water coral reef areas.

Enforcement and compliance

Effective control and policing, together with stakeholder acceptance and cooperation, will be crucial for the successful implementation of regulations and measures to protect the marine environment.

> **Recommendation 19**
> Enhance enforcement of existing legislation and establish punative penalties to prevent destruction of cold-water coral reefs.

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*Adopted by the 28th Session of the FAO Conference on 31 October 1995.

Monitoring and enforcing compliance with such regulations and measures in areas far off the coast or in international waters require considerable logistical and financial resources.

Recommendation 20

Assess the feasibility of extending the use of satellite vessel monitoring systems (VMS) to provide the responsible authorities with data related to compliance with regulations to protect cold-water coral reefs in national and/or international waters.

INTERNATIONAL COORDINATION AND AWARENESS

At present, most of the initiatives to improve international coordination and raise awareness of cold-water coral reefs are being carried out by individuals or small groups at a national or regional level. International events, such as the International Deep Sea Coral Symposium series (begun in 2000 in Halifax, Canada, and continued in 2003 in Erlangen, Germany) bring the scientific cold-water coral community together. However, they do not deliver the means of involving all stakeholders, coordinating sectoral activities and providing a policy delivery mechanism that could be achieved by a dedicated international forum/host organization which brings all stakeholders together, coordinates activities and establishes cooperative programmes of work.

Such a forum/host organization would also be able to raise the global awareness of cold-water coral reefs and reach out to countries, regions and other organizations which have not (yet) considered cold-water coral reefs. Where possible, existing international expertise and frameworks dealing with issues closely related to those relevant for cold-water coral reefs should be used, especially organizations addressing the conservation, protection and sustainable management of tropical warm-water coral reefs, e.g. the International Coral Reef Initiative (ICRI) and ICRI's operational networks, the International Coral Reef Action Network and the Global Coral Reef Monitoring Network.

The 58th session of the UN General Assembly noted that ICRI and other relevant bodies are considering incorporating cold-water coral ecosystems into their programmes of activities (Resolution 58/240). However, in order to do this, relevant organizations will have to be strengthened with additional resources to ensure that attention and resources are not diverted from their original objectives and mandates, e.g. in the case of ICRI to reverse the degradation of tropical warm-water reefs.

Recommendation 21

Support the incorporation of cold-water coral ecosystems into the programmes of activities of the International Coral Reef Initiative (ICRI) and other relevant bodies, and provide additional resources to strengthen these bodies.

Recommendation 22

Encourage the development and strengthening of global, regional and multinational cold-water coral reef partnerships and networks.

Recommendation 23

Support the inclusion of cold-water coral reefs as a key/representative ecosystem for deeper marine waters in existing or planned international monitoring and assessment programmes, such as the Global Ocean Observing System (GOOS), the Global Marine Assessment (GMA) and relevant programmes under Regional Seas Conventions and Action Plans.

The results of recent scientific studies and observations have contributed to raising the awareness of cold-water coral reefs at the national, regional and global levels, and the need for action has featured on the agendas of several international meetings associated with the protection of the marine environment. However, there is still a need to further disseminate information about the existence, worldwide distribution, threats and importance of cold-water corals. Some governments may still be unaware of the presence of colo-water corals or reefs in their waters.

One reason for timely conservation, protection and sustainable management of cold-water corals is to ensure that our children will have the opportunity to wonder at, study and benefit from these unique habitats. This will only be achieved with the full knowledge, understanding and support of the general public as to why efforts to prevent further damage and degradation of cold-water coral reefs are being made.

Recommendation 24

Further promote the awareness of cold-water coral reefs and the urgent need to conserve, protect and manage these ecosystems sustainably within relevant national governments, Regional Seas Conventions/Action Plans, intergovernmental organizations and the public.

Acronyms

ACES	Atlantic Coral Ecosystem Study
ARK	Arctic expeditions with RV Polarstern
AWI	Alfred Wegner Institute for Polar and Marine Research, Bremerhaven
CARACOLE	Carbonate Mounds and Cold Corals Expedition with RV l'Atalante and Victor ROV in 2001
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
DFO	Department of Fisheries and Oceans, Canada
EC	European Commission
EEZ	Exclusive economic zone
FAO	Food and Agriculture Organization of the United Nations
GEBCO	General Bathymetric Chart of the Oceans
GEOMAR	Forschungszentrum für Marine Geowissenschaften, Kiel
GIS	Geographic information system
GPS	Global positioning system
HAPC	Habitat of particular concern
HBOI	Harbor Branch Oceanographic Institution, Florida
ICES	International Council for the Exploration of the Sea
ICRI	International Coral Reef Initiative
IFREMER	French Research Institute for Exploitation of the Sea
IMR	Institute for Marine Research, Norway
IPAL	Institute of Paleontology, Erlangen University
IUCN	The World Conservation Union
JNCC	Joint Nature Conservation Committee
MBARI	Monterey Bay Aquarium Research Institute
MCBI	Marine Conservation Biology Institute
MPA	Marine protected area
NIWA	National Institute of Water and Atmospheric Research, New Zealand
NMFS	National Marine Fisheries Services, US
NOAA	National Oceanic and Atmospheric Administration, US
OCEANA	American Oceans Campaign
OHAPC	Oculina Habitat of Particular Concern
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
ROV	Remote operated vehicle
SAC	Special area of conservation
SEM	Scanning electron microscopy
SGCOR	Study Group on Cold-water Corals
TMBL	Tjärnö Marine Biological Laboratory, Sweden
TTR	Training-through-research
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
UNEP-WCMC	UNEP World Conservation Monitoring Centre
UNESCO	United Nations Educational, Scientific and Cultural Organization
VMS	Vessel monitoring system
WCPA	World Commission on Protected Areas, World Conservation Union
WHOI	Woods Hole Oceanographic Institution
WSSO	World Summit on Sustainable Development
WWF	World Wide Fund for Nature/World Wildlife Fund (US)

Glossary

Abyssal plain: An extensive, flat region of the ocean bottom from 4 000 to 7 000 m.

Actinians: Members of the class Anthozoa. With their bright colour, tentacles and general appearance they resemble flowers, leading to their common name, sea anemone.

Algae: Informal term covering a variety of photosynthetic, unicellular or primitive multicellular organisms of (predominantly) aquatic environments.

Anastomosing: Descriptive term for branches which re-fuse after having initially divided.

Ascidians: Tunicate animals, including sea squirts and red bait.

Bathyal zone: The benthic environment between the depths of 200 and 2 000 m. It includes mainly the continental slope and the oceanic ridges and rises.

Bathymetry: The study of ocean depth.

Benthic: Relating to the sea floor, including organisms living in or on the seabed.

Biodiversity: Assemblage of living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part.

Bivalve: Mollusc with two shells connected by a hinge (e.g. clams, oysters).

Bleaching: Expulsion of zooxanthellae by corals. Usually occurs as a result of environmental stress and frequently results in the death of the coral.

Bottom trawls: Non-selective method of fishing in which a large bag-shaped net is dragged or trawled. The mouth of the bag is kept open by various methods such as a wooden beam (beam trawl) or large flat board (otter trawl).

Brachiopods: Brachiopods ('arm feet') are a phylum of animals also known as lamp shells: bottom-dwelling marine invertebrates with two dissimilar protective shells held together by a hinge; superficially they look like molluscs.

Brittle star: Any of the 2 000 living species of marine invertebrates comprising the class Ophiuroidea (phylum Echinodermata). Their long, thin arms – usually five and often forked and spiny – are distinctly set off from the small disc-shaped body.

Bryozoa: Phylum of colonial animals that often share one coelomic cavity. Encrusting and branching forms secrete a protective housing of calcium carbonate or chitinous material.

Bycatch: Fishes or other animals caught by accident in fishing gear. Bycatch is usually thrown back dead or dying.

Carbonate mounds: Seabed features resulting from the growth of carbonate-producing organisms and current-controlled sedimentation.

Cetaceans: An aquatic mammal of the order Cetacea, including whales, porpoises and dolphins.

Clone: Asexually produced replicates of colonies.

Cold seep: Cold water seeps slowly from the sea floor (the opposite of hot, hydrothermal vents); often rich in hydrogen sulphide, a compound toxic to most animal life.

Cold water: Temperature regime not exceeding 20°C, and is meant here to draw a line between cold-water and tropical warm-water environments.

Cold-water coral ecosystems: Large aggregation of cold-water corals in terms of spatial coverage at a given locality.

Colonial animals: Animals that live in groups of attached or separate individuals. Groups of individuals may serve special functions.

Community: A group of organisms of different species that co-occur in the same habitat or area and interact through trophic and spatial relationships.

Continental margin: A zone separating the emergent continents from the deep-sea bottom; generally consists of the continental shelf, slope and rise.

Continental shelf: A gently sloping area extending from the low-water line to the depth of a marked increase in slope around the margin of a continent or island

Continental slope: A relatively steeply sloping surface lying seaward of the continental shelf.

Coral: A group of benthic anthozoans that exist as individuals or in colonies and may secrete calcium carbonate external skeletons.

Coral reef: Rigid coral structures that stand above the surrounding sea floor and owe their origins to the biological secretion of calcium carbonate by living organisms.

Cosmopolitan: With a worldwide distribution within habitat limits.

Crinoid: Any marine invertebrate of the class Crinoidea, usually possessing a somewhat cup-shaped body and five or more feathery arms.

Crustacea: A class of phylum Arthropoda that includes barnacles, copepods, lobsters, crabs and shrimp.

Cyanobacteria: Photosynthetic blue-green algae, intermediate between bacteria and higher plants.

Deep-sea trenches: Narrow, elongate depressions of the deep sea floor associated with a subduction zone. They are oriented parallel to volcanic arcs between the continental margin and the abyssal hills.

Deep water: The water beneath the permanent thermocline (pycnocline) that has a quite uniformly low temperature.

Demersal: Sinking to or lying on the bottom; living on or near the bottom and feeding on benthic organisms.

Dendroid: Having a branching structure reminiscent of that of a tree.

Diversity: The number of taxa in a group or place.

Drill cuttings: Inert pieces of rock, gravel and sand removed from a well during drilling.

Drilling fluid/drilling mud: Fluid pumped down a well bore during drilling; has multiple functions such as to cool and lubricate the drill bit, inhibit corrosion and remove drill cuttings from the hole.

Drumlins: Streamlined mounds of till that form at the base of moving glaciers. The long axis of these features is usually parallel to the glacier flow.

Echinodermata: Marine animals usually characterized by fivefold symmetry, possessing an internal skeleton of calcite plates, and a complex water vascular system. Includes echinoids (sea urchins), crinoids (sea lilies), asteroids (starfish), ophiurids (brittle stars) and holoturids (sea cucumbers).

Ecological limit: The dose or exposure level below which a significant adverse ecological effect is not expected.

Ecosystem: All the organisms in a biotic community and the abiotic environmental factors with which they interact.

Endemism: A taxa restricted in distribution to a particular geographical area and occurring nowhere else.

Epibenthic: Animals that live on the ocean bottom, either attached or moving freely over it.

Fecundity: The potential reproductive capacity of an organism or population, measured by the number of gametes (eggs) or asexual propagules.

Foraminifera: Protozoa of the order Foraminiferida which are abundant in the plankton and benthos of all oceans and possess a protective test (shell), usually composed of calcium carbonate.

Gamete: Sex cell; a special haploid cell or nucleus which unites with one of opposite sex to produce a (diploid) zygote.

Gametogenesis: The meiotic process by which mature gametes (ova and sperm) are formed. Oogenesis refers specifically to the production of ova and spermatogenesis to the production of sperm.

Gastropoda: A class of molluscs, most of which possess an asymmetrical spiral one-piece shell and a well-developed flattened foot. Includes snails, limpets, abalone, cowries, sea hares and sea slugs.

Gene flow: The movement of genes (strictly alleles) within and between populations.

Gene pool: The total complement of genes in a population.

Global warming: Increase in average temperatures caused by the greenhouse effect: carbon dioxide and other greenhouse gases trap solar-derived heat in the atmosphere near the Earth.

Grazing: Describes animals which rasp benthic algae or sessile animals, such as bryozoan crusts, from the substratum.

Habitat: Place and its living and non-living surroundings where an individual or population lives.

Hard coral: General term for skeletal Anthozoa. Synonymous with 'stony coral' (see Scleractinians).

High seas: This term, in municipal and international law, denotes all that continuous body of salt water in the world that is navigable in its character and that lies outside territorial waters and maritime belts of the various countries; also called open sea.

Hydrocarbon seeps: Where hydrocarbons seep slowly from the sea floor.

Hydrodynamic: Relates to the specific scientific principles that deal with the motion of fluids and the forces acting on solid bodies immersed in fluids, and in motion relative to them.

Hydrozoa: A class of coelenterates that characteristically exhibits alternation of generations with a sessile polypoid colony giving rise to a pelagic medusoid form by asexual budding.

Interglacial: A comparatively long warmer phase of a glacial period when considerable glacial retreat occurs.

Isotopes: Isotopes are atoms whose nuclei contain the same number of protons but a different number of neutrons. Isotopes that spontaneously decay are called radioactive isotopes; isotopes that do not are called stable.

Lander system: Scientific instrument designed for temporary deployment on the sea floor in order to monitor environmental parameters.

Larvae: A juvenile phase differing markedly in morphology and ecology from the adult.

Larval settlement: Settling of planctonic larvae on any hard substrate.

Lithoherm: Consolidated ridge-like seabed elevations composed of skeletal material such as coral rubble.

Megafauna: Animals exceeding 2 cm in length.

Mound provinces: Distinct geographical areas with clustered mound occurrences.

Nudibranch: Sea slug. A member of the mollusc class Gastropoda that has no protective covering as an adult. Respiration is carried on by gills or other projections on the dorsal surface.

Octocorallia: Subclass of the Anthozoa, with eight tentacles on each polyp. The skeleton can be organic axial or organomineral.

Offshore: The comparatively flat submerged zone of variable width extending from the breaker line to the edge of the continental shelf.

Overfishing: Applying a fishing effort beyond that which will generate a desirable, sustainable stock level. For long-lived species, overfishing starts well before the stock becomes overfished.

Panmictic populations: Continuous populations or races within which interbreeding is random.

Pelagic: Open water environments and organisms.

Physical backscatter: A reflection phenomenon of energy in which a non-reflective surface, which is a surface that does not reflect energy coherently, randomly scatters energy in all directions, including back in the direction from which it came.

Plankton: Passively drifting or weakly swimming organisms that are not independent of currents, including mostly microscopic algae, protozoa and larval forms of higher animals.

Plate tectonics: The study of movements of the Earth's lithospheric plates.

Polychaeta: Class of annelid worms that includes most of the marine segmented worms.

Polyp: A single individual of a colony or a solitary attached coelenterate.

Population: A group of organisms of the same species inhabiting a prescribed area.

Predation: The consumption of living tissue by another organism; commonly used to imply capture of one animal by another animal.

Productivity: A measure of the capacity of a biological system, e.g. the amount of fish supported or reproduced by a given area in a given time.

Recruitment: Refers to the addition of new individuals to a population.

Reef patch: A descriptive term for colonies composed of closely compacted upright branches.

Remote operated vehicle (ROV): Unmanned submersible connected to the research vessel by a cable; carries camera systems, manipulators or other devices.

Rock-hopper trawl: A demersal otter trawl with rubber discs attached to the ground rope and a second, off-centre rope, capable of trawling in areas of rough seabed.

Salinity: The concentration of salt in water, usually measured in parts per thousand (ppt).

Scleractinians: So called 'hard' corals which have limestone skeletons and which belong to the order Scleractinia.

Sclerites: Special structures within the coral tissue made of calcium carbonate.

Seamount: An individual peak extending several hundred metres above the ocean floor.

Sediment: Particles of organic or inorganic origin that accumulate in loose form.

Sediment resuspension: Current- or wave-induced uptake of sediment into the water column.

Sedimentary structures: This term refers to all characteristics in sedimentary rocks. These characteristics include layering, ripple marks, cross-bedding, and many more.

Shallow water: Water of depth such that surface waves are noticeably affected by bottom topography. Typically this implies a water depth equivalent to less than half the wave length.

Shelf break: Region where the continental shelf and continental slope meet. Commonly around 200 m water depth.

Sill: A submarine ridge partially separating bodies of water such as fjords and seas from one another or from the open ocean.

Soft coral: General term for askeletal Anthozoa.

Solitary corals: Corals composed of single individuals. There may be no clear distinction between single individuals with many mouths and colonies of individuals with single mouths.

Spawning: The release of gametes into the water column.

Speciation: Evolutionary processes which lead to an increase in the number of species.

Stony coral: General term for skeletal Anthozoa. Synonymous with hard coral.

Storm wave base: The plane or maximum depth to which waves may erode the sea bottom during severe storms.

Stylasterids: Corals of the family Stylasteridae, including lace corals; small, often brightly coloured, calcified hydrozoan corals with a delicate, branching structure.

Submarine canyons: Deep, V-shaped canyons cut into the continental slope and often associated with major rivers.

Suspension feeder: An organism that feeds by capturing particles suspended in the water column, e.g. barnacles.

Symbiosis: The close association between two organisms where there is substantial mutual benefit.

Systematics: The study of evolutionary and genetic relationships of organisms.

Thermocline: Layer of water column in which temperature gradient is pronounced.

Trophic level: A nourishment level in a food chain. Plant producers constitute the lowest level, followed by herbivores and a series of carnivores at the higher levels.

Upwelling: The process by which deep, cold, nutrient-laden water is brought to the surface, usually by diverging equatorial currents or coastal currents that pull water away from the coast.

Voucher specimen: A specimen archived in a permanent collection (e.g. a museum) as evidence of occurrence at a particular time and place and of any identification or description based on it.

Zooplankton: General term for tiny animals and other non-photosynthetic organisms of open water which have little or no capacity for independent movement.

References

Anderson OF, Clark MR (2003). Analysis of bycatch in the fishery for orange roughy, *Hoplostethus atlanticus*, on the South Tasman Rise. *Marine and Freshwater Research*, 54 (5), pp. 643-652.

Andrews AH, Cordes EE, Mahoney MM, Munk K, Coale KH, Cailliet GM, Heifetz J (2002). Age, growth and radiometric age validation of a deep-sea, habitat-forming gorgonian (*Primnoa resedaeformis*) from the Gulf of Alaska. *Hydrobiologia*, 471, pp. 101-110.

Andrews AH, Cailliet GM, Kerr Ferrey LA, Coale KH, Lundstrom C, DeVogelaere AP (in press). Investigations of age and growth for three deep-sea corals from the Davidson Seamount off central California. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Anon (2001). Seamount closures. *Seafood New Zealand*, June, 21 pp.

Auster PJ (in press). Are deep-water corals important habitats for fishes? In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Baco AR, Shank TM (in press). Population-genetic structure of the Hawaiian precious coral *Corallium lauuense* (Octocorallia: Corallidae) using macrosatellites. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Baker CM, Bett BJ, Billett DSM, Rogers AD (2001). An environmental perspective. In: *The Status of Natural Resources on the Highseas*, pp. 2-68, WWF/IUCN, Gland, Switzerland.

Bell N, Smith J (1999). Coral growing on North Sea oil rigs. *Nature*, 402, p. 601.

Bett BJ (2001). UK Atlantic Margin environmental survey: introduction and overview of bathyal benthic ecology. *Continental Shelf Research*, 21, pp. 917-956.

Beuck L, Freiwald A (in press). Bioerosion patterns of deep-water *Lophelia pertusa* (Scleractinia) thickets on Propeller Mound, northern Porcupine Seabight. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Birkeland C (ed) (1996). *Life and Death of Coral Reefs*, Chapman and Hall, 536 pp.

Boehlert GW, Genin A (1987). A review of the effects of seamounts on biological processes. In: *Seamounts, Islands and Atolls* (eds BH Keating, P Fryer, R Batiza, GW Boehlert), Geophysical Monographs, 43, pp. 319-334, Washington.

Boerbom CM, Smith JE, Risk MJ (1998). Bioerosion and micritization in the deep-sea coral *Desmophyllum cristagalli*. *Historical Biology*, 13, pp. 53-60.

Borets LA (1975). Some results of studies on the biology of the boarfish (*Pentaceros richardsoni* Smith). In: *Investigations of the Biology of Fishes and Fishery Oceanography*, pp. 82-90, TINRO, Vladivostok.

Breeze H, Derek DS, Butler M, Kostylev V (1997). *Distribution and Status of Deep-sea Corals off Nova Scotia. Marine Issues Committee Special Publication 1*. Ecology Action Centre, Halifax, Nova Scotia.

Broch H (1914). Stylasteridae. *The Danish Ingolf Expedition*, 5, pp. 1-25.

Brooke S, Young CM (2003). Reproductive ecology of a deep-water scleractinian coral, *Oculina varicosa*, from the southeast Florida shelf. *Continental Shelf Research*, 23, pp. 847-858.

Buddemeier RW, Kinzie RA (1976). Coral growth. *Oceanography and Marine Biology – An Annual Review*, 14, pp. 183-225.

Buhl-Mortensen L, Mortensen PB (2004). Crustaceans associated with the deep-water gorgonian corals *Paragorgia arborea* (L., 1758) and *Primnoa resedaeformis* (Gunn., 1763). *Journal of Natural History*, 38, pp. 1233-1247.

Buhl-Mortensen L, Mortensen PB (in press). Distribution and diversity of species associated with deep-sea gorgonian corals off Atlantic Canada. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Burgess SN, Babcock RC (in press). Reproductive ecology of three reef-forming, deep-sea corals in the New Zealand region. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Cairns SD (1979). The deep-water Scleractinia of the Caribbean Sea and adjacent waters. *Studies on the Fauna of Curaçao and other Caribbean Islands*, 57, 341 pp.

Cairns SD (1982). Antarctic and subantarctic Scleractinia. *Antarctic Research Series*, 34, 74 pp.

Cairns SD (1983). A generic revision of the Stylasterina (Coelenterata: Hydrozoa). *Bulletin of Marine Science*, 33, pp. 427-508.

Cairns SD (1984). New records of ahermatypic corals (Scleractinia) from the Hawaiian and Line Islands. *Bishop Museum Occasional Papers*, 25, pp. 1-30.

Cairns SD (1995). The marine fauna of New Zealand: Scleractinia (Cnidaria: Anthozoa). *New Zealand Oceanographic Institute Memoir*, 103, pp. 1-210.

Cairns SD (2001). A brief history of taxonomic research on azooxanthellate Scleractinia (Cnidaria: Anthozoa). *Bulletin of the Biological Society of Washington*, 10, pp. 191-203.

Cairns SD, Zibrowius H (1992). Revision of the Northeast Atlantic and Mediterranean Stylasteridae (Cnidaria: Hydrozoa). *Mémoires du Muséum National d'Histoire Naturelle Série A Zoologie*, 153, pp. 1-163.

Castro CB, Thiago CM, Medeiros MS (2003). First record of the family Coralliidae (Cnidaria: Anthozoa: Octocorallia) from the western South Atlantic, with a description of *Corallium medea* Bayer, 1964. *Zootaxa*, 323, pp. 1-8.

Cedhagen T (1994). Taxonomy and biology of *Hyrrokkin sarcophaga* gen. et sp. n., a parasitic foraminiferan (Rosalinidae). *Sarsia*, 79, pp. 65-82.

Cesar H, Burke L, Pet-Soede L (2003). *The Economics of Worldwide Coral Reef Degradation*, Cesar Environmental Economics Consulting, 23 pp.

Clark M, O'Driscoll R (2003). Deepwater fisheries and aspects of their impact on seamount habitat in New Zealand. *Journal of Northwest Atlantic Fishery Science*, 31, pp. 441-458.

Colman JG, Gordon DM, Lane AP, Forde MJ, Fitzpatrick JJ (in press). Carbonate mounds off Mauritania, North-West Africa: status of deep-water corals and implications for management of fishing and oil exploration activities. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Copley JTP, Tyler PA, Sheader M, Murton BJ, German CR (1996). Megafauna from sublittoral to abyssal depths along the Mid-Atlantic Ridge south of Iceland. *Oceanologica Acta*, 19, pp. 549-559.

Costello MJ, McCrea M, Freiwald A, Lundälv T, Jonsson L, Bett BJ, van Weering T, De Haas H, Roberts JM, Allen D (in press). Functional role of deep-sea cold-water *Lophelia* coral reefs as fish habitat in the Northeastern Atlantic. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Davies JM, Kingston PF (1992). Sources of environmental disturbance associated with offshore oil and gas developments. In: *North Sea Oil and the Environment – Developing oil and gas resources, environmental impacts and responses* (ed. WH Cairns), pp. 417-440, Elseviers Science Publishers Ltd, Essex.

Dawson EW (1984). The benthic fauna of the Chatham Rise: an assessment relative to possible effects of phosphorite mining. *Geologisches Jahrbuch*, Serie D, 65, pp. 209-231.

Delibrias G, Taviani M (1985). Dating the death of Mediterranean deep-sea scleractinian corals. *Marine Geology*, 62, pp. 175-180.

De Mol B, Van Rensbergen P, Pillen S, Van Herreweghe K, Van Rooji D, McDonnell A, Huvenne V, Ivanov M, Swennen R, Henriet JP (2002). Large deep-water coral banks in the Porcupine Basin, southwest of Ireland. *Marine Geology*, 188, pp. 193-231.

Di Geronimo I, Messina C, Rosso A, Sanfilippo R, Sciuto F, Vertino A (in press). Enhanced biodiversity in the deep: Early Pleistocene coral communities from southern Italy. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Dodge R, Lang J (1983). Environmental correlates of hermatypic coral (*Montastrea annularis*) growth on the East Flower Gardens Bank, north west Gulf of Mexico. *Limnology and Oceanography*, 28, pp. 228-240.

Dodge RE, Szmant-Froelich A (1985). Effects of drilling fluids on reef corals: a review. In: *Wastes in the Ocean* (eds IW Duedall, DR Kester, PK Park, BH Ketchum), pp. 341-364, Wiley (Interscience), New York.

Dodge R, Vaisnys J (1977). Coral populations and growth patterns: responses to sedimentation and turbidity associated with dredging. *Journal of Marine Research*, 35, pp. 715-730.

Dodge R, Aller R, Thomsom J (1974). Coral growth related to resuspension of bottom sediments. *Nature*, 247, pp. 574-577.

Dons C (1944). Norges korallrev. Det Kongelige Norske Videnskabers Selskab. *Forhandlinger*, 16, pp. 37-82.

Duncan PM (1877). On the rapidity of growth and variability of some Madreporaria on an Atlantic cable, with remarks upon the rate of accumulation of foraminiferal deposits. *Annals and Magazine of Natural History*, 20, pp. 361-365.

EC (1996). Interpretation manual of European Union habitats. In: *Council Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora*, Version EUR 15, European Commission Directorate General XI Environment, Nuclear Safety and Civil Protection, Nature Protection, Coastal Zones and Tourism, Brussels.

EC (2004). Council Regulation (EC) No 602/2004 of 22 March 2004 amending Regulation (EC) No 850/98 as regards the protection of deepwater coral reefs from the effects of trawling in an area north west of Scotland. *Official Journal of the European Union* L97 pp. 30-31. http://europa.eu.int/eurlex/pri/en/oj/dat/2004/l_097/l_09720040401en00300031.pdf

Epp D, Smoot NC (1989). Distribution of seamounts in the North Atlantic. *Nature*, 337, pp. 254-257.

Etnoyer P, Morgan L (2003). *Occurrences of Habitat-forming Deep-sea Corals in the Northeast Pacific Ocean: A report to NOAA's Office of Habitat Conservation*, p. 34, Marine Conservation Biology Institute, Redmond, WA.

Etnoyer P, Morgan L (in press). Records of habitat-forming deep-sea corals in the Northeast Pacific Ocean. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Farrow GE, Durant GP (1985). Carbonate-basaltic sediments from Cobb Seamount, Northeast Pacific: zonation, bioerosion and petrology. *Marine Geology*, 65, pp. 73-102.

Försterra G, Häussermann V (2003). First report on large Scleractinian (Cnidaria: Anthozoa) accumulations in cold-temperate shallow water of south Chilean fjords. *Zoologische Verhandelingen uitgegeven door het Rijksmuseum van Natuurlijke Historie te Leiden*, 345, pp. 117-128.

Fosså JH, Alvsvåg J (2003). Kartlegging og overvåkning av korallrev. In: *Havets Miljø 2003* (eds L Asplin, E Dahl), Fisken og Havet. Special Issue 2-2003, pp. 62-67.

Fosså JH, Mortensen PB, Furevik DM (2000). *Lophelia*-korallrev langs norskekysten forekomst og tilstand. *Fisken og Havet*, 2, pp. 1-94.

Fosså JH, Mortensen PB, Furevik DM (2002). The deep-water coral *Lophelia pertusa* in Norwegian waters: distribution and fishery impacts. *Hydrobiologia*, 471, pp. 1-12.

Foster AB (1980). Environmental variation in skeletal morphology within the Caribbean reef corals *Montastrea annularis* and *Siderastrea siderea*. *Bulletin of Marine Science*, 30, pp. 678-709.

Frank N, Lutringer A, Paterne M, Blamart D, Henriet JP, Van Rooij D, van Weering TCE (in press). Deep-water corals of the Northeastern Atlantic margin: carbonate mound evolution and upper intermediate water ventilation during the Holocene. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Frederiksen R, Jensen A, Westerberg H (1992). The distribution of the scleractinian coral *Lophelia pertusa* around the Faroe Islands and the relation to internal tidal mixing. *Sarsia*, 77, pp 157-171.

Freiwald A (2002). Reef-forming cold-water corals. In: *Ocean Margin Systems* (eds G Wefer, D Billett, D Hebbeln, BB Jørgensen, M Schlüter, TCE van Weering), pp. 365-385, Springer, Heidelberg.

Freiwald A, Roberts JM (eds) (in press). *Cold-water Corals and Ecosystems*, Springer Publishing House, Heidelberg, Germany.

Freiwald A, Schönfeld J (1996). Substrate pitting and boring pattern of *Hyrrokkin sarcophaga* Cedhagen, 1994 (Foraminifera) in a modern deep-water coral reef mound. *Marine Micropaleontology*, 28, pp. 199-207.

Freiwald A, Wilson JB)1998). Taphonomy of modern deep, cold-temperate water coral reefs. *Historical Biology*, 13, pp. 37-52.

Freiwald A, Henrich R, Pätzold J (1997). Anatomy of a deep-water coral reef mound from Stjernsund, West-Finnmark, northern Norway. *SEPM, Special Publication*, 56, pp. 141-161.

Freiwald A, Hühnerbach V, Lindberg B, Wilson JB, Campbell J (2002). The Sula Reef complex, Norwegian Shelf. *Facies*, 47, pp. 179-200.

Garrabou J, Harmelin JG (2002). A 20-year study on life-history traits of a harvested long-lived temperate coral in the NW Mediterranean: insights into conservation and management needs. *Journal of Animal Ecology*, 71, pp. 966-978.

Gass SE, Roberts JM (2003). The environmental sensivity of cold-water corals. *Erlanger Geologische Abhandlungen, Special Issue 4*, p. 109.

Gass SE, Willison JHM (in press). An assessment of the distribution of deep-sea corals in Atlantic Canada by using both scientific and local forms of knowledge. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Gattuso J-P, Allemand D, Frankignoulle M (1999). Photosynthesis and calcification at cellular, organismal and community levels in coral reefs: a review on interactions and control by carbonate chemistry. *American Zoologist*, 39, pp. 160-183.

Genin A, Dayton PK, Lonsdale PF, Spiess FN (1986). Corals on seamount peaks provide evidence of current acceleration over deep-sea topography. *Nature*, 322, pp. 59-61.

Golubic S, Schneider J (1979). Carbonate dissolution. In: *Biogeochemical Cycling of Mineral-forming Elements* (eds PA Trudinger, DJ Swaine), pp. 107-129, Elsevier Scientific Publishing Company, Amsterdam.

Gordon JDM (2003). The Rockall Trough, Northeast Atlantic: the cradle of deep-sea biological oceanography that is now being subjected to unsustainable fishing activity. *Journal of Northwest Atlantic Fishery Science*, 31, pp. 57-83.

Grehan AJ, Unnithan V, Olu K, Opderbecke J (in press). Fishing impacts on Irish deep-water coral reefs: making the case for coral conservation. In: *Proceedings from the Symposium on the Effects of Fishing Activities on Benthic Habitats: Linking Geology, Biology, Socioeconomics and Management, November 12-14th, 2002* (eds J Thomas, P Barnes), American Fisheries Society, Bethesda, Maryland, USA.

Grigg RW (1974). Growth rings: annual periodicity in two gorgonian corals. *Ecology*, 55, pp. 876-881.

Grigg RW (1984). Resource management of precious corals: a review and application to shallow water reef building corals. *Marine Ecology*, 5, pp. 57-74.

Grigg RW (1989). Precious coral fisheries of the Pacific and Mediterranean. In: *Marine Invertebrate Fisheries: Their assessment and management* (ed. JF Caddy), pp. 637-645, Wiley, New York.

Grigg RW (1993). Precious coral fisheries of Hawaii and the US Pacific Islands. *Marine Fisheries Review*, 55, pp. 50-60.

Grigg RW, Malahoff A, Chave EH, Landahl J (1987). Seamount benthic ecology and potential environmental impact from manganese crust mining in Hawaii. In: *Seamounts, Islands and Atolls* (eds BH Keating, P Fryer, R Batiza, GW Boehlert), Geophysical Monographs, 43, pp. 379-390, Washington.

Grygier MJ (1985). New ascothoracid crustacean endoparasites of Scleractinia. *Journal of Natural History*, 19, pp. 1029-1043.

Grygier MJ (1990). *Introcornia* (Crustacea: Ascothoracida: Petrarcidae) parasitic in an ahermatypic coral from St. Paul Island, Indian Ocean. *Vie et Milieu*, 40, pp. 313-318.

Grygier MJ, Cairns SD (1996). Suspected neoplasms in deep-sea corals (Scleractinia: Oculinidae: *Madrepora* spp.) reinterpreted as galls caused by *Petrarca madreporae* n. sp. (Crustacea: Ascothoracida: Petracidae). *Diseases of Aquatic Organisms*, 24, pp. 61-69.

Gubbay (2003). Seamounts of the North-East Atlantic. *WWF-OASIS Reports*, 37 pp.

Günther A (1990). Distribution and bathymetric zonation of shell-boring endoliths in recent reef and shelf environments: Cozumel, Yucatan (Mexico). *Facies*, 22, pp. 233-262.

Hall-Spencer J, Allain V, Fosså JH (2002). Trawling damage to Northeast Atlantic coral reefs. *Proceedings of the Royal Society of London* (B), 269, pp. 507-511.

Harrison WG, Fenton DG (1998). The Gully: A Scientific Review of its Environment and Ecosystem, Canadian Stock Assessment Secretariat Research Document, Department of Fisheries and Ocean, Ottawa, 98/83.

Heifetz J (2002). Coral in Alaska: distribution, abundance and species associations. *Hydrobiologia*, 471, pp. 19-28.

Herzog H, Drake E, Adams E (1997). CO_2 capture reuse and storage technologies for mitigating global climate change – A White Paper Final Report, DOE Order No DE-AF22-96PC0125.

Hess HH (1946). Drowned ancient islands of the Pacific Basin. *American Journal of Science*, 244, pp. 772-791.

Hirshfield MF, Roberts S, Allison DL (in press). Oceana's efforts to protect deep-sea corals in the United States. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Hoernle K, Mortimer N, Werner R, Hauff F (2003). RV Sonne Cruise Report SO-168. *Geomar Report*, 113, pp. 1-127.

Houghton J, Meira Filho L, Callandar B, Harris N, Kattenberg A, Maskell K (1996). *Climate Change 1995*. Cambridge University Press, Cambridge, UK.

Hovland M, Croker PF, Martin M (1994). Fault-associated seabed mounds (carbonate knolls?) off Western Ireland and North-West Australia. *Marine and Petroleum Geology*, 11, pp. 232-246.

Hovland M, Mortensen PB, Thomsen E, Brattegard T (1997). Substratum-related ahermatypic coral banks on the Norwegian continental shelf. *Proceedings of the 8th International Coral Reef Symposium, Panama City*, 2, pp. 1203-1206.

Hovland M, Mortensen PB, Brattegard T, Strass P, Rokoengen K (1998). Ahermatypic coral banks off mid-Norway: evidence for a link with seepage of light hydrocarbons. *Palaios*, 13, pp. 189-200.

Hovland MT, Vasshus S, Indreeide A, Austdal L, Nilsen Ø (2002). Mapping and imaging deep-sea coral reefs off Norway, 1982-2000. *Hydrobiologia*, 471, pp. 13-17.

Hubbs CL (1959). Initial discoveries of fish faunas on seamounts and offshore banks in the eastern Pacific. *Pacific Science*, 13, pp. 311-316.

Hudson JH, Shinn EA, Robbin DM (1982). Effects of offshore oil drilling on Philippine reef corals. *Bulletin of Marine Science*, 32, pp. 890-908.

Husebø Å, Nøttestad L, Fosså JH, Furevik DM, Jørgensen SB (2002). Distribution and abundance of fish in deep-sea coral habitats. *Hydrobiologia*, 471, pp. 91-99.

Huvenne VAI, Blondel P, Henriet J-P (2002). Textural analysis of sidescan sonar imagery from two mound provinces in the Porcupine Seabight. *Marine Geology*, 189, pp. 323-341.

Hyland J, Hardin D, Steinhauer M, Coats D, Green R, Neff J (1994). Environmental impact of offshore oil development on the outer continental shelf and slope off Point Arguello, California. *Marine Environmental Research*, 37, pp. 195-229.

ICES (2002). Report of the Study Group on Mapping the Occurrence of Cold-Water Corals, International Council for the Exploration of the Sea, Copenhagen, Denmark, CM 2002/ACE:05.

ICES (2003). Report of the Study Group on Cold-Water Corals (SGCOR) for the Advisory Committee on Ecosystems (ACE), 226 pp., Copenhagen, Denmark, ICES CM 2003/ACE:02.

Jaques TG (1972). On the occurrence of deep-sea corals on one of the Corner Seamounts. *Graduate School of Oceanography, Rhode Island, Research Project OCG 540*, pp. 1-56.

Jennings S, Kaiser MJ (1998). The effects of fishing on marine ecosystems. *Advances in Marine Biology*, 34, pp. 201-352.

Joubin ML (1915). Les coraux de mer profonde nuisibles aux chalutiers. *Office Scientifique et Technique des Pêches Maritimes, Notes et Mémoires*, 18, pp. 5-16.

Kaszemeik K, Freiwald A (2003). *Lophelia pertusa* (Scleractinia) – From Skeletal Structures to Growth Patterns and Morphotypes, 26 pp. Final ACES-Deliverable Report.

Keller NB (1976). The deep-sea madreporarian corals of the genus *Fungiacyathus* from the Kurile-Kamchatka, Aleutian Trenches. *Trudy Instituta Okeanologii*, 99, pp. 31-44.

Kenyon NH, Akhmetzhanov AM, Wheeler AJ, van Weering TCE, de Haas H, Ivanov M (2003). Giant carbonate mud mounds in the Southern Rockall Trough. *Marine Geology*, 195, pp. 5-30.

Kiriakoulakis K, Fisher E, Wolff GA (in press). Lipids and nitrogen isotopes of two deep-water corals from the North-East Atlantic: initial results and implications for their nutrition. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Kleypas JA, McManus JW, Menez LAB (1999). Environmental limits to coral reef development: where do we draw the line? *American Zoologist*, 39, pp. 146-159.

Koslow JA, Boehlert GW, Gordon JDM, Haedrich RL, Lorance P, Parin N (2000). Continental slope and deep-sea fisheries: implications for a fragile ecosystem. *ICES Journal of Marine Science*, 57, pp. 548-557.

Koslow JA, Gowlett-Holmes K, Lowry JK, O'Hara T, Poore GCB, Williams A (2001). Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. *Marine Ecology Progress Series*, 213, pp. 111-125.

Krieger KJ, Wing BL (2002). Megafauna associations with deep-water corals (*Primnoa* spp.) in the Gulf of Alaska. *Hydrobiologia*, 471, pp. 83-90.

Krone M, Biggs D (1980). Sublethal metabolic responses of the hermatypic coral *Madracis decactis* exposed to drilling mud enriched with ferrochrome lignosulfate. In: *Research on Environmental Fate and Effects of Drilling Fluids and Cuttings*, II, pp. 1079-1100, Courtesy Associates, Washington, DC.

Le Goff MC, Rogers AD (2002). Characterization of 10 microsatellite loci for the deep-sea coral *Lophelia pertusa* (Linnaeus 1758). *Molecular Ecology Notes*, 2, pp. 164-166.

Le Goff-Vitry MC, Rogers AD (in press). Molecular ecology of *Lophelia pertusa* in the NE Atlantic. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Le Goff-Vitry MC, Pybus OG, Rogers AD (2004). Genetic structure of the deep-sea coral *Lophelia pertusa* in the northeast Atlantic revealed by microsatellites and internal transcribed spacer techniques. *Molecular Ecology*, 13, pp. 537-549.

Long R, Grehan AJ (2002). Marine habitat protection in sea areas under the jurisdiction of a coastal member state of the European Union: the case of deep-water coral conservation in Ireland. *The International Journal of Marine and Coastal Law*, 17, pp. 235-261.

MacIntyre IG (1984). Preburial and shallow-subsurface alteration of modern scleractinian corals. *Palaeontographica Americana*, 54, pp. 229-243.

Marine Theme Participants at the 5th World Parks Congress, South Africa (2003). Ten-Year High Seas Marine Protected Area Strategy: A ten-year strategy to promote the development of a global representative system of high seas marine protected area networks. www.iucn.org/themes/marine/pdf/10ystrat.pdf.

Masson DG, Bett BJ, Billett DSM, Jacobs CL, Wheeler AJ, Wynn RB (2003). The origin of deep-water, coral-topped mounds in the Northern Rockall Trough, Northeast Atlantic. *Marine Geology*, 194, pp. 159-180.

McDonough JJ, Puglise KA (2003). Summary: Deep-Sea Corals Workshop. International planning and collaboration workshop for the Gulf of Mexico and the North Atlantic Ocean, Galway, Ireland, January 16-17, 2003. *NOAA Technical Memorandum NMFS-SPO-60*, pp. 1-51.

Messing CG, Neumann AC, Lang JC (1990). Biozonation of deep-water lithoherms and associated hardgrounds in the Northeastern Straits of Florida. *Palaios*, 5, pp. 15-33.

Mikkelsen N, Erlenkeuser H, Killingley JS, Berger WH (1982). Norwegian corals: radiocarbon and stable isotopes in *Lophelia pertusa*. *Boreas*, 11, pp. 163-171.

Moore JA, Vecchione M, Collette BB, Gibbons R, Hartel KE, Galbraith JK, Turnipseed M, Southworth M, Watkins E (2003). Biodiversity of Bear Seamount, New England Seamount Chain: results of exploratory trawling. *Journal of Northwest Atlantic Fishery Science*, 31, pp. 363-372.

Morgan LE, Chuenpagdee R (2003). *Shifting Gears: Addressing the collateral impacts of fishing methods in U.S. waters*. Island Press, Washington, DC.

Mortensen PB (2001). Aquarium observations on the deep-water coral *Lophelia pertusa* (L., 1758) (Scleractinia) and selected associated invertebrates. *Ophelia*, 54, pp. 83-104.

Mortensen PB, Buhl-Mortensen L (in press). Deep-water corals and their habitats in The Gully, a submarine canyon off Atlantic Canada. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Mortensen PB, Rapp HT (1998). Oxygen and carbon isotope ratios related to growth line patterns in skeletons of *Lophelia pertusa* (L.) (Anthozoa, Scleractinia): implications for determination of linear extension rates. *Sarsia*, 83, pp. 433-446.

Mortensen PB, Hovland M, Brattegard T, Farestveit R (1995). Deep water bioherms of the scleractinian coral *Lophelia pertusa* (L.) at 64°N on the Norwegian shelf: structure and associated megafauna. *Sarsia*, 80, pp. 145-158.

Mortensen PB, Hovland MT, Fosså JH, Furevik DM (2001). Distribution, abundance and size of *Lophelia pertusa* coral reefs in mid-Norway in relation to seabed characteristics. *Journal of the Marine Biological Association of the United Kingdom*, 81, pp. 581-597.

Mullins HT, Newton CR, Heath K, Vanburen HM (1981). Modern deep-water coral mounds north of Little Bahama Bank: criteria for recognition of deep-water coral bioherms in the rock record. *Journal of Sedimentary Petrology*, 51, pp. 999-1013.

Neumann AC (1966). Observations on coastal erosion in Bermuda and measurements of the boring rate of the sponge, *Cliona lampa*. *Limnology and Oceanography*, 11, pp. 92-108.

Norse EA, Watling L (1999). Impacts of mobile fishing gear: the biodiversity perspective. *American Fisheries Society Symposium*, 22, pp. 31-40.

Norwegian Council of State (2002). Report No. 12: Protecting the Riches of the Seas. Reports to the Storting (white papers), http://odin.dep.no/md/engelsk/publ/stmeld/022001-040016/index-dok000-b-n-a.html

Olsgard F, Gray JS (1995). A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian Continental Shelf. *Marine Ecology Progress Series*, 122, pp. 277-306.

Opresko DM (1974). *A Study of the Classification of the Antipatharia (Coelenterata: Anthozoa) with Descriptions of Eleven Species*. University of Miami, pp. 1-194.

Paull CK, Neumann AC, am Ende BA, Ussler W, Rodriguez NM (2000). Lithoherms on the Florida-Hatteras Slope. *Marine Geology*, 166, pp. 83-101.

Pauly D, Christensen V, Dalsgaard J, Froese R, Torres F (1998). Fishing down marine food webs. *Science*, 279, pp. 860-863.

Pauly D, Alder J, Bennett E, Christensen V, Tyedmers P, Watson R (2003). The future for fisheries. *Science*, 302, pp. 1359-1361.

Pfannkuche O (2004). RV Alkor Cruise Report ALK-232, unpublished report, 35 pp.

Probert PK, McKnight DG, Grove SL (1997). Benthic invertebrate bycatch from a deep-water trawl fishery, Chatham Rise, New Zealand. *Aquatic Conservation: Marine and freshwater ecosystems*, 7, pp. 27-40.

Raimondi PT, Barnett AM, Krause PR (1997). The effects of drilling muds on marine invertebrate larvae and adults. *Environmental Toxicology and Chemistry*, 16, pp. 1218-1228.

Reed JK (1981). *In situ* growth rates of the scleractinian coral *Oculina varicosa* occurring with zooxanthellae on 6-m reefs and without on 80-m banks, *Proceedings of the Fourth International Coral Reef Symposium*, 2, pp. 201-206, Manila.

Reed JK (2002a). Deep-water *Oculina* reefs of Florida: biology, impacts, and management. *Hydrobiologia*, 471, pp. 43-55.

Reed JK (2002b). Comparison of deep-water coral reefs and lithoherms off southeastern USA. *Hydrobiologia*, 471, pp. 57-69.

Reed JK, Shepard AN, Koenig CC, Scanlon KM (in press). Mapping, habitat characterization, and fish surveys of the deep-water *Oculina* Coral Reef Marine Protected Area: a review of historical and current research. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Reyes J, Santodomingo N, Gracia A, Borrero-Pérez G, Navas G, Mejía-Ladino LM, Bermúdez A, Benavides M (in press). Southern Caribbean azooxanthellate coral communities off Colombia. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Richer de Forges B (1990). Explorations for bathyal fauna in the New Caledonian economic zone. *Mémoires du Muséum National d'Histoire Naturelle Série A Zoologie*, 145, pp. 9-54.

Richer de Forges B (1993). Deep-sea crabs of the Tasman Seamounts (Crustacea: Decapoda: Brachyura). *Records of the Australian Museum*, 45, pp. 11-24.

Richer de Forges B, Koslow JA, Poore GCB (2000). Diversity and endemism of the benthic seamount fauna in the Southwest Pacific. *Nature*, 405, pp. 944-947.

Risk MJ, Heikoop JM, Snow MG, Beukens R (2002). Lifespans and growth patterns of two deep-sea corals: *Primnoa resedaeformis* and *Desmophyllum cristagalli*. *Hydrobiologia*, 471, pp. 125-131.

Roberts JM (2000a). Report on subsea video showing marine growth suspected to be *Lophelia pertusa* around the Brent Alpha platform, 10 pp., Scottish Association for Marine Science, Dunstaffnage Marine Laboratory, Oban.

Roberts JM (2000b). Full effects of oil rigs on corals are not yet known. *Nature*, 403, p. 242.

Roberts JM (2002). The occurrence of the coral *Lophelia pertusa* and other conspicuous epifauna around an oil platform in the North Sea. *Journal of the Society for Underwater Technology*, 25, pp. 83-91.

Roberts JM, Harvey SM, Lamont PA, Gage JD, Humphery JD (2000). Seabed photography, environmental assessment and evidence for deep-water trawling on the continental margin west of the Hebrides. *Hydrobiologia*, 441, pp. 173-183.

Roberts JM, Long D, Wilson JB, Mortensen PB, Gage JD (2003). The cold-water coral *Lophelia pertusa* (Scleractinia) and enigmatic seabed mounds along the north-east Atlantic margin: are they related? *Marine Pollution Bulletin*, 46, pp. 7-20.

Roberts JM, Peppe OC, Dodds LA, Mercer DJ, Thomson WT, Gage JD, Meldrum DT (in press). Monitoring environmental variability around cold-water coral reefs: the use of a benthic photolander and the potential of seafloor observatories. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Rogers AD (1994). The biology of seamounts. *Advances in Marine Biology*, 30, pp. 305-350.

Rogers AD (1999). The biology of *Lophelia pertusa* (Linnaeus, 1758) and other deep-water reef-forming corals and impacts from human activities. *International Revue of Hydrobiology*, 84, pp. 315-406.

Sayfy A, Willison M, Sheppard V, Millar D (2003). Canada's first ever coral reef discovered; conservation measures urgently needed. *Newsletter of Canadian Parks and Wilderness Society Nova Scotia*, 3, p. 7.

Schröder-Ritzrau A, Freiwald A, Mangini A (in press). U/Th-dating of deep-water corals from the Eastern North Atlantic and the Western Mediterranean Sea. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Schroeder WW (2002). Observations of *Lophelia pertusa* and the surficial geology at a deep-water site in the Northeastern Gulf of Mexico. *Hydrobiologia*, 471, pp. 29-33.

Schroeder WW, Brooke SD, Olson JB, Phaneuf B, McDonough III JJ, Etnoyer P (in press). Occurrence of deep-water *Lophelia pertusa* and *Madrepora oculata* in the Gulf of Mexico. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Shelton GAB (1980). *Lophelia pertusa* (L.): electrical conduction and behaviour in a deep-water coral. *Journal of the Marine Biological Association of the United Kingdom*, 60, pp. 517-528.

Shester G, Ayers J (in press). A cost effective approach to protecting deep-sea coral and sponge ecosystems with an application to Alaska's Aleutian Islands region. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Smith DK, Jordan TH (1988). Seamount statistics in the Pacific Ocean. *Journal of Geophysical Research*, 93, pp. 2899-2918.

Spalding MD, Ravilious C, Green EP (2001). *World Atlas of Coral Reefs*, prepared at the UNEP World Conservation Monitoring Centre. University of California Press, Berkeley CA.

Spiro B, Roberts JM, Gage J, Chenery S (2000). $^{18}O/^{16}O$ and $^{13}C/^{12}C$ in an ahermatypic deep-water coral *Lophelia pertusa* from the North Atlantic: a case of disequilibrium isotope fractionation. *Rapid Communications in Mass Spectrometry*, 14, pp. 1332-1336.

Squires DF (1965). Deep-water coral structure on the Campbell Plateau, New Zealand. *Deep-Sea Research*, 12, pp. 785-788.

Stetson TR, Squires DF, Pratt RM (1962). Coral banks occurring in deep water on the Blake Plateau. *American Museum Novitates*, 2114, pp. 1-39.

Stone RP, Malecha PW (2003). Deep-sea coral habitat in the Aleutian Islands of Alaska. *Erlanger Geologische Abhandlungen*, Special Volume 4, p. 81.

Strømgren T (1971). Vertical and horizontal distribution of *Lophelia pertusa* (Linné) in Trondheimsfjorden on the west coast of Norway. *Det Kongelige Norske Videnskabers Selskabs Skrifter*, 6, pp. 1-9.

Szmant-Froelich A, Johnson V, Hoen T, Battey J, Smith GJ, Fleishmann E, Porter J, Dalemeyer D (1981). The physiological effects of oil drilling muds on the Caribbean coral *Montastrea annularis*. *Proceedings of the 4th International Coral Reef Symposium, Manila*, pp. 18-20.

Taviani M, Corselli C, Freiwald A, Malinverno E, Mastrototaro F, Remia A, Savini A, Tursi A, CORAL Shipboard Staff (in press). Rise, decline and ressurrection of deep-coral banks in the Mediterranean Basin: results of 2002 Coral Mission in the Ionian Sea. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Thompson JJ, Bright T (1980). Effects of an offshore drilling fluid on selected corals. In: *Research on Environmental Fate and Effects of Drilling Fluids and Cuttings*, 2, pp. 1044-1078, Washington DC.

Tunesi L, Diviacco G, Mo G (2001). Observations by submersible on the biocoenosis of the deep-sea corals off Portofino Promontory (Northwestern Mediterranean Sea). In: *Proceedings of the First International Symposium on Deep-sea Corals* (eds JHM Willison, J Hall, S Gass, ELR Kenchington, M Butler, P Doherty), pp. 76-87, Ecology Action Centre and Nova Scotia Museum, Halifax, Nova Scotia.

Turner SJ, Trush SF, Hewitt JE, Cummings VJ, Funnell G (1999). Fishing impacts and the degradation or loss of habitat structure. *Fisheries Management and Ecology*, 6, pp. 401-420.

United Nations (1982). UNCLOS Treaty. www.un.org/Depts/los/convention_agreements/convention_overview_convention.htm.

van der Laan JD, Hogeweg P (1992). Waves of crown-of-thorns starfish outbreaks – where do they come from? *Coral Reefs*, 11, pp. 207-213.

Van Rooij D, De Mol B, Huvenne V, Ivanov M, Henriet J-P (2003). Seismic evidence of current-controlled sedimentation in the Belgica Mound province, upper Porcupine slope, southwest of Ireland. *Marine Geology*, 195, pp. 31-53.

van Weering TCE, de Haas H, de Stigter HC, Lykke-Andersen H, Kouvaev I (2003). Structure and development of giant carbonate mounds at the SW and SE Rockall Trough margins, NE Atlantic Ocean. *Marine Geology*, 198, pp. 67-81.

Veron JEN (2000). *Corals of the World* (ed M Stafford-Smith), Australian Institute of Marine Science and CR R Qld Pty Ltd, 463 pp.

Viana AR, Faugères JC, Kowsmann RO, Lima JAM, Caddah LFG, Rizzo JG (1998). Hydrology, morphology and sedimentology of the Campos Continental Margin, offshore Brazil. *Sedimentary Geology*, 115, pp. 133-157.

Wabnitz C, Taylor M, Green E, Razak T (2003). *From Ocean to Aquarium. The global trade in marine ornamental species*. UNEP-WCMC Biodiversity Series, 17, p. 64.

Waller R (in press). Deep-water Scleractinia (Cnidaria: Anthozoa): current knowledge of reproductive processes. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Waller R, Tyler PA (in press). The reproductive biology of two deep-water reef building scleractinians from the NE Atlantic Ocean. *Coral Reefs*.

Watling L, Risk M (2002). Biology of cold-water corals. *Hydrobiologia, Special Issue*, 471, pp. 1-164.

White M (2003). Comparison of near seabed currents at two locations in the Porcupine Seabight – implications for benthic fauna. *Journal of the Marine Biological Association of the United Kingdom*, 83, pp. 683-686.

White M, Mohn C, de Stigter H, Mottram G (in press). Deep-water coral development as a function of hydrodynamics and surface productivity around the submarine banks of the Rockall Trough, NE Atlantic. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Wilkinson C (ed) (2002). *Status of Coral Reefs of the World: 2002*, Australian Institute of Marine Science.

Willison JHM, Hall J, Gass SE, Kenchington ELR, Butler M, Doherty P (eds) (2001). *Proceedings of the First International Symposium on Deep-sea Corals*, 231 pp. Ecology Action Centre, Halifax, Nova Scotia.

Wilson JB (1979a). The distribution of the coral *Lophelia pertusa* (L.) (*L. prolifera*) in the North-East Atlantic. *Journal of the Marine Biological Association of the United Kingdom*, 59, pp. 149-164.

Wilson JB (1979b). 'Patch' development of the deep-water coral *Lophelia pertusa* (L.) on Rockall Bank. *Journal of the Marine Biological Association of the United Kingdom*, 59, pp. 165-177.

Wilson RR, Kaufman RS (1987). Seamount biota and biogeography. In: *Seamounts, Islands and Atolls* (eds BH Keating, P Fryer, R Batiza, GW Backland), Geophysical Monographs, 43, pp. 355-377, Washington.

Wisshak M, Freiwald A, Gektidis M, Lundälv T (in press). The physical niche of the bathyal *Lophelia pertusa* in a non-bathyal setting: environmental controls and palaeoecological implications. In: *Cold-water Corals and Ecosystems* (eds A Freiwald, JM Roberts), Springer Publishing House, Heidelberg, Germany.

Witherell D, Coon C (2001). Protecting gorgonian corals off Alaska from fishing impacts. In: *Proceedings of the First International Symposium on Deep-Sea Corals* (eds JHM Willison, J Hall, SE Gass, ELR Kenchington, M Butler, P Doherty), Halifax, Nova Scotia.

Wood R (1995). The changing biology of reef-building. *Palaios*, 10, pp. 517-529.

Wood R (1999). *Reef Evolution*, 432 pp. Oxford University Press, Oxford

Zibrowius H (1973). Scléractiniaires des Iles Saint Paul et Amsterdam (Sud de l'Océan Indien). *Tethys*, 5, pp. 747-778.

Zibrowius H (1980). Les Scléractiniaires de la Méditerranée et de l'Atlantique nord-oriental. *Mémoires de l'Institut Océanographique*, Monaco, 11, pp. 1-284.

Zibrowius H (1981). Associations of Hydrocorallia Stylasterina with gall-inhabiting Copepoda Siphonostomatoidea from the South-West Pacific. *Bijdragen tot de Dierkunde*, 51, pp. 268-286.

Selection of websites with cold-water coral information

www.imr.no/coral

Institute of Marine Research, University of Bergen, Norway

The principal objective of the Institute is to provide scientific advice on marine resources, the marine environment and aquaculture to the authorities, industry and society as a whole. The work of the Institute is primarily concentrated on the ecosystems of the Barents Sea, the Norwegian Sea, the North Sea and the Norwegian coastal zone.

www.cool-corals.de

Institute of Paleontology, University of Erlangen-Nuremberg, Germany

Information about cold-water coral research, cruises and the outcome of the 2nd International Symposium on Deep-sea Corals.

www.panda.org/about_wwf/where_we_work/europe/where/ne_atlantic/lophelia.cfm

World Wide Fund for Nature (WWF)

Special topic concerning deep-water corals: 'On the ground of the North-East Atlantic' on WWF's website. WWF is the major non-governmental organization dedicated to the protection of the world's natural environments.

www.marlin.ac.uk

The Marine Life Information Network for Britain & Ireland

The Marine Life Information Network (MarLIN) programme provides information on marine environmental management, protection and education. Its centrepiece is an extensive database on marine species and their habitats.

www.ecoserve.ie/projects/coral/biology.html

Ecoserve – Ecological Consultancy Services Limited, Dublin, Ireland

Special section on the biology of *Lophelia pertusa* on the Ecoserve website. Ecoserve is a company providing technical environmental services, including impact and nature conservation assessment, ecotoxicology, monitoring, etc., specializing in marine and freshwater systems.

www.sams.ac.uk/sams/projects/benthic/lophelia.htm

Scottish Association for Marine Science (SAMS), based at the Dunstaffnage Marine Laboratory, Oban, UK

Special section on *Lophelia pertusa* on the SAMS website.The Association promotes marine research and education in Scotland. SAMS aims to raise the awareness of marine science through school visits, open days, public seminars and the Marine Science Degree of the UHI Millennium Institute.

www.marinbi.com/skarnsundet/skarnsundet.htm

Personal website by Frank Emil Moen, Trondheim, Norway

Excellent picture gallery – mainly deep-water corals from Skarnsundet-Trondheimsfjorden, Norway, by Erling Svensen and Frank Emil Moen, both experienced divers and avid underwater photographers.

www.coris.noaa.gov/about/deep/deep.html

National Oceanic and Atmospheric Administration, US Department of Commerce

Extensive section on deep-water corals in NOAA's Coral Reef Information System (CoRIS). CoRIS is designed to provide the public with a single point of access for coral reef data and information derived from many NOAA programmes and projects.

www.oceana.org/

American Oceans Campaign (Oceana), Washington, United States

Various topics on deep-sea environments on the Oceana website. Oceana is a non-profit international advocacy organization dedicated to restoring and protecting the world's oceans through policy advocacy, science, law and public education.

www.wwf.ca/NewsAndFacts/Resources.asp?type=resources

WWF Canada has a strong focus on cold-water coral and seamount conservation within its marine programme. It will shortly be producing a new report about *Lophelia* reefs in the northwest Atlantic (Grand Banks) ecoregion.

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UNEP WCMC

Cold-water coral reefs
Out of sight – no longer out of mind

This document has been produced by a team of international experts, with the support of the Governments of Ireland, Norway and the United Kingdom as well as the World Wide Fund for Nature (WWF) and the United Nations Environment Programme (UNEP). It presents a comprehensive and up-to-date compilation of information and data on marine cold-water coral reefs from around the world.

Recent underwater studies have shown the beauty and diversity of cold-water coral reefs, which are comparable in their size and complex structure to the warm-water coral reefs of the tropics.

Cold-water coral reefs, Out of sight – no longer out of mind describes the various cold-water coral ecosystems and associations together with their known and potential worldwide geographical distribution. Case studies and observations from several locations illustrate the state of these reefs and highlight their vulnerability to threats caused by human activities, which have already destroyed or affected a large number of cold-water coral reefs.

Cold-water coral reefs, Out of sight – no longer out of mind aims to raise the awareness of decision makers and industrial and environmental stakeholders about cold-water coral reefs. It provides managers as well as national and international policy makers with a set of expert recommendations for the concerted and urgent action that needs to be taken in the conservation, protection and sustainable management of these fascinating, beautiful but fragile ecosystems.

Photos above: JNCC/Heather [illegible]

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