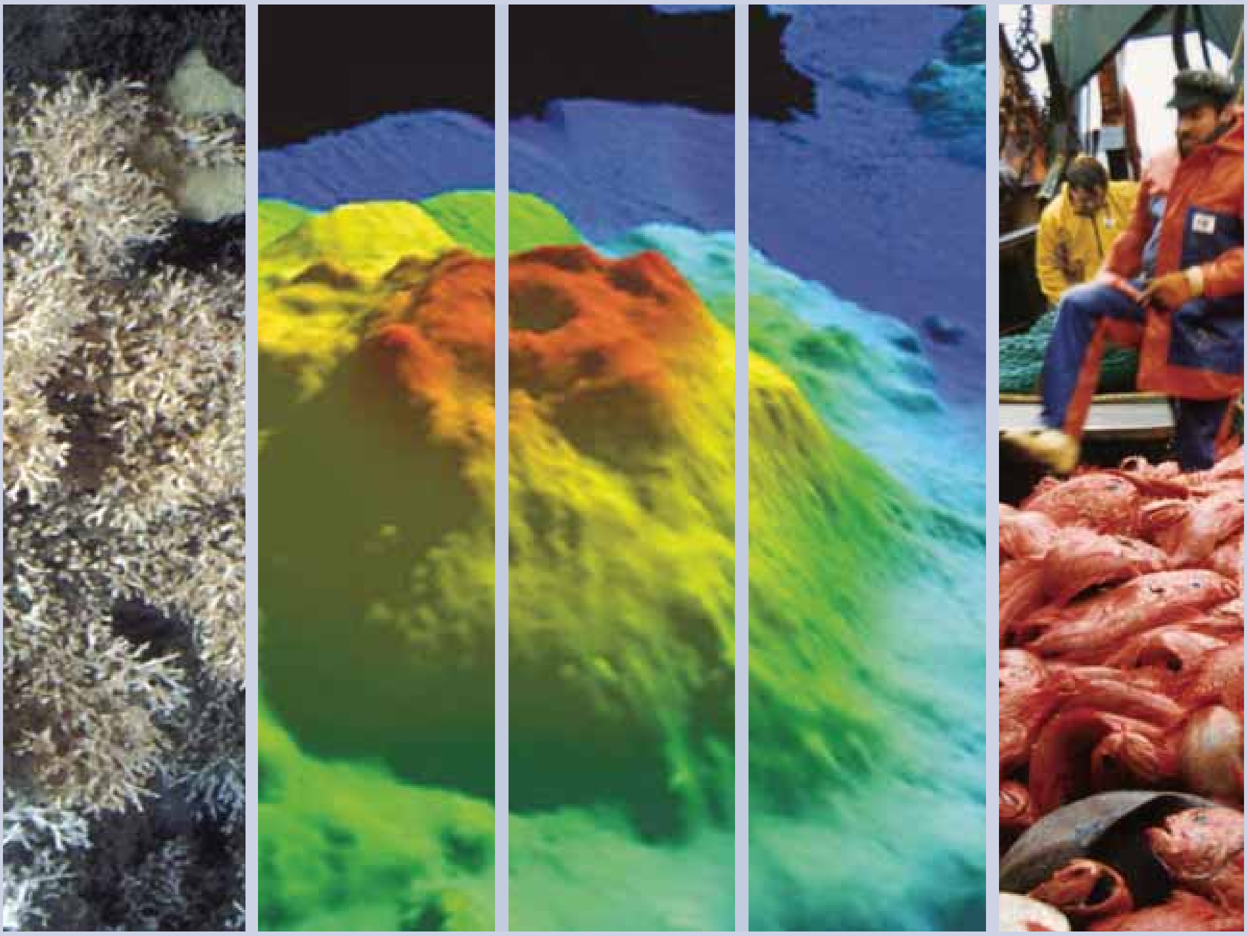
United Nations Educational, Scientific and Cultural Organization
Intergovernmental Oceanographic Commission
CENSUS OF MARINE LIFE
NIWA Taihoro Nukurangi
agriculture, nature and food quality

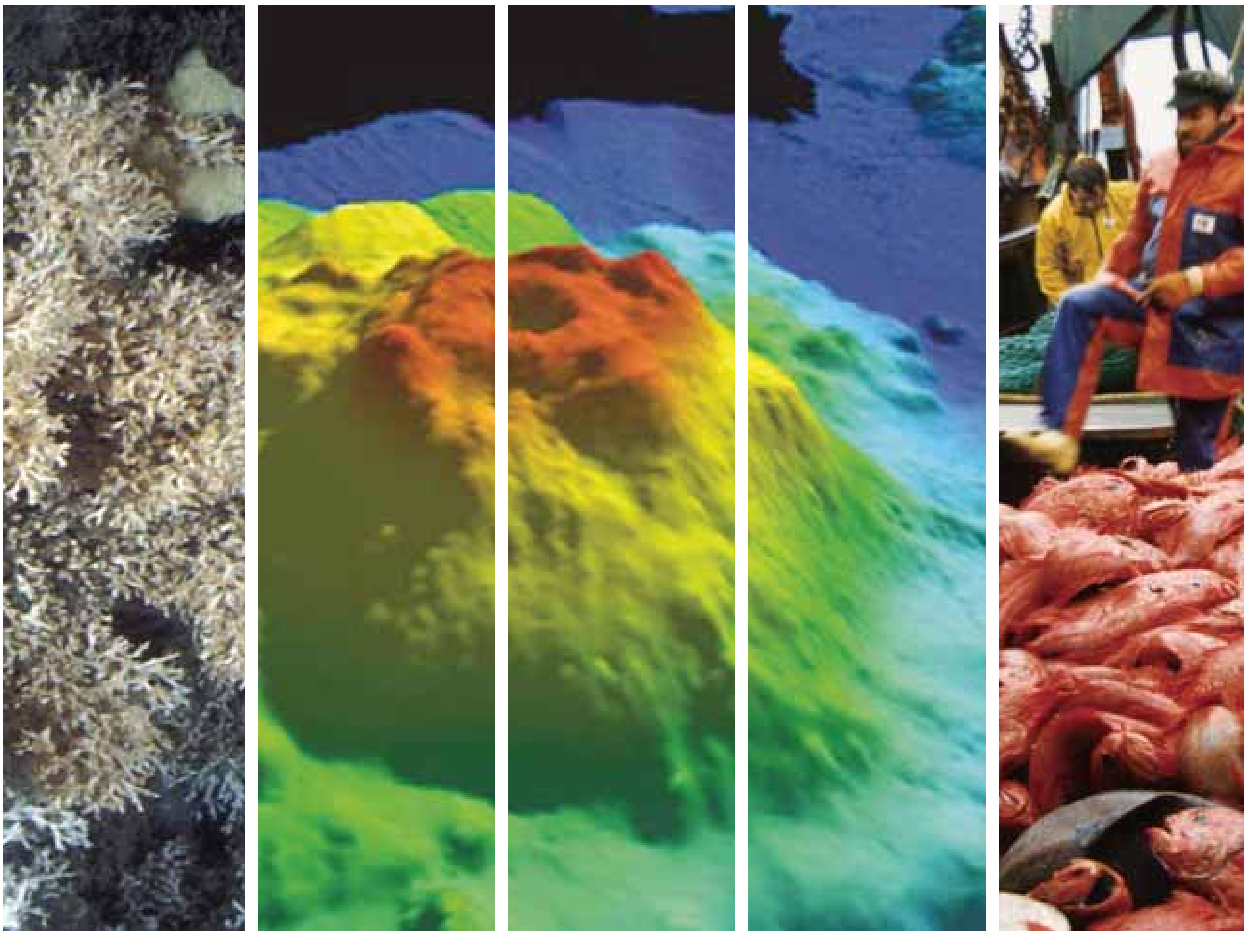
Seamounts, deep-sea corals and fisheries



Census of Marine Life on Seamounts (CenSeam)
Data Analysis Working Group

UNEP WCMC
Regional Seas

Seamounts, deep-sea corals and **fisheries**



Vulnerability of deep-sea corals to fishing on seamounts beyond areas of national jurisdiction

UNEP WCMC

Regional Seas

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DISCLAIMER

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CENSUS OF MARINE LIFE AND CENSEAM

The Census of Marine Life (CoML) is an international science research programme with the goal of assessing and explaining the diversity, distribution and abundance of marine life – past, present and future. It involves researchers in more than 70 countries working on a range of poorly understood habitats. In 2005 a CoML field project was established to research and sample seamounts (Stocks et al. 2004; censeam.niwa.co.nz). This project, termed CenSeam (a Global Census of Marine Life on Seamounts), provides a framework to integrate, guide and expand seamount research efforts on a global scale. It has established a 'seamount researcher network of almost 200 people around the world, and is collating existing seamount information and expanding a database of seamount biodiversity. Its Steering Committee comprises people who are at the forefront of seamount research, and can therefore contribute a wealth of knowledge and experience to issues of seamount biodiversity, fisheries and conservation.

One of the key themes of CenSeam is to assess the impacts of fisheries on seamounts, and to this end, it has established a Data Analysis Working Group (DAWG) that includes people with a wide range of expertise on seamount datasets and analysis and modelling techniques.

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Supporting organizations

UNEP's Regional Seas Programme aims to address the accelerating degradation of the world's oceans and coastal areas through the sustainable management and use of the marine and coastal environment, by engaging neighbouring countries in comprehensive and specific actions to protect their shared marine environment.

The UNEP World Conservation Monitoring Centre (UNEP-WCMC) is the biodiversity assessment and policy implementation arm of the United Nations Environmental Programme (UNEP), the world's foremost intergovernmental environment organization. UNEP-WCMC aims to help decision makers recognize the value of biodiversity to people everywhere, and to apply this knowledge to all that they do. The Centre's challenge is to transform complex data into policy-relevant information, to build tools and systems for analysis and integration, and to support the needs of nations and the international community as they engage in programmes of action.

The Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) provides Member States of the United Nations with an essential mechanism for global cooperation in the study of the ocean. The IOC assists governments to address their individual and collective ocean and coastal problems through the sharing of knowledge, information and technology and through the coordination of national programmes.

Department of Nature, Ministry of Agriculture, Nature and Food Quality, Netherlands.

The Census of Marine Life (CoML) is a global network of researchers in more than 70 nations engaged in a ten-year initiative to assess and explain the diversity, distribution and abundance of marine life in the oceans – past, present and future.

The National Institute of Water and Atmospheric Research (NIWA) is a research organization based in New Zealand, and is an independent provider of environmental research and consultancy services.

Foreword

'How inappropriate to call this planet Earth, when it is quite clearly Ocean'

attributed to Arthur C Clarke

A look at a map of the world shows how true this statement is. Approximately two-thirds of our planet is covered by the oceans. The volume of living space provided by the seas is 168 times larger than that of terrestrial habitats and harbours more than 90 per cent of the planet's living biomass.

The way most world maps depict the oceans is deceiving: while the land is shown in great detail with colours ranging from greens, yellows and browns, the sea is nearly always indicated in subtle shades of pale blue. This belies the true structure of the seafloor, which is as complex and varied as that of the continents – or even more so. Some of the largest geological features on Earth are found on the bottom of the oceans. The mid-ocean ridge system spans around 64 000 km, four times longer than the Andes, the Rocky Mountains and the Himalayas combined. The largest ocean trench dwarfs the Grand Canyon, and is deep enough for Mount Everest to fit in with room to spare.

Only in the last decades, advanced technology has revealed that there are also countless smaller features – seamounts – arising in every shape and form from the sea floor of the deep sea, often in marine areas beyond national jurisdiction. Observations with submersibles and remote controlled cameras have documented that seamounts provide habitat for a large variety of marine animals and unique ecosystems, many of which are still to be discovered and described. However, the same observations also provided alarming evidence that seamount habitats are increasingly threatened by human activities, especially from the rapid increase of deep-sea fishing.

The United Nations General Assembly has repeatedly called upon States and international organizations to urgently take action to address destructive practices, such as bottom trawling, and their adverse impacts on the marine biodiversity and vulnerable ecosystems, especially cold-water corals on seamounts.

This report, compiled by an international group of leading experts working under the Census of Marine Life programme, responds to these calls. It provides a fascinating insight into what we know about seamounts, deep-sea corals and fisheries, and uses the latest facts and figures to predict the existence and vulnerability of seamount communities in areas for which we have no or only insufficient information.

The deep waters and high seas are the Earth's final frontiers for exploration. Conservation, management and sustainable use of the resources they provide are among the most critical and pressing ocean issues today.

Seamounts and their associated ecosystems are important and precious for life in the oceans, and for humankind. We hope that this report provides inspiration to take concerted action to prevent their further degradation, before it is too late.

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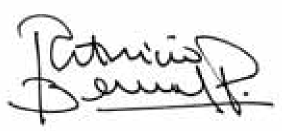


Patricio Bernal, *Executive Secretary,*
Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO)

Executive summary

The oceans cover 361 million square kilometres, almost three-quarters (71 per cent) of the surface of the Earth. The overwhelming majority (95 per cent) of the ocean area is deeper than 130 m, and nearly two-thirds (64 per cent) are located in areas beyond national jurisdiction. Recent advances in science and technology have provided an unprecedented insight into the deep sea, the largest realm on Earth and the final frontier for exploration. Satellite and shipborne remote sensors have charted the sea floor, revealing a complexity of morphological features such as trenches, ridges and seamounts which rival those on land. Submersibles and remotely operated vehicles have documented rich and diverse ecosystems and communities, which has changed how we view life in the oceans.

The same advances in technology have also documented the increasing footprint of human activities in the remote and little-known waters and sea floor of the deep and high seas. A large number of video observations have not only documented the rich biodiversity of deep-sea ecosystems such as cold-water coral reefs, but also gathered evidence that many of these biological communities had been impacted or destroyed by human activities, especially by fishing such as bottom trawling. In light of the concerns raised by the scientific community, the UN General Assembly has discussed vulnerable marine ecosystems and biodiversity in areas beyond national jurisdiction at its sessions over the last four years (2003-2006), and called, *inter alia,* 'for urgent consideration of ways to integrate and improve, on a scientific basis, the management of risks to the marine biodiversity of seamounts, cold-water coral reefs and certain other underwater features'.

This report, produced by the Data Analysis Working Group of the global census of marine life on seamounts (CenSeam), is a contribution to the international response to this call. It reveals, for the first time, the global scale of the likely vulnerability of habitat-forming stony (scleractinian) corals, and by proxy a diverse assemblage of other species, to the impacts of trawling on seamounts in areas beyond national jurisdiction. In order to support, focus and guide the ongoing international discussions, and the emerging activities for the conservation and sustainable management of cold-water coral ecosystems on seamounts, the report:

1. compiles and/or summarizes data and information on the global distribution of seamounts, deep-sea corals on seamounts and deep-water seamount fisheries;
2. predicts the global occurrence of environmental conditions suitable for stony corals from existing records on seamounts and identifies the seamounts on which they are most likely to occur globally;
3. compares the predicted distribution of stony corals on seamounts with that of deep-water fishing on seamounts worldwide;
4. qualitatively assesses the vulnerability of communities living on seamounts to putative impacts by deep-water fishing activities;
5. highlights critical information gaps in the development of risk assessments to seamount biota globally.

SEAMOUNT CHARACTERISTICS AND DISTRIBUTION

A seamount is an elevation of the seabed with a summit of limited extent that does not reach the surface. Seamounts are prominent and ubiquitous geological features, which occur most commonly in chains or clusters, often along the mid-ocean ridges, or arise as isolated features from the sea floor. Generally volcanic in origin, seamounts are often conical in shape when young, becoming less regular with geological time as a result of erosion. Seamounts often have a complex topography of terraces, canyons, pinnacles, crevices and craters – telltale signs of the geological processes which formed them and of the scouring over time by the currents which flow around and over them.

As seamounts protrude into the water column, they are subject to, and interact with, the water currents surrounding them. Seamounts can modify major currents, increasing the velocity of water masses that pass around them. This often leads to complex vortices and current patterns that can erode the seamount sediments and expose hard substrata. The effects of seamounts on the surrounding water masses can include the formation of 'Taylor' caps or columns, whereby a rotating body of water is retained over the summit of a seamount.

In the present study the global position of only large seamounts (>1 000 m elevation) were taken into account due to methodological constraints. Based on an analysis of updated satellite data, the location of 14 287 large seamounts has been predicted. This is likely an underestimate. Extrapolations from other satellite measurements estimate that there may be up to 100 000 large seamounts worldwide.

Numbers of predicted seamounts peak between 30ºN and 30ºS, with a rapid decline above 50ºN and below 60ºS. The majority of large seamounts (8 955) occur in the Pacific Ocean area (63 per cent), with 2 704 (19 per cent) in the Atlantic Ocean and 1 658 (12 per cent) in the Indian Ocean. A small proportion of seamounts are distributed

between the Southern Ocean (898; 6 per cent), the Mediterranean/Black Seas (59) and Arctic Ocean (13) (both less than 1 per cent).

An analysis of the occurrence of these seamounts inside and outside of Exclusive Economic Zones (EEZs) indicates that just over half (52 per cent) of the world's large seamounts are located beyond areas of national jurisdiction. The majority of these seamounts (10 223; 72 per cent) have summits shallower than 3 000 m water depth.

DEEP-SEA CORALS AND BIODIVERSITY

Compared to the surrounding deep-sea environment, seamounts may form biological hotspots with a distinct, abundant and diverse fauna, and sometimes contain many species new to science. The distribution of organisms on seamounts is strongly influenced by the interaction between the seamount topography and currents. The occurrence of hard substrata means that, in contrast to the mostly soft sediments of the surrounding deep sea, seamount communities are often dominated by sessile, permanently attached organisms that feed on particles of food suspended in the water. Corals are a prominent component of the suspension-feeding fauna on many seamounts, accompanied by barnacles, bryozoans, polychaete worms, molluscs, sponges, sea squirts and crinoids (which include sea lilies and feather stars).

Most deep-sea corals belong to the Hexacorallia, including stony corals (scleractinians) and black corals (antipatharians), or the Octocorallia, which include soft corals such as gorgonians.

Three-dimensional structures rising above the sea floor in the form of reefs created by some species of stony coral, as well as coral 'beds' formed by black corals and octocorals, are common features on seamounts and continental shelves, slopes, banks and ridges. Coral frameworks add habitat complexity to seamounts and other deep-water environments. They offer refugia for a great variety of invertebrates and fish (including commercially important species) within, or in association with, the living and dead coral framework. Cold-water corals are frequently concentrated in areas of the strongest currents near ridges and pinnacles, providing hard substrata for colonization by other encrusting organisms and allowing them better access to food brought by prevailing currents. Although the co-existence between coral and non-coral species is in most cases still unknown, recent research is showing that some coral/non-coral relationships may show different levels of dependency. **A review of direct dependencies on cold-water corals globally, including those on seamounts, has shown that of the 983 coral-associated species studied, 114 were characterized as mutually dependent, of which 36 were exclusively dependent on cnidarians (group of animals that contains the corals, hydroids, jellyfishes and sea anemones). A recent study recorded more than 1 300 species associated with the stony coral *Lophelia pertusa* on the European continental slope or shelf. Thus some cold-water corals may be regarded as 'ecosystem engineers' because they create, modify and maintain habitat for other organisms, similar to trees in a forest.**

Cold-water corals can form a significant component of the species diversity on seamounts and play a key ecological role in their biological communities. The assessment of the potential impacts of bottom trawling on corals is therefore a useful proxy for gauging the effects of these activities on seamount benthic biodiversity as a whole. A comprehensive assessment of biodiversity is currently impossible because of the lack of data for many faunal groups living on seamounts.

DISTRIBUTION OF CORALS ON SEAMOUNTS

One of the data sources utilized for this report was a database of 3 235 records of known occurrences of five major coral groups found on seamounts, including some shallower features <1 000 m elevation. Existing records show that the stony corals (scleractinians) were the most diverse and commonly observed coral group on seamounts (249 species, 1 715 records) followed by Octocorallia (161 species, 959 records), Stylasterida (68 species, 374 records), Antipatharia (34 species, 159 records) and Zoanthidea (14 species, 28 records). These records included all species of corals, including those that were reef-forming, contributed to reef formation, or occur as isolated colonies.

The most evident finding in analysing the coral database is that sampling of seamounts has not taken place evenly across the world's oceans, and that there are significant geographic gaps in the distribution of studied seamounts. **For some regions, such as the Indian Ocean, very few seamount samples are available. In total, less than 300 seamounts have been sampled for corals, representing only 2.1 per cent of the identified number of seamounts in the oceans globally (or 0.03 per cent when assuming there are 100 000 large seamounts).** Only a relatively small number of coral species have wide geographic distributions, and very few have near cosmopolitan distributions. Many of the widely distributed species are the primary reef, habitat or framework-building stony corals such as *Lophelia pertusa*, *Madrepora oculata* and *Solenosmilia variabilis*.

In most parts of the world, stony corals were the most diverse group, followed by the octocorals. However, in the northeastern Pacific, octocorals are markedly more diverse than stony corals. Most stony corals and stylasterid species occur in the upper 1 000-1 500 m depth range. Antipatharians also occurred in the upper 1 000 m, although a higher proportion of species occurs in deeper waters than the two previous groups. Octocorals were distributed to greater depths, with most species in the upper 2 000 m. Very little sampling has occurred below 2 000 m.

There are a number of reasons for the differences in the depth and regional distribution of the coral groups, including species-related preferences of the nature of substrates available for attachment, quantity, quality and abundance of food at different depths, the depth of the aragonite saturation horizon, temperature and the availability of essential elements and nutrients.

PREDICTING GLOBAL DISTRIBUTION OF STONY CORALS ON SEAMOUNTS

The dataset for corals on seamounts revealed significant areas of weakness in our knowledge of coral diversity and distribution on seamounts, especially the lack of sampling on seamounts at equatorial latitudes. **Thus, to make a reasonable assessment of the vulnerability of seamount corals to bottom trawling (and, by proxy, determine the potential impacts of this activity on non-coral assemblages), it was necessary to fill the sampling gaps by predicting the global occurrence of suitable coral habitat by modelling coral distribution.**

An environmental niche factor analysis (ENFA) was used to model the global distribution of deep-sea stony corals on seamounts and to predict habitat suitability for unsampled regions. Other groups of coral, such as octocorals, for example, can also form important habitats such as coral beds. These corals may have very different distributions to stony corals, which would also be useful to appreciate in the context of determining the vulnerability of seamount communities to bottom trawling. The available data for octocorals are, unfortunately, currently too limited to enable appropriate modelling.

ENFA compares the observed distribution of a species to the background distribution of a variety of environmental factors. In this way, the model assesses the environmental niche of a taxonomic group – i.e. how narrow or wide this niche is – identifies the relative difference between the niche and the mean background environment, and reveals those environmental factors that are important in determining the distribution of the studied group.

The model used and combined:

(i). the location data of 14 287 predicted large seamounts;
(ii). the location records of stony corals (Scleractinia) on seamounts; and
(iii). physical, biological and chemical oceanographic data from a variety of sources for 12 environmental parameters (temperature; salinity; depth of coral occurrence; surface chlorophyll; dissolved oxygen; per cent oxygen saturation; overlying water productivity; export primary productivity; regional current velocity; total alkalinity; total dissolved inorganic carbon; aragonite saturation state).

The model predictions were as follows: in near-surface waters (0-250 m), habitat predicted to be suitable for stony corals lies in the southern North Atlantic, the South Atlantic, much of the Pacific, and the southern Indian Ocean. The Southern Ocean and the northern North Atlantic are, however, unsuitable. Below 250 m depth, the suitability patterns for coral habitat change substantially. In depths of 250-750 m, a narrow band occurs around 30ºN ± 10º, and a broader band of suitable habitat occurs around 40ºS ± 20º. In depths of 750-1 250 m, the North Pacific and northern Indian Ocean are unsuitable for stony corals. The circum-global band of suitable habitat at around 40ºS narrows with increasing depth (to ± 10º). Suitable habitat areas also occur in the North Atlantic and tropical western Atlantic. These areas remain suitable for stony corals with increasing depth (1 250-1 750 m; 1 750-2 250 m; 2 250 m-2 500 m), whereas the band at 40ºS breaks up into smaller suitable habitat areas around the southeast coast of South America and the tip of South Africa.

The global extent of habitat suitability for seamount stony corals was predicted to be at its maximum between around 250 m and 750 m. The majority of the suitable habitat for stony corals on seamounts occurs in areas beyond national jurisdiction. However, suitable habitats are also predicted in deeper waters under national jurisdiction, especially in the EEZs of countries:

1. **between 20ºS and 60ºS off Southern Africa, South America and in the Australia/New Zealand region;**
2. **off Northwest Africa; and**
3. **around 30ºN in the Caribbean.**

Combining the predicted habitat suitability with the summit depth of predicted seamounts indicates that the majority of seamounts that may provide suitable habitat for stony corals on their summits are located in the Atlantic Ocean. The rest are mostly clustered in a band between 15ºS and 50ºS. A few seamounts elsewhere, such as in the South Pacific, with summits in the depth range between 0 m and 250 m, are highly suitable. In the Atlantic, a large proportion of suitable seamount summit habitat is beyond national jurisdiction, whereas in the Pacific, most of this seamount habitat lies within EEZs. In the southern Indian Ocean, suitable habitat appears both within and outside of EEZs. When analysing habitat suitability on the basis of summit depth, it should be noted that suitable habitat for stony corals might also occur on the slopes of seamounts, i.e. at depths greater than the summit.

The analysis found the following environmental factors were important for determining suitable habitat for stony corals: high levels of aragonite saturation, dissolved oxygen, per cent oxygen saturation, and low values of total dissolved inorganic carbon. Neither surface chlorophyll nor regional current velocity appears to be important for the global distribution of stony corals on seamounts. Nevertheless, these factors may be important for the distribution of corals at smaller spatial scales, such as on an individual seamount.

The strong dependency of coral distribution on the availability of aragonite (a form of calcium carbonate) is noteworthy. Stony corals use aragonite to form their hard skeletons. A reduction in the availability of aragonite, for example through anthropogenically induced acidification of the oceans due to rising CO_2 levels, will limit the amount of suitable habitat for stony corals.

SEAMOUNT FISH AND FISHERIES

Seamounts support a large and diverse fish fauna. Recent reviews indicate that up to 798 species are found on and around seamounts. Most of these fish species are not exclusive to seamounts, and occur widely on continental shelf and slope habitats. Seamounts can be an important habitat for commercially valuable species, which may form dense aggregations for spawning or feeding targeted by large-scale fisheries.

For the purpose of this report, the distribution and depth ranges of commercial fish species were compiled from a number of Internet and literature sources, including seamount fisheries catch data of Soviet, Russian and Ukrainian operations since the 1960s; published data on Japanese, New Zealand, Australian, European Union (EU) and Southern African fisheries; Food and Agriculture Organization of the United Nations (FAO) catch statistics; and unpublished sources. Although known to be incomplete, this is the most comprehensive compilation attempted to date for seamount fisheries, and is believed to give a reasonable indication of the general distribution of seamount catch over the last four decades.

Deep-water trawl fisheries occur in areas beyond national jurisdiction for around 20 major species. These include alfonsino *(Beryx splendens)*, black cardinalfish *(Epigonus telescopus)*, orange roughy *(Hoplostethus atlanticus)*, armourhead and southern boarfish *(Pseudopentaceros* spp.), redfishes *(Sebastes* spp.*)*, macrourid rattails (primarily roundnose grenadier *Coryphaenoides rupestris)*, oreos (including smooth oreo *Pseudocyttus maculatus,* black oreo *Allocyttus niger)* and Patagonian toothfish *(Dissostichus eleginoides)*, and in some areas Antarctic toothfish (*Dissostichus mawsoni*), which has a restricted southern distribution. Many of these fisheries use bottom-trawl gear. Other fisheries occur over seamounts, such as those for pelagic species (mainly tunas) and target species for smaller-scale line fisheries (e.g. black scabbardfish *Aphanopus carbo*).

The distribution of four of the most important seamount fish species (for either their abundance or commercial value) is as follows:

1. **ORANGE ROUGHY is widely distributed throughout the Northern and Southern Atlantic Oceans, the mid-southern Indian Ocean and the South Pacific. It does not extend into the North Pacific. It is frequently associated with seamounts for spawning or feeding, although it is also widespread over the general continental slope.**
2. **ALFONSINO has a global distribution, being found in all the major oceans. It is a shallower species than orange roughy, occurring mainly at depths of 400-600 m. It is associated with seamount and bank habitat.**
3. **ROUNDNOSE GRENADIER is restricted to the North Atlantic, where it occurs on both sides, as well as on the Mid-Atlantic Ridge, where aggregations occur over peaks of the ridge.**
4. **PATAGONIAN TOOTHFISH has a very wide depth range and is sometimes associated with seamounts, but it is also found on general slope and large bank features.**

The distribution of historical seamount fisheries includes heavy fishing on seamounts in the North Pacific Ocean around Hawaii for armourhead and alfonsino; in the South Pacific for alfonsino, orange roughy and oreos; in the southern Indian Ocean for orange roughy and alfonsino; in the North Atlantic for roundnose grenadier, alfonsino, orange roughy, redfish and cardinalfish; and in the South Atlantic for alfonsino and orange roughy. Antarctic waters have been fished for toothfish, icefish and notothenioid cods.

The total historical catch from seamounts has been estimated at over 2 million tonnes. Many seamount fish stocks have been overexploited, and without proper and sustainable management, they have followed a 'boom and bust' cycle. After very high initial catches per unit effort, the stocks were depleted rapidly over short time scales (<5 years) and are now closed to fishing or no longer support commercial fisheries. The life history characteristics of many deep-water fish species (e.g. slow growth rate, late age of sexual maturity) make the recovery and recolonization of previously fished seamounts slow.

Over the last decade, exploratory fishing for deep-water species in many areas beyond national jurisdiction has focussed on alfonsino and orange roughy. The depth distribution of the two main target fisheries for alfonsino and orange roughy differ. The former is primarily fished between 250 and 750 m, and includes associated commercial species like black cardinalfish and southern boarfish. The orange roughy fisheries on seamounts,

between 750 and 1 250 m depth (deeper fishing can occur on the continental slope), include black and smooth oreos as bycatch. Seamount summit depth data was used to indicate where such suitable fisheries habitat might occur in areas beyond national jurisdiction. Combined with information on the geographical distribution of the commercial species, various areas where fishing could occur were broadly identified. Many of these areas are in the southern Indian Ocean, South Atlantic and North Atlantic. The South Pacific Ocean also has a number of ridge structures with seamounts that could host stocks of alfonsino and orange roughy. Many of these areas have already been fished and some are known to have been explored, but commercial fisheries have not developed.

ASSESSING THE VULNERABILITY OF STONY CORALS ON SEAMOUNTS

In order to assess the likely vulnerability of corals and the biodiversity of benthic animals on seamounts to the impact of fishing, the report examines the overlap and interaction between:

1. the predicted global distribution of suitable habitat for stony corals;
2. the location of predicted large seamounts with summits in depth ranges of alfonsino and orange roughy fisheries; and
3. the distribution of the fishing activity on seamounts for these two species, and combines this with information on the known effects of trawling.

Many long-lived epibenthic animals such as corals have an important structural role within sea floor communities, providing essential habitat for a large number of species. Consequently, the loss of such animals lowers survivorship and recolonization of the associated fauna, and has spawned analogies with forest clear-felling on land. A considerable body of evidence on the ecological impacts of trawling is available for shallow waters, but scientific information on the effects of fishing on deep-sea seamount ecosystems is much more limited to studies from seas off northern Europe, Australia and New Zealand. These studies suggested that trawling had largely removed the habitats and ecosystems formed by the corals, and thereby negatively affected the diversity, abundance, biomass and composition of the overall benthic invertebrate community.

The intensity of trawling on seamounts can be very high. From several hundred to several thousand trawls have been carried out on small seamount features in the orange roughy fisheries around Australia and New Zealand. Such intense fishing means that the same area of the sea floor may be trawled repeatedly, causing long-term damage to the coral communities by preventing any significant recovery or recolonization. Trawling's impact on sea floor biota differs depending on the gear type used. The most severe damage has been reported from the use of bottom trawls in the orange roughy fisheries on seamounts. Information is currently lacking about the potential impact of trawling practices for alfonsino, where mid-water trawls are often used on seamounts. These may have only a small impact if they are deployed well above the sea floor. However, in many cases the gear is most effective when fished very close to, or even lightly touching, the bottom. Thus, it is likely that the effects of the alfonsino fisheries on the benthic fauna would be similar to that of the orange roughy fisheries.

The comparison between the distributions of commercially exploited fish, fishing effort and coral habitat on seamounts highlighted a broad band of the southern Atlantic, Pacific and Indian Oceans between about 30°S and 50°S, where there are numerous seamounts at fishable depths, and high habitat suitability for corals at depths between 250 m and 750 m (the preferred alfonsino fisheries depth range), and again – but somewhat narrower – between 750 m and 1 250 m depth (the preferred orange roughy fisheries depth range).

This spatial concordance suggests there could be further commercial exploration for alfonsino and orange roughy fisheries on large seamounts in the central-eastern southern Indian Ocean, the southern portions of the Mid-Atlantic Ridge in the South Atlantic, and some regions of the southern-central Pacific Ocean. Importantly, since these areas also contain habitat suitable for stony coral, impacts on deep-water corals and seamount ecosystems in general are likely to arise in such a scenario. However, it is uncertain whether fisheries exploration will result in economic fisheries.

A WAY FORWARD

This report has identified sizeable geographical areas with large seamounts, which are suitable for stony corals and are vulnerable to the impacts of expanding deep-sea fishing activities. To establish and implement adequate and effective management plans and protection measures for these areas beyond national jurisdiction will present major challenges for international cooperation. In addition, the report has identified that there are large gaps in the current knowledge of the distribution of seamounts and the biodiversity they harbour.

In light of these findings, the report recommends a number of activities to be carried out collaboratively by all stakeholders under the following headings:

How can the impacts of fishing on seamounts be managed in areas beyond national jurisdiction?

Management initiatives for seamount fisheries within national EEZs have increased in recent years. Several countries have closed seamounts to fisheries, established habitat exclusion areas and stipulated method restrictions, depth limits, individual seamount catch quotas and bycatch quotas.

In comparison, fisheries beyond areas of national jurisdiction have often been entirely unregulated. There are 12 Regional Fisheries Management Organizations (RFMOs) with responsibility to agree on binding measures that cover areas beyond national jurisdiction, including some of the geographical areas identified in this report that might see further expansion of exploratory fishing for alfonsino and orange roughy on seamounts. An RFMO covers parts of the eastern South Atlantic where exploratory fishing has occurred in recent decades, and where further trawling could occur. However, the western side of the South Atlantic is not similarly covered by an international management organization. There have been recent efforts to improve cooperative management of fisheries in the Indian Ocean, although there are no areas covered by an RFMO. In addition, efforts are underway – in the South Pacific, for example – to establish a new regional fisheries convention and body, which would fill a large gap in global fisheries management. However, it should be noted that only the five RFMOs for the Southern Ocean, Northwest Atlantic, Northeast Atlantic, Southeast Atlantic and the Mediterranean currently have the legal competence to manage most or all fisheries resources within their areas of application, including the management of deep-sea stocks beyond national jurisdiction. The other RFMOs have competence only with respect to particular target species like tuna or salmon.

In the light of the recent international dialogues concerning the conservation and sustainable management and use of biodiversity in areas beyond national jurisdiction held within and outside the United Nations system, various fisheries bodies are more actively updating their mandates and including benthic protection measures as part of their fisheries management portfolios. **It appears that a growing legislation and policy framework, including an expanding RFMO network, particularly in the southern hemisphere, could enable the adequate protection and management of the risks to vulnerable seamount ecosystems and resources identified in this report. In order to be successful, a number of challenges will have to be overcome, including:**

1. **Establishing adequate data reporting requirements for commercial fishing fleets. Some unregulated and unreported fishing activities take place, even in areas where there are well-defined fishery codes of practice and allowable catch limits (e.g. Patagonian toothfish fishery). Some countries require vessels registered to them to report detailed catch and effort data, but many do not. Therefore it is difficult at times to know where certain landings have been taken.**
2. **Ensuring compliance with measures, especially in areas that are far offshore and where vessels are difficult to detect. Compliance monitoring is also acute in southern hemisphere high seas areas, where there are no quotas for offshore fisheries.**
3. **Facilitating RFMOs, where necessary, to undertake ecosystem-based management of fisheries on the high seas.**
4. **Establishing, where appropriate, dialogue to ensure free exchange of information between RFMOs, governments, conservation bodies, the fishing industry and scientists working on benthic ecosystems.**

The experiences gained by countries in the protection of seamount environments in their EEZs and in the management of their national deep-water fisheries can provide useful case examples for the approach to be taken under RFMOs. Other regional bodies, such as Regional Sea Conventions and Action Plans, might be able to provide lessons learned from regional cooperation to conserve, protect and use coastal marine ecosystems and resources sustainably, including the implementation of an ecosystem approach in oceans management and the establishment of networks of marine protected areas (MPAs). Regional Sea Conventions and Action Plans also provide a framework for raising awareness of coral habitats in deep water areas under national jurisdiction, and coordinating and supporting the efforts of individual countries to conserve and manage these ecosystems and resources sustainably.

In calling for urgent action to address the impact of destructive fishing practices on vulnerable marine ecosystems, Paragraph 66 of UN General Assembly Resolution 59/25 places a strong emphasis on the need to consider the question of bottom-trawl fishing on seamounts and other vulnerable marine ecosystems on a scientific and precautionary basis, consistent with international law. The UN Fish Stocks Agreement (FSA) Articles 5 and 6 – 'General principles' and the 'Application of the precautionary approach' – also establish clear obligations for fisheries conservation and the protection of marine biodiversity and the marine environment from destructive fishing practices. The Articles also establish that the use of science is essential to meeting these objectives and obligations. At the same time, the FSA recognizes that scientific understanding may not be complete or comprehensive, and in such circumstances, caution must be exercised. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures.

A precautionary approach, consistent with the general principles for fisheries conservation contained in the FSA, as well as the UN FAO Code of Conduct for Responsible Fisheries and the principles and obligations for biodiversity conservation in the Convention on Biological Diversity (CBD), would require the exercise of considerable caution in relation to permitting or regulating bottom-trawl fishing on the high seas on seamounts. This is because of the widespread distribution of stony corals and associated assemblages on seamounts in many high seas regions, and the likelihood that seamounts at fishable depths may also contain other species vulnerable to deep-sea bottom trawling even in the absence of stony corals. In this regard, a prudent approach to the management of bottom-trawl fisheries on seamounts on the high seas would be to ascertain whether vulnerable species and ecosystems are associated with a particular area of seamounts of potential interest for fishing, and only then permitting well-regulated fishing activity provided that no vulnerable ecosystems would be adversely impacted.

Further and improved seamount research

The conclusions of this report apply only to the association of stony corals with large seamounts. In order to consider other taxonomic groups on a wider range of seamounts, further sampling and research is required.

Spatial coverage of sampling of seamounts is poor and data gaps currently impede a comprehensive assessment of biodiversity and species distributions. Only 80 of the 300 biologically surveyed seamounts have had at least a moderate level of sampling. Existing surveys have tended to concentrate on a few geographic areas, thus the existing data on seamount biota are highly patchy on a global scale, and the biological communities of tropical seamounts remain poorly documented for large parts of the oceans. Most biological surveys on seamounts have been relatively shallow and thus the great majority of deeper seamounts remain largely unexplored. Very few individual seamounts have been comprehensively surveyed to determine the variability of faunal assemblages within a single seamount. In addition to the previous spatial gaps in sampling coverage, there are a number of technical issues that make direct comparisons of seamount data sometimes problematic. These issues relate to the availability of non-aggregated data, differences in collection methods and taxonomic resolution.

In order to expand the type of analyses conducted for this report to other faunal groups common on seamounts, and to work at the level of individual species, certain steps should be taken. These include the adoption of a minimum set of standardized seamount sampling protocols; more funding for existing taxonomic experts and training of new taxonomists; increased accessibility of full (non-aggregated) datasets from seamount expeditions through searchable databases; and the further development of integrated, Internet-based information systems such as Seamounts Online and the Ocean Biogeographic Information System.

It should be noted that the activities under the two headings above are closely interrelated and linked. Increased research and collaboration between scientists and fishing companies will not only improve the amount and quality of data, it will also expand the scientific foundation for reviewing existing measures (e.g. those which were taken on a precautionary basis in the light of information gaps), and for developing new, focussed management strategies to mitigate against negative human impacts on seamounts and their associated ecosystems and biodiversity. Requirements in this context include:

1. obtaining better seamount location information; addressing geographic data gaps (including the sampling of other deep-sea habitats);
2. assessing the spatial scale of variability on and between seamounts; increasing the amount and scope of genetic studies;
3. undertaking better studies to assess trawling impacts; assessing recovery from trawling impacts; undertaking a range of studies to improve functional understanding of seamount ecosystems; and
4. implementing the means to obtain better fisheries information.

Without a concerted effort by a number of organizations, institutions, consortia and individuals to attend to the previously identified gaps in data and understanding, the ability of any body to effectively and responsibly manage and mitigate the impact of fishing on seamount ecosystems will be severely constrained. Considering what this report has revealed about the vulnerability of seamount biota – particularly deep-sea corals – to fishing, now is the time for this collaborative effort to begin in earnest.

Contents

1. Introduction

M. Clark (NIWA)

Seamounts are prominent and ubiquitous features found on the sea floor of all ocean basins, both within and outside marine areas under national jurisdiction. With food availability on and above seamounts often higher than that of the surrounding waters and ocean floors, seamounts may function as biological hotspots, which attract a rich fauna. Pelagic predators such as sharks, tuna, billfish, turtles, seabirds and marine mammals can aggregate in the vicinity of seamounts (Worm et al., 2003). Deep-sea fish species such as orange roughy (Pankhurst, 1988; Clark, 1999; Lack et al., 2003) and eels (Tsukamoto, 2006) form spawning aggregations around seamounts.

The bottom fauna on seamounts can also be highly diverse and abundant, and they sometimes contain many species new to science (Parin et al., 1997; Richer de Forges et al., 2000; Koslow et al., 2001). Suspension-feeding organisms, such as deep-sea corals, are frequently prolific on seamounts, mainly because the topographic relief creates fast-flowing currents and rocky substrata, providing suspension feeders with a good food supply and attachment sites (Rogers, 1994). Corals are recognized as an important functional group of seamount ecosystems, as they can form extensive, complex and fragile three-dimensional structures. These may take the form of deep-water reefs built by stony corals (scleractinians) (Rogers, 1999; Freiwald et al., 2004; Roberts et al., 2006), or coral gardens or beds formed by black corals and octocorals (e.g. Stone, 2006). All can provide important habitat for a great variety of associated invertebrates and fish, which use the coral as food, attachment sites and/or for protection and shelter. Deep-water corals can support a rich fauna of closely associated animals with, for example, greater than 1 300 species reported living on *Lophelia pertusa* reefs in the northeastern Atlantic alone (Roberts et al., 2006). Many fish species, including several of commercial significance, show spatial associations with deep-water corals (e.g. Stone, 2006), and fish catches have been found to be higher in, and around, deep-water coral reefs (Husebø et al., 2002).

The fragility of cold-water corals makes them highly vulnerable to fishing impacts, particularly from bottom trawling (Koslow et al., 2001; Fosså et al., 2002; Hall-Spencer et al., 2002), but also from gill nets and long-lining gear (Freiwald et al., 2004; ICES, 2005, 2006). Ground-fishing gear can completely devastate coral colonies (Fosså et al., 2002), and such direct human impacts can be extensive. For example, coral bycatch in the first year of the orange roughy fishery on the South Tasman Rise was estimated at 1 750 tonnes, but this fell rapidly to 100 tonnes by the third year of the fishery as attached organisms on the seabed were progressively removed by repeated trawling (Anderson and Clark, 2003). Because corals provide critical habitat for many other seamount species, destruction of corals has 'knock-on' effects, resulting in markedly lower species diversity and biomass of bottom-living fauna (Clark et al., 1999; Koslow et

***Benthoctopus* sp. and crinoid, Davidson Seamount, 2 422 m.** (NOAA/MBARI)

Brisingid sea star, Hatton Bank.
(DTI SEA Programme, C/o Bhavani Narayanaswamy)

al., 2001; Smith, 2001; Clark and O'Driscoll, 2003). Importantly, recovery of cold-water coral ecosystems from fishing impacts is likely to be extremely slow or even impossible, because corals are long lived and grow extremely slowly (in the order of a few millimetres per year). Individual octocorals can reach ages of several hundred (Andrews et al., 2002; Risk et al., 2002; Sherwood et al., 2006) or even more than a thousand years old (Druffel et al., 1995), and larger reef complexes, formed by stony corals, may be more 8 000 years old (Freiwald et al., 2004; Roberts et al., 2006). Corals also have specific habitat requirements and may be sensitive to alteration of the character of the seabed by fishing gear, or to increased sedimentation resulting from trawling (Commonwealth of Australia, 2002; ICES, 2006). Such effects may prevent recovery of cold-water coral reefs or octocoral gardens permanently (Rogers, 1999; ICES, 2006).

There has been a dramatic expansion of fishing over the last 50 years (Royal Commission on Environmental Pollution, 2004) and the exploitation of deep-sea species of fish in the last 25 years (Lack et al., 2003). The expansion of deep-sea fisheries has been driven by the depletion of shallow fisheries based on the continental shelf, the establishment of the 200 nautical mile economic exclusion zones by states under the UN Convention on Law of the Sea (UNCLOS), overcapacity of fishing fleets, technological advances in fishing – including developments in navigation, acoustics and capture gear and in the power of vessels – and the availability of subsidies for building new fishing vessels equipped for deep-sea fishing (Lack et al., 2003; Royal Commission on Environmental Pollution, 2004). It is estimated that 40 per cent of the world's trawling grounds are now located in waters deeper than the continental shelf (Roberts, 2002). The catch of commercial fish species beyond areas of national jurisdiction by bottom trawling has been estimated at about 200 000 tonnes annually (Gianni, 2004). Most of this is taken from shelf and slope areas of the Northwest Atlantic, but outside this region fishing effort tends to focus on deep-water species from seamounts. Over 77 fish species have been commercially harvested from seamounts (Rogers, 1994), including major fisheries for orange roughy *(Hoplostethus atlanticus)*, pelagic armourhead *(Pseudopentaceros* spp.) and alfonsino *(Beryx splendens)*. Most of these fisheries have not been managed in a sustainable manner, with many examples of 'boom and bust' fisheries, which rapidly developed and then declined sharply within a decade (Koslow et al., 2000; Clark, 2001; Lack et al, 2003). In most cases there is insufficient information on the target fish species, let alone the seamount ecosystem, to provide an adequate basis for good management (Lack et al., 2003). Furthermore, the life-history characteristics of many exploited deep-sea fish are unlike those of shallow-water species, rendering some fisheries management practices inappropriate (Lack et al., 2003).

In the light of the evidence found in numerous *in situ* observations, the scientific community raised concern about the damage that trawling can have on the bottom-dwelling (benthic) communities in deep-waters and on seamounts (MCBI, 2003 et seq.). Taking into account that most of the potential areas affected by the expanding deep-sea fishing activities are in areas beyond national jurisdiction, the United Nations General Assembly (UNGA) addressed the issue in its 58th (2004), 59th (2005) and 60th sessions (2006), both in its discussions on 'Oceans and the Law of the Sea' and 'Sustainable Fisheries'. Seamounts and cold-water corals/reefs were specifically mentioned in the following resolutions:

UN resolutions on oceans and the law of the sea (UN General Assembly, 2003, 2004a, 2005a, 2006)

> Reaffirms the need for States and competent international organizations to urgently consider ways

to integrate and improve, based on the best available scientific information and in accordance with the Convention [UN Convention on Oceans and the Law of the Sea, 1982] and related agreements and instruments, the management of risks to the marine biodiversity of seamounts, cold-water corals, hydrothermal vents and certain other underwater features; (Resolution 60/30, Paragraph 73, following similar text in the previous resolutions 59/24, 58-240 and 57-141)

Calls upon States and international organizations to urgently take action to address, in accordance with international law, destructive practices that have adverse impacts on marine biodiversity and ecosystems, including seamounts, hydrothermal vents and cold-water corals; (Resolutions 60/30, Paragraph 77 and 59/24)

UN resolutions on sustainable fisheries (UN General Assembly, 2004b, 2005b)

Requests the Secretary-General, in close cooperation with the Food and Agriculture Organization of the United Nations (FAO), 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; (Resolution 58/14, Paragraph 46).

Calls upon States, either by themselves or through regional fisheries management organizations or arrangements, where these are competent to do so, to take action urgently, and consider on a case-by-case basis and on a scientific basis, including the application of the precautionary approach, the interim prohibition of destructive fishing practices, including bottom trawling that has adverse impacts on vulnerable marine ecosystems, including seamounts, hydrothermal vents and cold-water corals located beyond national jurisdiction, until such time as appropriate conservation and management measures have been adopted in accordance with international law; (Resolution 59/25, Paragraph 66)

In 2003, the UNGA requested the Secretary General to prepare a report on vulnerable marine ecosystems and biodiversity in areas beyond national jurisdiction (cf. paragraph 52 of Resolution 58/240). Following the examination of this report in 2004, the UNGA decided to establish an Ad Hoc Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction (cf. Paragraph 73 in Resolution 59/24). The outcome of their first meeting (New York, 13-17 February 2006) will be presented to the 61st session of the UNGA.

Furthermore, the UNGA requested in 2005 the Secretary General, in cooperation with the FAO, to include in his next report concerning fisheries a section on the actions taken by States and regional fisheries management organizations and arrangements to give effect to Paragraphs 66 to 69 of Resolution 59/25, in order to facilitate discussion of the matters covered in those paragraphs. The UNGA also agreed to review, within two years, progress on action taken in response to the requests made in these paragraphs, with a view to further recommendations, where necessary, in areas where arrangements are inadequate.

From the above, it is apparent that the UNGA discussions on:

(i). conservation and sustainable management of vulnerable marine biodiversity and ecosystems (including seamount communities) in areas beyond national jurisdiction, and
(ii). the role of regional fisheries management organizations or arrangements in regulating bottom fisheries and the impacts of fishing on vulnerable marine ecosystems are set to continue.

It is hoped that the scientific findings presented in this report by members of the Census of Marine Life programme CenSeam will help and guide policy and decision makers to make progress on these issues.

STUDY OBJECTIVES

The study presented here aimed to:

1. compile and/or summarize data for the distribution of large seamounts, deep-sea corals on seamounts and deep-water seamount fisheries;
2. predict the global occurrence of environmental conditions suitable for stony corals from existing records on seamounts and identify the seamounts on which they are most likely to occur globally;
3. compare the predicted distribution of stony corals on seamounts with that of deep-water fishing on seamounts worldwide;
4. qualitatively assess the vulnerability of communities living on seamounts to putative impacts by deep-water fishing activities; and
5. highlight critical information gaps in the development of risk assessments to seamount biota globally.

2. Seamount characteristics and distribution

SMALL AND LARGE SEAMOUNTS

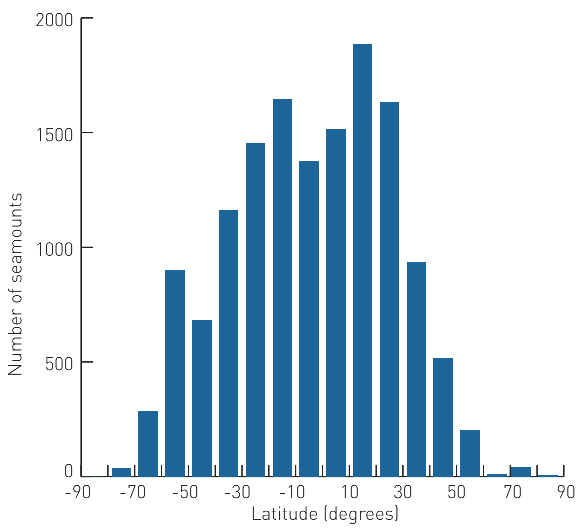
Seamounts are submarine elevations with a limited extent across the summit and have a variety of shapes, but are generally conical with a circular, elliptical or more elongate base (Rogers, 1994). The slopes of seamounts can be extremely steep, with some showing gradients of up to 60º (e.g. Sagalevitch et al., 1992), although, in general, slopes are less steep (generally less than 20º in the New Zealand region; Rowden et al., 2005). Younger seamounts tend to be more conical and regular in shape, whereas older seamounts that have been subject to scouring and erosion by currents are less regular. Geophysical definitions distinguish between (i) hills, with summits lower than 500 m; (ii) knolls, with summits between 500 m and 1 000 m; and (iii) seamounts, with summits over 1 000 m. However, the size component of seamount definitions has become more flexible with the growing appreciation of the abundance of elevated sea floor features of similar morphology but with smaller vertical extent (greater than 50 m; Smith and Cann, 1990); the observation that such features may represent similar habitat and faunistic characteristics as their larger counterparts (e.g. Epp and Smoot, 1989; Rogers, 1994; Rowden et al., 2005); and because small features are targeted by commercial fisheries (greater than 100 m, Brodie and Clark, 2004). Differences in the methodologies available to determine the number and distribution of seamounts have led to a distinction between 'small' and 'large' seamounts. Generally, large seamounts are those with a vertical height of greater than 1 000 m (e.g. Wessel, 2001) or 1 500 m (ICES, 2006). For global and regional studies of seamounts and aspects of the present report, methodological and practical constraints mean that examinations have been restricted to large seamounts only (e.g. ICES, 2006).

HOW MANY LARGE SEAMOUNTS ARE THERE?

The deep oceans are the largest ecosystem on Earth. This vast area of seabed has been only partially mapped; therefore it is not possible to give a figure for the number of (both small and large) seamounts globally. Attempts at estimating the numbers of seamounts globally have been made by extrapolation of the known numbers of seamounts in a geographic region (e.g. Smith and Jordan, 1988 for the Pacific Ocean). Recently, satellite sensors have been used to estimate the position and size of large seamounts. Seamounts are masses of rock and give rise to anomalies in the usual straight-down force of gravity. These minute variations in the Earth's gravitational pull cause seawater to be attracted to seamounts. This means that the sea surface is pitched up over a seamount with a shape that reflects the underlying topographic feature (Wessel, 1997 and 2001). Satellite sensors can detect the anomalies in the Earth's gravitational field (e.g. Seasat gravity sensor) or the small differences in sea-surface height (e.g. Geosat/ERS1 altimeter) (Stone et al., 2004). Efforts to estimate the number of seamounts worldwide using satellite altimetry and gravitational gradient data have indicated that there are between 5 000 and 16 000 features with an elevation greater than 1 000 m (reviewed in Stone et al., 2004). However, the available satellite datasets are limited in terms of resolution because of defence policy, and there are limitations in the methods employed by researchers. This has led to analyses that suggest (after extrapolation) that globally there may be as many as 100 000 seamounts with an elevation of more than 1 000 m (Wessel, 2001). The most recent (non-extrapolative) estimate of the global number of large seamounts is 14 287 (Kitchingman and Lai, 2004). This number originated from the Sea Around Us Project (SAUP), which used depth difference algorithms applied to a digital global elevation

Fig. 2.1 Distribution of predicted large seamounts by latitude.

Source: Kitchingman and Lai (2004)



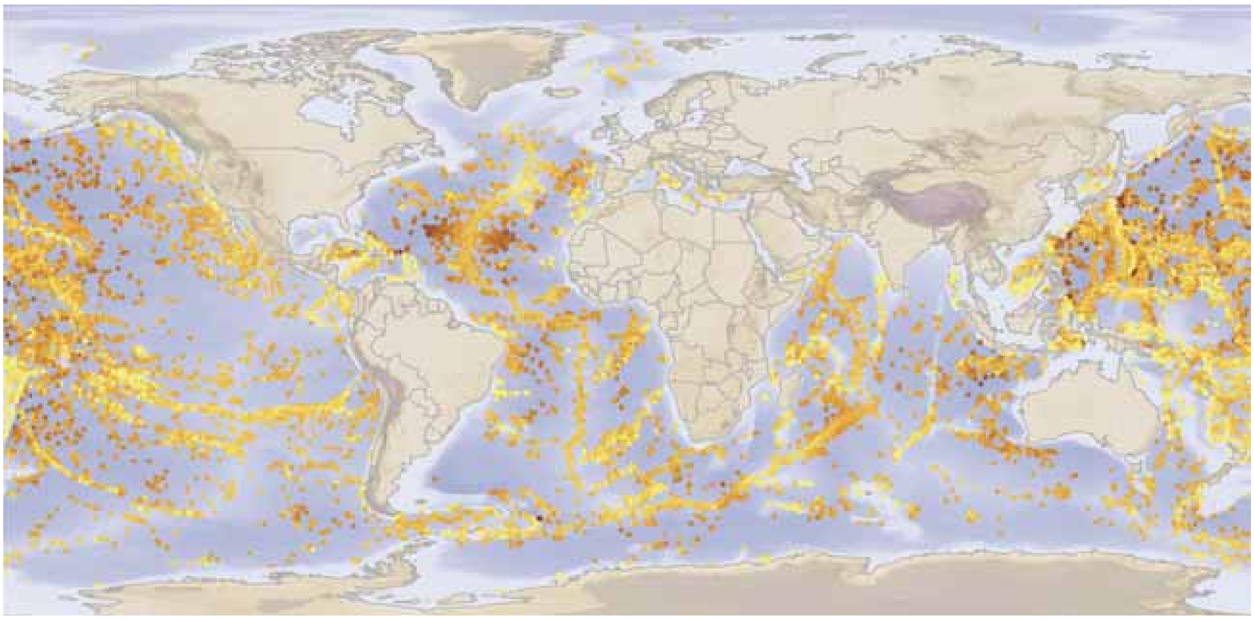


Fig. 2.2 Global distribution and summit depths of predicted large seamounts.
Source: Kitchingman and Lai (2004)

Key

Summit depth (m)	Summit depth (m)
0-500	4 000-4 500
500-1 000	4 500-5 000
1 000-1 500	5 000-5 500
1 500-2 000	5 500-6 000
2 000-2 500	6 000-6 500
2 500-3 000	6 500-7 000
3 000-3 500	7 000-7 500
3 500-4 000	

map and a more generalized definition to detect seamounts that fit into ecological and management contexts.

Kitchingman and Lai (2004) used the National Oceanic and Atmospheric Administration's (NOAA) ETOPO2 dataset as the source for all analyses to estimate the global number and location of large seamounts. The dataset was supplied at a 2-minute cell resolution (13.7 km^2 at the equator), which allowed for a generalized global analysis, but certainly missed many seamounts. Thus the estimated number is an underestimate of the global number of large seamounts. Two methods were used to identify possible seamounts. The first method involves isolating peaks that have significant rise from the ocean floor. The second method isolates peaks with a circular or elliptical base in an effort to eliminate peaks found along ridges. The two methods produced different numbers of predicted seamounts (30 314 and 15 962, respectively). The overlapping seamounts (14 287) found by using both these methodologies were used as the SAUP seamount dataset. Characteristics of the second method could mean that some 'real' seamounts that occur on ridges could be eliminated from the dataset, as well as possibly including some features such as semi-circular banks.

The SAUP data not only provide information on the location and elevation of predicted seamounts but also, usefully, on the depth of the seamount summit.

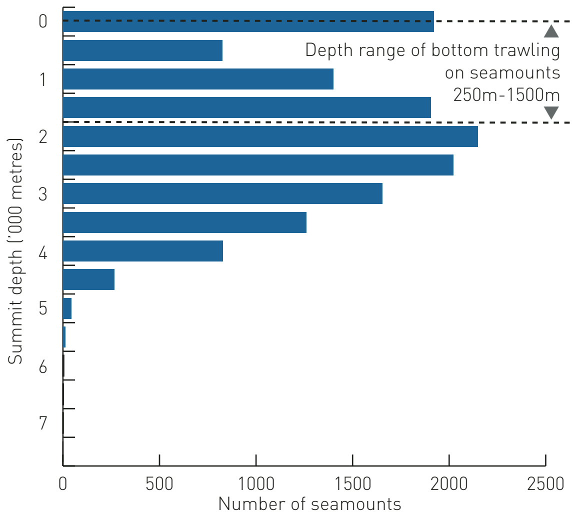
WHERE ARE THE LARGE SEAMOUNTS LOCATED?

The distribution by latitude of the large seamounts estimated from an analysis of global digital elevation data generated by SAUP (Kitchingman and Lai, 2004) is shown in Figure 2.1. The location of some seamounts will be in error because the combining of the results from the two methods used by Kitchinman and Lai (2004) will reduce the location of seamounts with a double peak to a single location at a mid-point between the two, maintaining the shallower depth value of the pair. The error in real-world location is enhanced by a misregistration of the underlying ETOPO2 bathymetry dataset. However, ground truthing performed on a dataset of known seamounts produced from a combination of data from the US Department of Defense Gazetteer of Undersea Features (1989) and SeamountsOnline revealed that approximately 60 per cent of the known seamounts were within 30 arc minutes of predicted seamounts.

Numbers of identified seamounts peak between 30ºS and 30ºN, with a rapid decline above 50ºN and below 60ºS. Available surface (ocean) area by latitude probably drives this pattern. Figure 2.2 shows the global distribution and summit depths of the large seamounts identified by

Fig. 2.3 Summit depths of predicted large seamounts and current depth range of bottom trawling on seamounts.

Source: Kitchingman and Lai (2004)



Kitchingman and Lai (2004), many of which are located along plate boundaries. Table 2.1 shows the distribution of large seamounts in the United Nation's Food and Agriculture Organization (FAO) major fishing areas, and identifies the number of large seamounts that fall outside the EEZs of countries, i.e. are in areas beyond national jurisdiction (Kitchingham et al., in press). Although FAO areas do not exactly fit oceanic boundaries, their use allows broad and more specific comparison with other studies and allows an appreciation of seamounts in a global and regional fishery management context. The majority of large seamounts occur in the Pacific Ocean area (63 per cent), with 19 per cent and 12 per cent of seamounts occurring in the Atlantic and Indian Ocean areas, respectively. A small overall proportion of seamounts are distributed between the Southern Ocean (6 per cent), Mediterranean/Black Seas and Arctic Ocean (both less than 1 per cent) areas. The occurrence of large seamounts inside and outside EEZs shows that just over half (52 per cent) of the world's large

Table 2.1: Number of predicted large seamounts in major FAO fishing areas and in areas beyond national jurisdiction

Ocean Areas	FAO area	Number of predicted large seamounts	Number of predicted large seamounts in areas beyond national jurisdiction
Pacific	**All**	**8 955**	**3 540**
Eastern Central	77	2 735	967
Northeast	67	265	176
Northwest	61	1 350	630
Southeast	87	939	700
Southwest	81	996	643
Western Central	71	2 670	424
Atlantic	**All**	**2 704**	**1 959**
Eastern Central	34	536	433
Northeast	27	325	211
Northwest	21	83	77
Southeast	47	639	512
Southwest	41	452	301
Western Central	31	669	425
Indian	**All**	**1 658**	**1 082**
Eastern	57	588	426
Western	51	1 070	656
Mediterranean and Black Seas	**37**	**59**	**59**
Southern Ocean	**All**	**898**	**713**
Atlantic, Antarctic	48	498	371
Indian Ocean, Antarctic	58	212	154
Pacific, Antarctic	88	188	188
Arctic	18	13	13
Totals	**-**	**14 287**	**7 366**

Source: Kitchingham et al. (in press)

seamounts are located in marine areas beyond national jurisdiction. Figure 2.3 shows that there are many large seamounts with summits at less than 500 m depth, and another peak between 1 500 m and 3 000 m. Thus, most large seamounts have summits shallower than 3 000 m water depth. The current depth range of bottom trawling for commercially valuable fish (250-1 500 m) encompasses about 18 per cent of the summits of large seamounts.

THE ORIGIN AND PHYSICAL ENVIRONMENT OF SEAMOUNTS

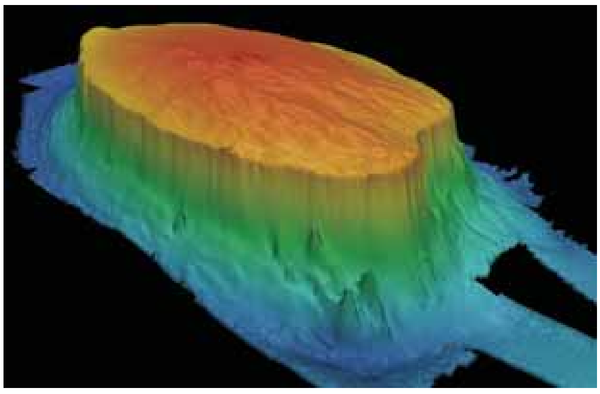
Seamounts are generally volcanic in origin and may be associated with the continental margin or located on the abyssal plains, either as isolated features, clusters or chains. Most commonly, however, seamounts occur along the mid-ocean ridges. These are areas where new oceanic crust is formed by lava welling up from magma chambers below the sea floor, generating enormous ranges of seamounts. As the oceanic crust is formed and moves away from the mid-ocean ridge, the associated seamounts move with it, becoming older and subsiding, causing decreased elevation. Seamounts are also associated with areas where oceanic plates meet and one plate is subducted under the other. The enormous pressures associated with this process melt the subducted plate, resulting in an arc of volcanic activity giving rise to islands and seamounts lying adjacent to an oceanic trench. Examples include the Scotia Arc in the Southern Ocean and the islands of Tonga and associated seamounts in the southwestern Pacific. Seamounts are also generated by ocean hotspots, areas where plumes of magma well up from the Earth's mantle and form volcanoes on the sea floor. In geological time scales, as oceanic plate passes over the hotspot, a chain of seamounts and islands is formed. Examples include the Hawaiian Islands and Emperor Seamount Chain in the North Pacific, and the Louisville Seamount Chain in the southwestern Pacific. Seamounts on or close to the continental margin can have different origins, arising from rifting margin volcanoes or rifted continental blocks. As a result of the volcanic origin of seamounts they may be associated with high temperature (e.g. Marianas Seamounts or Brothers Seamount, Kermadec Ridge) or low temperature (e.g. Loihi Seamount, Hawaiian Ridge) hydrothermal venting, though the majority of seamounts are no longer geologically active and are not venting. The bases of seamounts associated with continental margins tend to be shallower and have an overall elevation lower than those located away from continents (e.g. Rowden et al., 2005). In some cases, for example the Rosemary Bank in the northeastern Atlantic, such features may be termed banks, as definitions of the two types of features can overlap (ICES, 2006).

WHAT ENVIRONMENTAL CONDITIONS INFLUENCE LIFE ON SEAMOUNTS?

The geographical location, depth and elevation of the seamount determine the interactions of the seamount with the water masses and currents that impinge on it. Water masses have different environmental characteristics such as flow velocity, temperature, salinity, nutrient availability and pH. The environmental characteristics of the waters that overly seamounts can influence the spatial and temporal patterns of supply of organic material to a seamount benthic (seabed) community in terms of phytoplankton, zooplankton and organic detritus (dead organisms, faecal pellets, and so on). Pelagic communities and supply of larvae will also largely reflect the dominant oceanographic influences on a seamount.

Within the immediate vicinity of a seamount, complex current-topography interactions can take place at all scales. At the largest scale, seamount chains can divert major currents (e.g. the Emperor Seamount chain deflects the Kuroshio and subarctic currents; Roden et al., 1982; Roden and Taft, 1985; Vastano et al., 1985). At smaller scales, the interactions of seamounts with the surrounding currents are complex and difficult to measure, although in some cases such responses can be modelled. For example, models predict the formation of a rotating body of water retained over the summit of a seamount (known as a 'Taylor' column). Observations have demonstrated the existence of such columns above many seamounts (Meincke, 1971; Vastano and Warren, 1976; Cheney et al., 1980; Genin et al., 1989; Roden, 1991; Dower et al., 1992), although the stratification of water layers above a seamount often reduces the column to a cap. Seamounts may also interact with tides, amplifying them and accelerating currents to greater than 40 cm s^{-1} (Chapman, 1989; Genin et al., 1989; Noble and Mullineaux, 1989). The seamounts themselves may also generate internal tides (Noble et al., 1988) and generate or interact

Side scan sonar image of Anton Dohrn Seamount, Northeast Atlantic. (DTI SEA Programme, c/o Colin Jacobs)



with internal waves (e.g. Bell, 1975; Wunsch and Webb, 1979; Eriksen, 1982a, 1982b, 1985, 1991; Kaneko et al., 1986; Brink, 1989; Genin et al., 1989). Such phenomena can lead to the generation of periodic, small-scale, fast, short-duration bottom currents.

The depth of the seamount summit below the ocean surface is one of the most important physical factors in determining the abundance and diversity of benthic communities on seamounts and has been used to classify them (e.g. ICES, 2006). Seamounts with a depth of less than 250 m reach into the euphotic zone, where enough light penetrates to allow photosynthesis, and therefore communities that include algae can develop. Seamounts with a summit depth down to 1 000 m are likely to interact with layers of zooplankton that undergo a daily vertical migration in the water column (Wilson and Boehlert, 2004). These migrating plankton form a relatively thin layer of organisms detectable by echo sounders (deep scattering layer, or DSL). Several observations indicate that the topography of seamounts can trap descending layers of zooplankton, which provide a source of food for seamount-associated species (Rogers, 1994; Seki and Somerton, 1994; Haury et al., 2000). Whether or not this takes place depends on the depth of the seamount summit in relation to the vertical depth range over which the plankton migrate. It also depends on the intensity of horizontal currents that advect the DSL over the seamount at night. Studies of the fish populations of the Great Meteor Seamount have shown that they prey on the DSL and are concentrated around the margins of the summit to maximize chances of encountering zooplankton (Fock et al., 2002). Such mechanisms may also be important in the nutrition of abundant benthic communities on seamounts. For example, over the Nasca and Sala Y Gómez Seamounts in the southeastern Pacific, the lower depth of distribution of the lobster *Projasus bahamondei*, a dominant megabenthic predator, coincided with the deepest depth of migration of the DSL (Parin et al., 1997). Other mechanisms of concentration of food may also operate around seamounts associated with eddies or up- or down-welling currents and the relative movement behaviour of zooplankton (Genin, 2004). It is important to note that currently there is little understanding of the ecological links between the pelagic ecosystem, especially of larger predators such as fish, and communities of benthic organisms living on seamounts. Thus it is unknown how the removal of large quantities of fish biomass, by fisheries, from the vicinity of seamounts would affect the benthic community (Commonwealth of Australia, 2002; Lack et al., 2003).

The distribution of sediments and benthic communities on seamounts is a function of the current velocity near the seabed. Such currents may displace material off the seamount and resuspend organic material. Many seamounts also have distinct 'moats' around the base where currents scour out sediments lying around the seamount (e.g. Anton Dohrn Seamount, northeastern Atlantic). Some seamounts, known as guyots, are flat-topped and often covered in sediment as a result of wave-erosion when they were exposed as islands. However, seamounts are notable for the occurrence of hard substrata and complex small-scale topography, which show a marked contrast to the surrounding deep seabed – which tends to comprise fine sediments (hard substrata can occur elsewhere on banks and the slopes of continental shelves). The occurrence of terraces, canyons, pinnacles, crevices, craters, rocks and cobbles can exert a strong influence on the distribution of animals and plants on seamounts (reviewed in Rogers, 1994). Topographic relief controls local current flow regimes, and filter-feeding organisms such as corals are frequently concentrated in areas of strongest currents near ridges and pinnacles (Genin et al., 1986).

The following chapter will examine in greater detail the biological communities that seamounts can support, and ask how well their diversity can be assessed on a global scale.

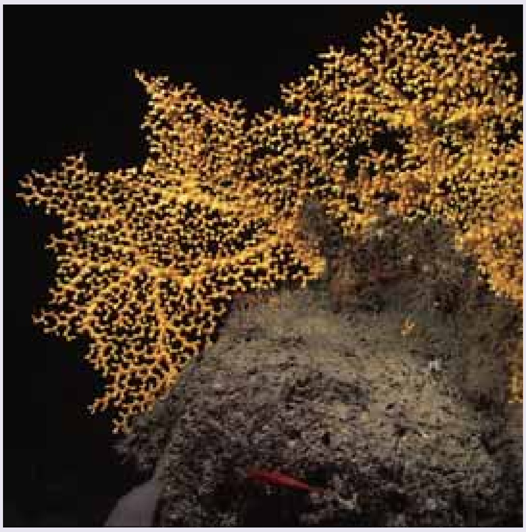
3. Deep-sea corals and seamount biodiversity

THE DIVERSITY OF LIFE ON SEAMOUNTS

The occurrence of hard substrata on seamounts means that, seamount communities can be dominated by sessile organisms that are permanently attached to the seabed – not possible on the soft sediments of most of the surrounding deep-sea floor. On seamounts with very shallow summits that penetrate the euphotic zone, such as the Vema Seamount in the southeastern Atlantic Ocean or the Gorringe Bank in the northeastern Atlantic Ocean, plant life can occur with kelp and encrusting calcareous algae dominating hard substrates (Simpson and Heydorn, 1965; Oceana 2006). The deepest records of living marine plants are of encrusting coralline algae from seamounts in the Caribbean living at 268 m depth (Littler et al., 1985). In the tropics, reef-forming corals such as *Acropora* spp., *Pocillopora* spp., *Porites* spp. and *Montastrea* spp. can occur on shallow seamounts which are often drowned atolls, such as the Raita Bank on the Hawaiian Ridge. Other animal groups that occur commonly on hard substrata on shallow seamounts include sponges, hydroids, azooxanthellate corals, molluscs, echinoderms and ascidians (sea squirts) (Simpson and Heydorn, 1965; Oceana, 2006).

On seamounts with deeper summits, the dominant megafauna (i.e., generally those animals that can be easily seen in photographs or video) are the attached, sessile organisms that feed on particles of food suspended in the water. The predominant suspension feeders are from the phylum Cnidaria and include sea anemones, sea pens, hydroids, stony corals, gorgonian corals and black corals (reviewed in Rogers, 1994; see also Koslow and Gowlett-Holmes, 1998; Koslow et al., 2001; Rowden et al., 2002). Other common suspension feeders include barnacles, bryozoans, polychaete worms, molluscs, sponges, ascidians, basket stars, brittle stars and crinoids. There is also an associated mobile benthic fauna that includes echinoderms (starfish, sea urchins and sea cucumbers) and crustaceans such as crabs and lobsters, some of which have commercial value (reviewed in Rogers, 1994).

Deep-sea or cold-water corals (Box 1) are a group of organisms that have drawn a great deal of public attention recently. Whilst their existence has been known since the 18th century, it was only with the advent of modern technologies – which allowed fisheries, oil exploration and scientific observations to penetrate into deeper areas – that the scale and abundance of cold-water coral ecosystems



Deep Atlantic Stepping Stones ScienceTeam/IFE/URI/NOAA

Box 1: What is a coral?

Corals are found within the phylum Cnidaria (coming from the Greek word *cnidos,* which means stinging nettle). Four main classes of Cnidaria are known: the Anthozoa (which contains the true corals, anemones and sea pens); Hydrozoa (the most diverse class, comprising hydroids, siphonophores and many medusae); Cubozoa (the box jellies); and Scyphozoa (true jellyfish).

Corals can exist as individuals or in colonies, and stony corals may secrete external skeletons made of aragonite, a form of calcium carbonate. Corals can be found in the photic zone of the ocean, where sunlight penetrates (with symbiotic photosynthetic zooxanthellae, a type of alga), as well as in the deep sea – the so-called 'cold-water corals'.

Cold-water coral ecosystems are populated by members from two classes of the Cnidaria. The main corals that will be discussed in this report are: scleractinians (stony corals), octocorals (which include the gorgonians), antipatharians (black corals) and zooanthideans (anemone-like hexacorals), which are all found within the Anthozoa, and the stylasterids (hydrocorals), which are found within the Hydrozoa.

***Chrysogorgia* sp., Davidson Seamount.**
(NOAA/MBARI)

Holothurian, cerianthid anemone and *Hymenaster koehleri*, Davidson Seamount, 2 854 m. (NOAA/MBARI)

were revealed. Deep-sea coral reefs are common features of continental shelves, slopes, banks, ridges and seamounts (Rogers, 1999; Friewald et al., 2004; Roberts et al., 2006). Today, as knowledge of their biology and ecology expands, it is becoming clear that deep-sea corals are particularly vulnerable to physical disturbance such as bottom trawling (Koslow et al., 2001; Clark and O'Driscoll, 2003; Freiwald et al., 2004; Rogers, 2004). Furthermore, because deep-sea corals have slow growth rates and poor post-disturbance recovery potential (Roberts et al., 2006), major research efforts on their conservation are emerging globally (e.g. Weaver et al., 2004). However, in addition to the direct effects of disturbance on deep-sea corals, it is becoming increasingly evident that they are an integral component of the overall species assemblage, and that the disturbance of deep-sea coral will have an equally destructive impact on the wider biological community.

Whilst hard substrata are more common on seamounts than elsewhere in the deep sea, sediments are common towards the base of seamounts or on terraces or summits of flat-topped seamounts (so-called guyots). These sediments originate from different sources, and their distribution and particle size depend on the local current regime and biological activity. Sites characterized by low exposure to currents exhibit fine, poorly sorted sediments, whilst those that are exposed to stronger currents tend to be coarser and may also be associated with bedforms such as ripples or sand waves (Levin and Thomas, 1989). There are only a few studies on the biology of seamount sediments, but it is known that they host a wide diversity of organisms that may burrow into sediments, or live amongst the sediment's particles or on its surface. The animals found in the sediment, known as the infauna, are classed according to size. The macrofauna (animals typically 500-250 μm in size) are dominated by polychaetes in the few studies on seamount infauna. These include many families common in other deep-sea habitats such as Paraonidae, Cirratulidae, Sabellidae, Syllidae and Ampharetidae (Levin and Thomas, 1989). Other common groups include crustaceans, molluscs, ribbon worms, peanut worms and oligochaetes. The smaller animals that live amongst the sand grains, known as the meiofauna (250-48 μm in size) include nematode worms, tiny crustaceans and some more unusual groups of marine invertebrates such as loriciferans and kinorhynchs. Observations indicate that there can be an inverse relationship between diversity of the infaunal community and current strength. This is because vigorous currents lead to more coarse sediments, with a lower content of bacteria and organic food particles and higher incidence of abrasion resulting from turbation (Levin and Thomas, 1989). The summit of Great Meteor, in the Northeast Atlantic, is covered in coarse, calcareous sediments that are home to a highly unusual community of tiny meiofaunal animals. These include new species of Loricifera (Gad, 2004a) epsilonematid nematode worms (Gad 2004b) and harpacticoid copepods (George and Schminke, 2002). The species, genera and families are not typical for deep-sea sediments and are more characteristic of littoral or shallow subtidal sediments. Larger animals living on the surface of sediments include sea pens, sponges, stalked-barnacles, gorgonians, cerianthid sea anemones, crinoids, brittle stars, sea urchins and sea cucumbers. Xenophyophores, giant single-celled organisms that agglutinate different types of particles (e.g. foraminiferan shells, sand, volcanic glass) to create elaborate dwellings of a variety of shapes, are particularly common on seamount sediments (Rogers, 1994). Many of these organisms are suspension feeders and tend to favour areas exposed to strong currents.

THE RELATIONSHIP BETWEEN CORALS AND OTHER LIFE

The most spectacular benthic communities on seamounts are those associated with biological habitats or bioherms, such as cold-water coral reefs (Koslow et al., 2001). It has been suggested that cold-water coral reefs are 'the most three-dimensionally complex habitats in the deep ocean' (Roberts et al., 2006). As a result, there may be an associated, complex community of organisms that is dynamically linked to either the habitat structure provided by coral, or the living coral (Koslow et al., 2001; Freiwald et al., 2002). As such, cold-water coral reefs can play a similar ecological role to that of shallow-water coral reef systems (Rogers, 1999).

The diversity of animals associated with cold-water coral reefs is extremely high and comparable to, or higher than, their tropical shallow-water counterparts (Rogers, 1999; Buhl-Mortensen and Mortensen, 2005). For example, greater than 1 300 species have been reported to date as being closely associated with cold-water coral reefs in the northeastern Atlantic Ocean (Roberts et al., 2006). A varying proportion of associated species may be new to science, depending on geographic area investigated (e.g. Richer de Forges et al., 2000). The reasons for this highly diverse association are not fully understood. However, the added habitat complexity to the environment is thought to offer refugia for numerous invertebrates and fish within the living and dead coral reef framework, coral rubble and sediments, while at the same time providing hard substrates for colonization by other sessile or encrusting organisms such anemones, bryozoans and other corals (Freiwald et al., 2002). In this sense, some cold-water corals may be regarded as 'ecosystem engineers' – that is, they create, modify and maintain habitat for other organisms (Jones et al., 1994). Many fish species, including several of commercial significance, show spatial co-occurrence with deep-water corals (Auster et al., 2005; Stone, 2006), and fish catches have been found to be higher in and around deep-water coral reefs (Husebø et al., 2002).

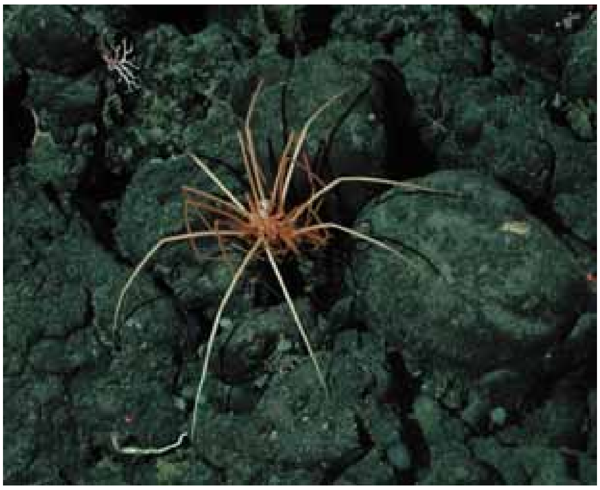
The reefs formed by some stony corals (scleractinians) are not the only three-dimensional structures built by corals. Large branching and treelike corals such as antipatharians (black corals) and octocorals (including the gorgonians) can also provide an extension of the benthic habitat through forming so-called coral beds or gardens (Stone, 2006). The branches of these corals are raised off the seabed into the overlying water (emergent epifauna), providing rigid platforms for other sedentary and sessile species, thereby allowing them better access to food brought by prevailing currents (Stone, 2006). Such non-reef forming corals, along with other organisms such as sponges, therefore have an important role in providing habitat for other species. In the Aleutian Islands, 97 per cent of juvenile rockfish and 96 per cent of juvenile golden king crabs have

***Lepidion* sp., swimming amongst coral framework, Hatton Bank.** (DTI SEA Programme, c/o Bhavani Narayanaswamy)

been observed as associated with emergent epifauna such as octocorals and sponges (Stone, 2006). Such observations do not necessarily indicate dependence by fish on emergent epifauna. Recent studies in the Hawaiian archipelago on associations between black corals (Antipathes spp.) and fish in shallow water have indicated that many fish may routinely pass through the branches of coral colonies, treating it as general habitat. A few species regularly used the coral for protection from perceived threats, and only one species of fish was restricted to the branches of coral trees (Boland and Parrish, 2005). The fish communities of deeper slopes in Hawaii also use octocorals and zoanthids as shelter interchangeably with non-biotic habitat (Parrish and Baco, in press). In some cases observations suggest that fish and corals occur together because they may have similar habitat requirements on seamounts and banks (Mundy and Parrish, 2004; Parrish and Baco, in press). In a similar way, despite concentrations of orange roughy on the Tasmanian Seamounts, juveniles or young fish of this species have not been found associated with the corals; and though the adults occur in the same physical environment as the epibenthic fauna, no interaction has been observed between them (Smith, 2001). The association of fish and corals may attract large predators. For example, the endangered Hawaiian monk seal *(Monachus schauinslandi)* forages preferentially for fish amongst beds of deep-sea octocorals and antipatharians (Parrish et al., 2002).

In addition to the general coexistence of coral and non-coral species, some animals have formed strong relationships with their coral hosts. A recent review of direct dependencies on cold-water corals globally has shown that of the 983 coral associated species studied, 114 were characterized as mutually dependent, of which 36 were exclusively dependent to cnidarians (Buhl-Mortensen and Mortensen, 2004). Such commensal relationships may come in a variety of forms: some animals are obligate inhabitants on or within the coral skeleton, such as the polychaete *Gorgoniapolynoe caeciliae* on the gorgonian *Candidella imbricata* (Eckelbarger et al., 2005); the amphipod *Pleusymtes comitari* associated with the gorgonian *Acanthogorgia* sp. (Myers and Hall-Spencer, 2004); and the polychaete *Eunice norvegicus* associations with the scleractinians *Lophelia pertusa* and *Madrepora oculata* (Rogers, 1999; Mortensen, 2001; Roberts, 2005). *E. norvegicus* lives in tubes that become calcified by *Lophelia pertusa* or *Madrepora oculata* as they grow, conferring protection to the worm which also acts as a kleptoparasite on the corals (Mortensen, 2001; Roberts, 2005). The worm tubes aggregate coral colonies, strengthening the coral framework, and the worms defend the coral vigorously from predators. Numerous species of ophiuroid brittle stars are obligate inhabitants of tree-forming corals such as the antipatharia (Stewart, 1998 and references therein; Buhl-Mortensen and Mortensen, 2004), which in exchange 'clean' corals of the build-up of detrital material that could clog their polyps. Such coral associates may be regarded as important structural species in that they may be important for the viability of the key structural species in reef and coral garden habitats (ICES, 2006). Other types of relationship also exist, for example epitoniid gastropods are specifically adapted to feed on coral polyps (B Marshall, personal communication, Museum of New Zealand Te Papa Tongarewa, Wellington, New Zealand).

***Lophelia pertusa* framework with rich associated invertebrate fauna, Hatton Bank.**
(DTI SEA Programme, c/o Bhavani Narayanaswamy)



Pycnogonids found on slope and base of Davidson Seamount (1 570 m); also note the chiton.
(NOAA/MBARI)

Fragment of live stony coral *Lophelia pertusa* with polychaete worm *Eunice norvegicus*.
(Paul Tyler, School of Ocean & Earth Science, University of Southampton)

ATTEMPTING TO DETERMINE GLOBAL SEAMOUNT FAUNAL DIVERSITY

It is important to understand the relationships between coral colonies and the fauna that is likely to be dependent on them for food and habitat. In this sense, better understanding of the entire deep-sea coral community on seamounts will lead to a more comprehensive view of the potential impact on them from human activities such as bottom trawling.

In order to examine the global benthic invertebrate community composition on seamounts where corals have also been found, a freely available online resource of seamount related biological data, SeamountsOnline (Stocks, 2006) was used. SeamountsOnline is currently the largest database of its kind, spanning a wide taxonomic and geographic range of published accounts of animal and plant species occurrences on seamounts, as well as unpublished data provided voluntarily by seamount researchers. Data from SeamountsOnline used here are the most up to date at the time of the analysis (last accessed July 13, 2006).

Our analysis was constrained to those seamounts for which coral has been sampled. For this, we consider in total the members of the Antipatharia, Octocorallia, Scleractinia, Stylasterida and Zoanthidea to be the coral community with potential for providing substrate or unique habitat. At the time of this analysis, the database held approximately 15 841 observations of 3 701 species from 287 seamounts around the globe. We use the term 'observation' to mean a record of the occurrence of a species on a seamount.

Both corals and other members of the benthic community have been sampled on 47 seamounts (including seamounts <1 000 m). However, it should be noted that there can be a sampling bias towards the communities that were targeted (e.g. whilst hard substrates have generally been sampled, some studies have targeted soft substrates), and that the majority of seamounts have been under-sampled, so that the number of species should be considered an underestimate. Among the 47 seamounts, 322 coral species and 1 158 non-coral species are recorded from 5 541 observations. However, it must be noted that co-occurrence of corals and other benthic species does not necessarily indicate an association. That is, coral and non-coral species examined here were not necessarily collected simultaneously, nor were they necessarily collected from the same area of the seamount. In addition, some scleractinian coral species that form frameworks may have an exceptional influence on non-coral species diversity, as the reefs they form have a high associated biodiversity (e.g. Rogers, 1999; Freiwald et al., 2004; Roberts et al., 2006). Therefore, the main assumption for this analysis is that coral and non-coral species collected on the same seamount are possibly associated, in the sense that any impact on the seamount would potentially affect both coral and non-coral communities.

GLOBAL DISTRIBUTION OF SAMPLING ON SEAMOUNTS

The geographic distribution of 47 seamounts examined here, and the number of observations from which data were generated, is shown in Table 3.1. The map (Figure 3.1) shows that generally the North Atlantic and Southwest Pacific are the two main centres, with the highest numbers of observations of both corals and non-coral seamount species. Most seamounts examined fall within national EEZs, although exceptions include seamounts in the eastern Atlantic (Josephine, Great Meteor, Plato, Hyeres, Cruiser

Table 3.1: Ocean area and FAO area of seamounts used for the biodiversity analysis, together with the predicted number of large seamounts per FAO area (* indicates seamounts <1 000 m elevation).

Seamount Name (Number refers to Figure 3.1)	Ocean Area	FAO Area	Estimated total no. of large seamounts per FAO area
1. Galicia Bank 2. Joao de Castro Bank 3. Josephine Seamount 4. Le Danois Bank* 5. Lousy Bank 6. Ormonde Seamount	Atlantic, Northeast	27	325
7. Atlantis Seamount 8. Cruiser Tablemount 9. Great Meteor Tablemount 10. Hyeres Seamount 11. Plato Seamount 12. Seine Seamount	Atlantic, Eastern Central	34	536
13. Andy's Seamount* 14. Dory Hill* 15. Hill 38* 16. Macca's Seamount* 17. Main Pedra Seamount* 18. Sister I Seamount*	Indian, Eastern	57	588
19. Kinmei and Koko Seamounts	Pacific, Northwest	61	1 350
20. Dickens Seamount 21. Giacomini Seamount 22. Pratt Seamount 23. Welker Seamount	Pacific, Northeast	67	265
24. Antigonia* 25. Argo Seamount 26. Jumeau East Seamount 27. Jumeau West Seamount* 28. Kaimon Maru Seamount 29. Nova Bank 30. Titov Seamount*	Pacific, Western Central	71	2 670
31. Bank 8 32. Bonanza Seamount* 33. Brooks Banks 34. Cross Seamount 35. Fieberling Tablemount 36. Horizon Tablemount 37. Ladd Seamount 38. Loihi Seamount 39. Middle Bank 40. Raita Bank 41. Salmon Bank 42. Twin Banks 43. Volcano 6	Pacific, Eastern Central	77	2 735
44. Britannia Guyot 45. Gascoyne Tablemount 46. Gifford Tablemount 47. Taupo Seamount	Pacific, Southwest	81	996

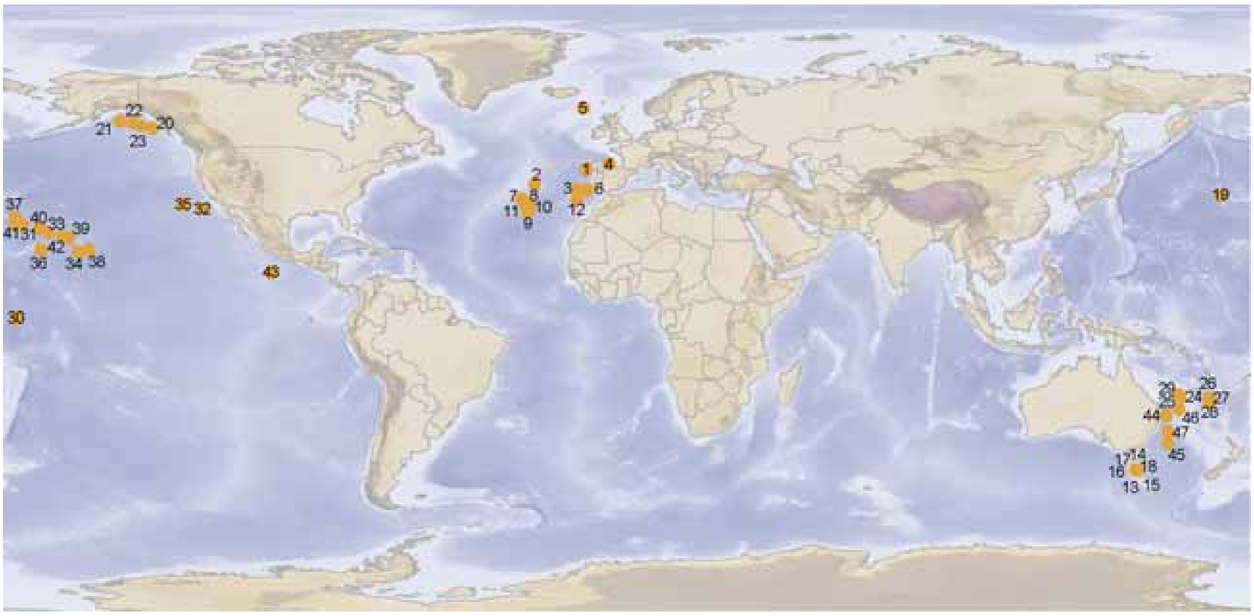


Figure 3.1: Locations of seamounts from where coral and non-coral species data were compiled for the biodiversity analysis. The numbers refer to the seamounts listed in Table 3.1.

and Atlantis Seamounts), the eastern Pacific (Fieberling and Volcano 6 Seamounts), the western Pacific (Kinmei and Koko Seamount) and the South Pacific (Gifford Seamount). Seamounts where comparative data exist are restricted to eight FAO areas (Table 3.1). Within FAO areas, the number of seamounts sampled is limited to only a small fraction of the total estimated number of large seamounts.

Some of the seamounts were subject to recent and/or continued studies, which produced useful species inventories. In the North Atlantic Ocean, the Atlantis, Cruiser, Great Meteor, Hyeres and Josephine seamounts have been particularly well studied (Figure 3.1). Numerous species of sessile (e.g. brachiopods, bryozoans, fan worms, sponges, barnacles, tunicates) and mobile (e.g. crinoid feather stars) suspension feeders have been observed. However, the occurrence of species that typically live within soft sediments (e.g. *Echinocardium* heart urchins, cuspidarid bivalves and numerous polychaete families) suggests that soft sediment habitats also exist on these seamounts.

Seamounts in the Southwest Pacific have received much recent attention, and represent the most comprehensively studied region in terms of their benthic communities. The Antigonia, Jumeau East, Jumeau West, Kaimon Maru and Nova seamounts have useful species inventories, where, in addition to those components found in North Atlantic seamounts, species of ascidians, hydroids and anemones were commonly sampled.

The coral communities of the Central Pacific and Northeast Pacific seamounts have been generally poorly studied. This may reflect an historical and present day scientific interest restricted to seamount fisheries of these regions. In the Central Pacific, however, the Cross and Horizon Seamounts have been well studied, and show similar community components to those described above at a similar taxonomic level.

Finally, common to most seamount species inventories are numerous observations of mobile epifauna such as decapods, gastropods, nudibranchs, pycnogonids and

Sea urchin on sediments on Rockall Bank.
(DTI SEA Programme, c/o Bhavani Narayanaswamy)

Table 3.2: Summary of sampling effort on seamounts

Number of Observations	Number of seamounts	Mean number of coral species recorded per seamount	Mean number of non-coral species recorded per seamount
<10	7	2	3
11-25	5	5	10
26-50	12	11	9
51-100	11	8	32
101-200	3	26	64
201-500	6	17	119
501–1 000	3	21	172

Source: SeamountsOnline

echinoderms. These groups are typically categorized as detritivores or predators, suggesting higher levels of trophic complexity within seamount communities.

A PRELIMINARY ASSESSMENT OF GLOBAL SEAMOUNT FAUNAL DIVERSITY

A summary of the sampling effort on large seamounts is given in Table 3.2, expressed in terms of the total number observations per seamount, mean number of coral species and mean number of non-coral species observed per seamount. The majority of seamounts have had a total of 26-100 reported observations, with means of up to 11 species of coral and 32 non-coral species observed on each seamount. The numbers of non-coral species observed increased as total number of observations increased, with the highest mean number of non-coral species observed being 172 per seamount. The mean number of coral species observed varied from two species per seamount to 26 species per seamount. Although these data could be interpreted as suggesting a link between numbers of coral species and numbers of non-coral species in the community overall, the data are highly dependent on the numbers of observations made. This reflects the inadequate sampling of the fauna on all of the seamounts studied. As a result of the limited sampling on seamounts where both corals and non-coral species have been observed, any conclusion on the relationship between coral and non-coral diversity or further analysis and interpretation of these data would be inappropriate at this time.

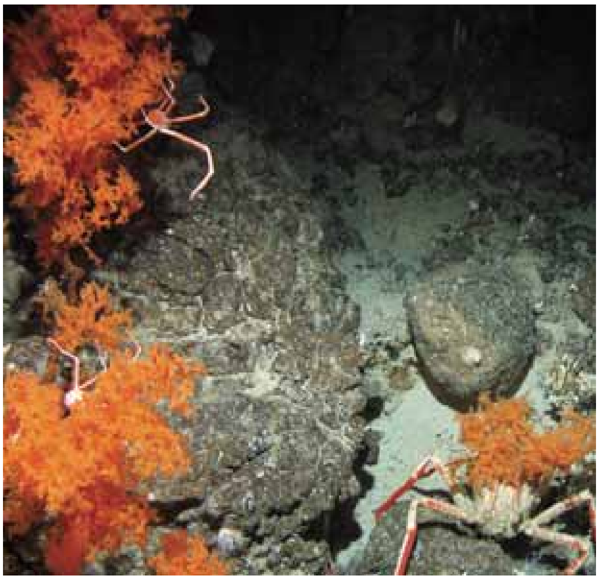
HOW TO ALTERNATIVELY ASSESS SEAMOUNT FAUNAL DIVERSITY

The comparative global analysis of the few well-sampled seamount assemblages indicates that a complex community of invertebrates may exist on those seamounts that harbour corals. However, the most evident finding is that there are significant geographic gaps in the distribution of studied seamounts. This is highlighted by the limited number of FAO areas represented by studied seamounts, and the limited number of seamounts studied in areas beyond national jurisdiction in general. Examination of coral communities is limited primarily to a few seamounts in the North Atlantic and Southwest Pacific Oceans, representing only a fraction of the total number of seamounts where biological collections have been made worldwide. Furthermore, taxonomic gaps in species inventories are likely where sampling or research aims have targeted specific components of the community, such as in the central, western and eastern North Pacific. Nonetheless, the examination of SeamountsOnline data has been useful for identifying these taxonomic and geographic gaps in the global picture of seamount biodiversity.

It has been widely suggested that negative impacts on seamount coral assemblages are likely to have significant impacts on a wider benthic community (e.g. Fosså et al., 2002; Koslow et al., 2001; Lack et al., 2003), and may have possible cascading effects on the benthic and pelagic community as a whole, although these are poorly understood (Commonwealth of Australia, 2002; Lack et al., 2003). Currently there is insufficient global data to assess directly the potential vulnerability of seamount communities. Assessing the potential impacts of disturbance by bottom trawling on the seamount coral community using available cold-water coral data as a proxy for the whole seamount benthic community is a prudent alternative. The first step in this approach is taken in the following chapter of this report.

4. Distribution of corals on seamounts

***Graneledone boreopacifica* and *Trissopathes* sp., Davidson Seamount, 1 973 m depth.** (NOAA/MBARI)



Antipatharian coral, *Munidopsis* sp. and *Paramola* sp., Hatton Bank. (DTI SEA Programme, c/o Bhavani Narayanaswamy)

THE NEED TO ASSESS THE DISTRIBUTION OF CORALS

Analyses of the diversity of seamount communities have generally aimed at assessing the overall diversity of seamount communities and levels of potential endemism (e.g. Richer de Forges et al., 2000). However, such studies have revealed little about how species within specific groups are distributed on seamounts at regional and global scales. Such information is critical in understanding what environmental factors influence species diversity on seamounts. It is also important in predicting the impacts of human activities on seamount communities in the absence of detailed data. Data on the occurrence of species on seamounts is sparse and scattered over a variety of sources. For some groups of animals, most notably those comprising large, conspicuous organisms, there are a substantial number of observations. Fortunately, data for corals was sufficient for a detailed analysis of the distribution of corals on seamounts that had several principle aims:

(i). to identify global hotspots in seamount coral diversity;
(ii). to compare the distribution of different coral groups; and
(iii). to understand the limitations of available data for corals in terms of geographic coverage (Rogers et al., in press).

THE TASK OF COMPILING USEFUL DATA

A database was generated for records of all known occurrences of corals on seamounts, including some shallower features of <1 000 m elevation and some banks associated with the continental margin (n = 3 235; Rogers et al., in press). The coral database consisted of records of the presence of a coral species at a locality and could not be used to infer species absence. This included records of Scleractinia (stony corals); Octocorallia (including gorgonians); Antipatharia (black corals); Stylasterida (stylasterids/hydrocorals) and Zoanthidea (zoanthids). These records included all species of corals including those that are reef-forming, contribute to reef formation, or occur as isolated colonies. Corals were chosen as they are the most commonly recorded group of benthic animals recorded from seamounts (Stocks, 2004) and are also often associated with a diversity of other species (Rogers, 1999; Freiwald et al., 2004; Buhl-Mortensen and Mortensen, 2005; Roberts et al., 2006). As such, corals may be representative of the biological diversity of the hard-substrata benthic communities on seamounts in general (see arguments in previous chapter).

These records were extracted from the primary scientific literature, from museum databases, from online data

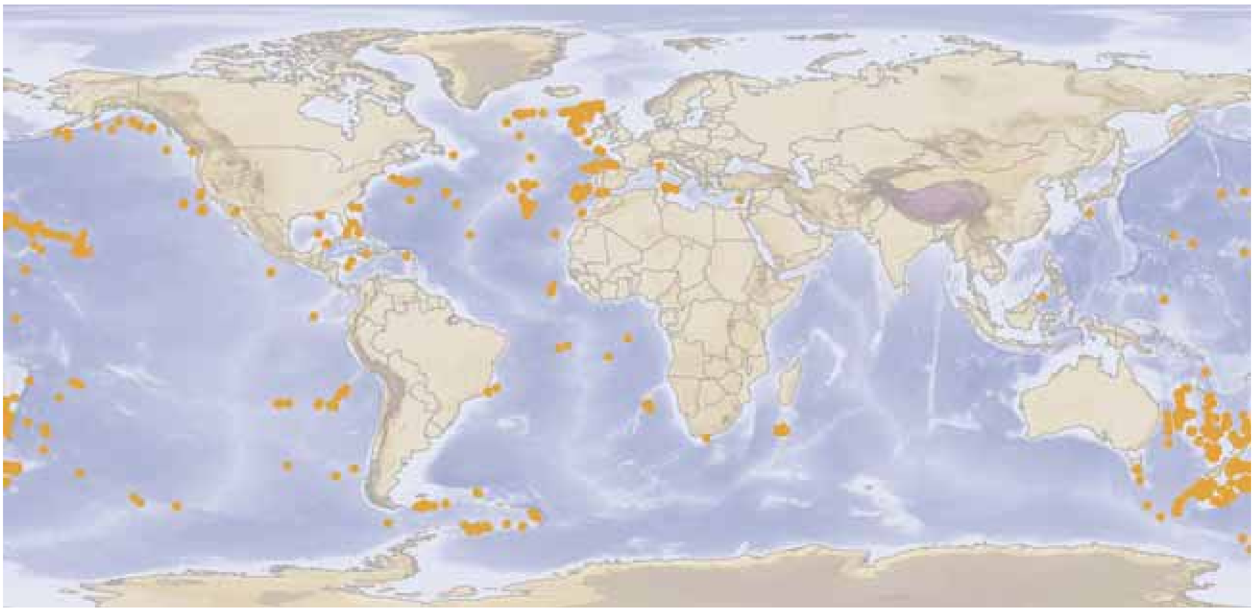


Fig. 4.1 Global distribution of seamounts with records of corals (Scleractinia, Octocorallia, Antipatharia, Stylasterida and Zoanthidea). *Source: Rogers et al. (in press)*

sources (Seamounts Online; Biogeoinformatics of Hexacorals), from reports and from the records held by scientists. Records were included in the database if corals were identified to species level or occasionally to genus if this represented a single unidentified species within the genus on a seamount. Information recorded for each record, if available, included the species name; ocean region; seamount; location, which was the exact latitude and longitude of the specimen collection if available or that of the seamount given in IOC-IHO GEBCO database; depth or depth range from which the specimen was collected; whether the specimen was alive, dead or if this information was unknown; the origin of the record; and any other pertinent notes.

GLOBAL DISTRIBUTION OF RECORDS FOR SEAMOUNT CORALS

Analyses of the corals on the seamount database demonstrated that sampling of seamounts has not taken place across the world's oceans evenly (Rogers et al., in press). Examination of a map of all coral (Scleractinia, Octocorallia, Antipatharia, Stylasterida and Zoanthidea) records shows that for some regions very few seamount samples have been taken, including the entire Indian Ocean

***Bathypathes* sp., Davidson Seamount, 2 467 m.** (NOAA/MBARI)

***Munidopsis* sp., orange hydroid and amphipods on drifting kelp, Davidson Seamount, 1 400 m** (NOAA/MBARI)

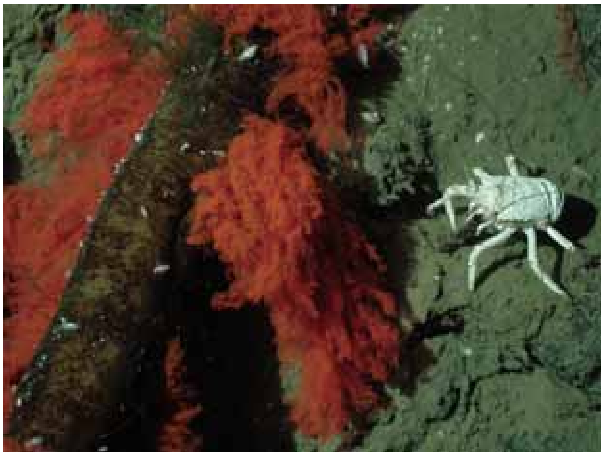


Table 4.1: Numbers of records, species, genera and families recorded for all coral groups from seamounts

Group	Total of records	Number of species	Number of genera	Number of families
Scleractinia	1 713	249	85	20
Octocorallia	957	161	68	21
Stylasterida	372	68	18	2
Antipatharia	157	34	22	6
Zoanthidea	28	14	6	3

Source: Rogers et al. (in press)

and other regions, such as the South Atlantic, central southern Pacific and much of the Southern Ocean (Figure 4.1). It is also apparent that some areas have been well sampled, such as around New Zealand, Hawaii, off western North America and in the Northeast and Northwest Atlantic. In total, fewer than 300 seamounts have been sampled for corals, representing 2.1 per cent of the identified number of large seamounts in the oceans globally (or 0.03 per cent when assuming there are 100 000 seamounts with elevation greater than 1 000 m).

PATTERNS OF CORAL DIVERSITY

One of the most notable results of analyses of the database was the finding that most coral species found on seamounts are restricted to a single ocean and most of these to a single region within an ocean (Rogers et al., in press). Only a relatively small number of species have wide geographic distributions, and very few have near-cosmopolitan distributions. Often the taxonomy and systematic status of such globally distributed species is not entirely resolved, and it is possible that some of these species represent clusters of morphologically similar sibling or cryptic species (see Le Goff-Vitry et al., 2004). Many of the widely distributed species are the primary framework building corals of cold-water reefs (e.g. *Lophelia pertusa, Solenosmilia variabilis* and *Madrepora oculata*). It is not known to what extent the limited sampling of seamounts influenced this result, and certainly some coral species have a wider geographic distribution than is apparent from the occurrences recorded on seamounts (Rogers et al., in press).

A global analysis of the species richness of corals on seamounts on a 10º by 10º latitudinal and longitudinal grid was also carried out (Rogers et al., in press). This analysis showed that several geographic areas appeared to be hotspots of coral diversity. However, an analysis of the relationship between the numbers of coral samples for each grid box indicated that species richness was strongly dependent on sampling effort (Rogers et al., in press). Species richness of corals was also analysed by latitude (Rogers et al., in press) because there has been a suggestion that biological diversity in the oceans peaks at mid-latitudes (Worm et al., 2003). This suggestion seemed to be confirmed by the coral diversity on seamounts, which also peaked at mid-latitudes. However, this proved to be an artefact, caused by an equatorial gap in the sampling of seamount fauna (Rogers et al., in press).

Despite the limitations of the coral on seamounts dataset, some broad patterns in distribution were detected.

Table 4.2: Numbers of species of the two main coral groups that occur on seamounts in different ocean regions

Ocean Region	Coral group: Scleractinia	Coral group: Octocorallia
Northeast Atlantic	48	27
Northwest Atlantic	9	7
Southeast Atlantic	10	1
Southwest Atlantic	5	1
Northeast Pacific	15	54
Northwest Pacific	3	3
Southeast Pacific	3	-
Southwest Pacific	108	20
Southern Ocean	8	4

Source: Rogers et al. (in press)

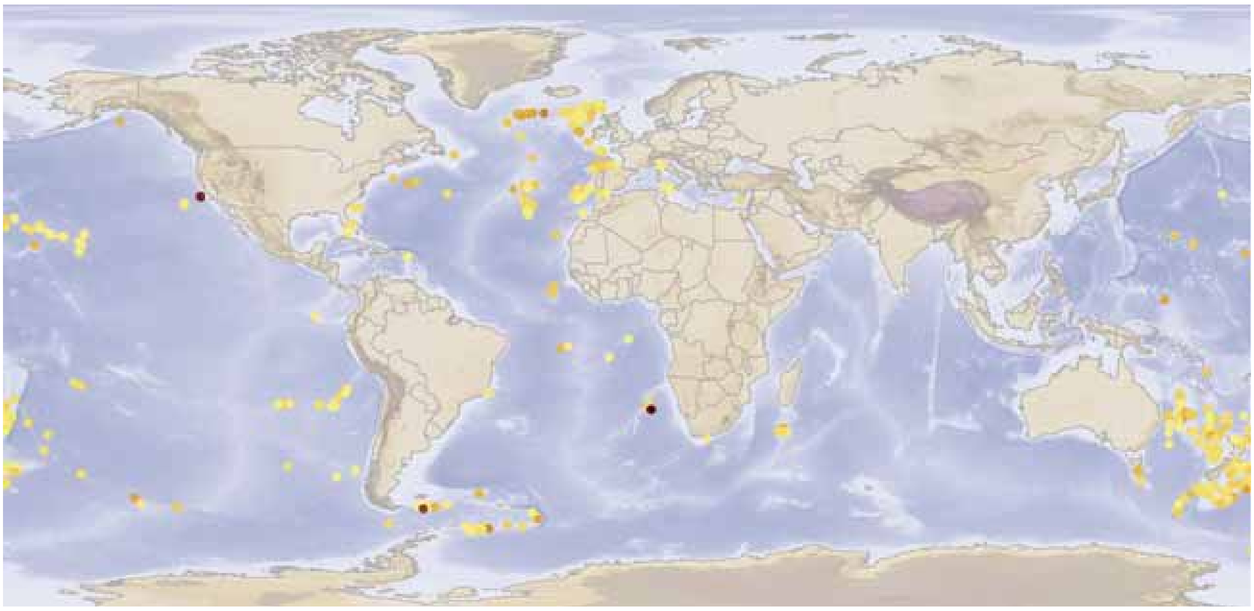


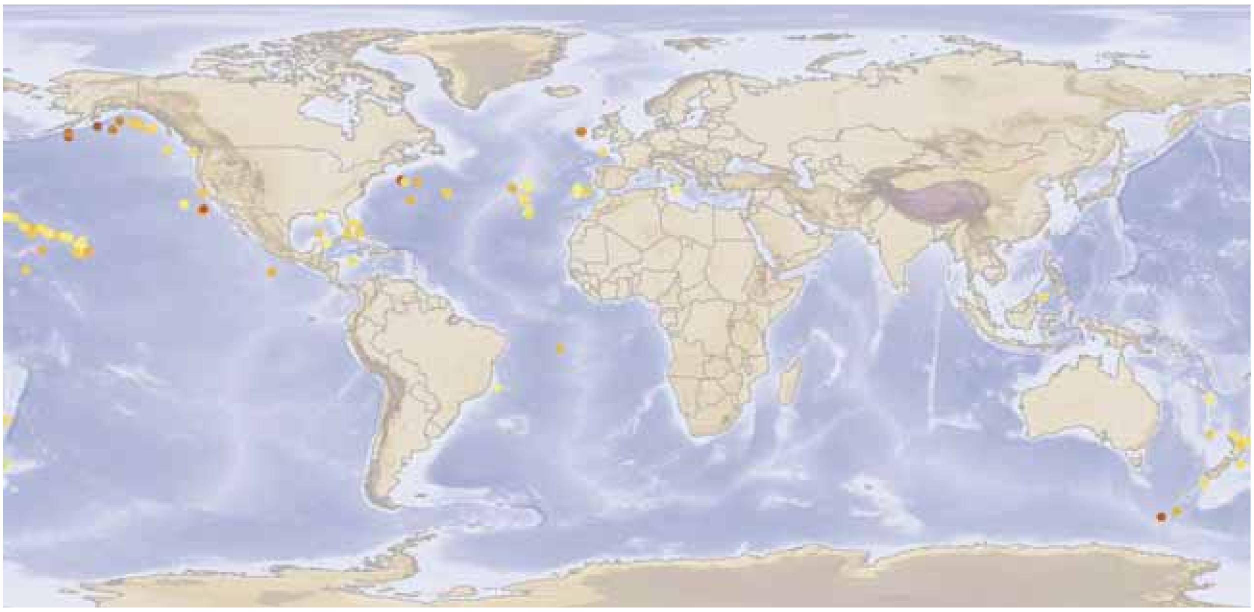
Figure 4.2: Known locations of scleractinian corals on seamounts. *Source: Rogers et al. (in press)*

Key (above and below)

Summit depth (m)	Summit depth (m)
0-500	2 500-3 000
500-1 000	3 000-3 500
1 000-1 500	3 500-4 000
1 500-2 000	4 000-4 500
2 000-2 500	4 500-5 000

Scleractinian corals are the most diverse and commonly observed group, with 249 species having been recorded. This is followed by the octocorals, the stylasterids, the antipatharians and the zoanthids in order of diversity and number of records (Table 4.1). Fewer than 1 500 species of scleractinian corals have been described, and seamounts therefore potentially host a substantial fraction of the global scleractinian fauna, and a very large fraction of

Fig. 4.3: Known locations of octocorals on seamounts. *Source: Rogers et al. (in press)*



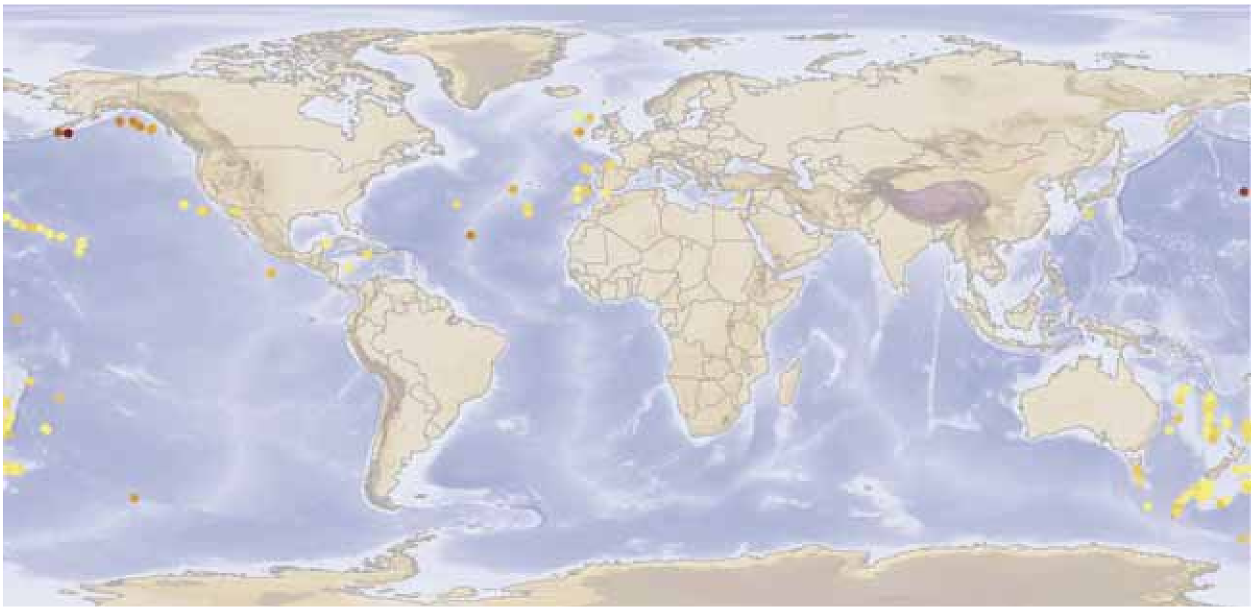


Figure 4.4: Known locations of antipatharian corals on seamounts. *Source: Rogers et al. (in press)*

Key

Summit depth (m)	Summit depth (m)
0-500	2 500-3 000
500-1 000	3 000-3 500
1 000-1 500	3 500-4 000
1 500-2 000	4 000-4 500
2 000-2 500	4 500-5 000

azooxanthellate coral species living in deeper waters (Rogers et al., in press).

Comparison of the relative diversity of the coral groups in different regions of the oceans revealed significant differences (Table 4.2). In most parts of the world, Scleractinia were the most diverse group, followed by the Octocorallia. However, in the northeastern Pacific, this trend was reversed. Here, octocorals are markedly more diverse than scleractinians (Rogers et al., in press). The north-eastern Pacific is characterized by a shallow aragonite saturation horizon, which may explain the lower relative diversity of stony corals in this region (Guinotte et al., 2006). Scleractinia need to accumulate large quantities of aragonite to build the coral skeleton. Undersaturation of aragonite makes this process more difficult and may result in the dissolution of dead coral skeletons, potentially preventing the occurrence of cold-water coral reefs. Given the present evidence of acidification of the oceans, this has significant implications for the global distribution of cold-water corals and coral reefs (Orr et al., 2005; Royal Society, 2005; see Chapter 5). It is also notable that the seamounts of the northeastern Pacific are very isolated, and differences in dispersal capacity between the two coral groups may also influence their distribution. The feeding ecology of scleractinians and octocorals is also different, and this may also result in contrasting environmental preferences of the two coral groups.

THE RELATIVE OCCURRENCE AND DEPTH DISTRIBUTION OF THE MAIN CORAL GROUPS

Analysis of the depth distribution of the four main different coral groups, the Scleractinia, Octocorallia, Stylasterida, Antipatharia and Zoanthidea, found that the different coral groups occurred at different depths (Figures 4.2-4.4). Most scleractinian and stylasterid species occur in the upper 1 000-1 500 m (Rogers et al., in press). Octocorals can be found in greater depths, with most species occurring in the upper 2 000 m. Antipatharians also occurred in the upper 1 000 m, although a higher proportion of species occurs deeper than scleractinians or stylasterids. A variance analysis, using a Generalised Linear Model (GLM), of the whole dataset showed that the depth distributions were different between the four coral groups. Analysis in pairs showed the depth distributions of scleractinian and stylasterids to be similar and different from both octocorals and antipatharians (Rogers et al., in press). Sampling effort to date limits our understanding of coral distribution below 2 500 m.

GETTING A BETTER UNDERSTANDING OF CORAL DISTRIBUTION ON SEAMOUNTS

The relative occurrence and distribution of corals on seamounts demonstrate that the depth of the seamount summit will have a significant influence on the composition of the coral communities present. This is likely to apply also to other groups of sessile organisms (Rogers et al., in press). The greatest diversity of corals observed on seamounts occurs in the upper 1 000 m of the oceans, and the depth ranges with the highest coral diversity overlap with those where most deep-sea fishing currently takes place (250-1 500 m; Koslow et al., 2000; ICES, 2005).

Given that depth is one of the major factors influencing physical classification of seamounts (Rowden et al., 2005; ICES, 2006), this will be a significant factor in predicting the diversity of coral communities on unsampled seamounts. However, it should be noted that even for mean depths, the results for the GLM indicated that taxonomic groups of coral have only a relatively small influence on depth distribution (it explains about 10 to 13 per cent of the variation), and that many other factors – such as the physical environment of a seamount – will also determine species composition and distribution (Rowden et al., 2005).

Overall, the analyses revealed new patterns in the regional and vertical distribution of coral species. The reasons for differences in the depth and regional distribution of the different coral groups are most likely related to the nature of substrates available for attachment; the quantity, quality and abundance of food at different depths (see Chapters 2 and 3); but also to the aragonite saturation horizon, temperature and the amounts of different essential elements and nutrients (Bonilla and Piñón, 2002). The dataset also revealed significant areas of weakness in our knowledge of seamount coral diversity, especially in the lack of sampling of seamounts in equatorial latitudes. Thus, in order to make a reasonable assessment of the vulnerability of corals and, by proxy, non-coral communities on seamounts to bottom trawling, it is currently necessary to use models to predict the global occurrence of suitable coral habitat.

5. Predicting global distribution of stony corals on seamounts

***Paragorgia arborea*, Davidson Seamount, 1 779 m.**
(NOAA/MBARI)

KNOWN CORAL DISTRIBUTION

The previous chapter demonstrates that our knowledge of the distribution of corals on seamounts is limited. Most records come from heavily sampled regions such as the Northeast Atlantic and around New Zealand, a pattern that is unlikely to represent the true distribution of these corals. There are very few data from seamounts in some regions, such as the south-central Pacific and the Indian Ocean, and the vast majority of large seamounts have not been sampled at all. In order to improve our knowledge of where and why deep-sea corals are found on seamounts, further sampling and research has to be conducted, but this is time-consuming and expensive. A short-term alternative, although not replacing the need for further sampling, is to use a modelling approach.

A common problem in biology is attempting to predict in which areas an organism is likely to be found, given a limited set of observations of its distribution. Understanding the factors, such as climate and food availability, that drive its distribution (Gaston, 2003) can help. Models (Box 2) can be used to predict the distribution of a species from observed occurrences and absences of individuals and their relationship to measurable environmental parameters (Guisan and Zimmermann, 2000; Guisan and Thuiller, 2005).

In this chapter we construct a habitat suitability model to gain insight into the global distribution of deep-sea corals on seamounts. Some scleractinian corals form complex structures and frameworks such as reefs that provide habitat for other deep-sea species (Rogers, 1999; Freiwald et al., 2004). Better knowledge of the distribution of such species supplies a useful proxy for the biodiversity of benthic communities of seamounts (see Chapter 3).

Other groups of coral, such as octocorals, for example, can also form important habitats such as coral gardens (e.g. Stone, 2006; see Chapter 3). These corals may have very different distributions from that of stony corals, which would also be useful to appreciate in the context of determining the vulnerability of seamounts communities to bottom trawling. Unfortunately, the available data for octocorals are currently too limited to enable appropriate modelling.

Box 2: What is a model?

A model, in this context, is a simplified, abstracted representation of a real-world system. Models are typically constructed using mathematical equations or statistical functions that are programmed into a computer. For example, existing data (such as known seamount coral distributions) are fed into the model, and the output (such as predicted habitat suitability maps for seamount corals) is used to aid in the understanding of patterns and processes and to make predictions. Models are often compared and tested against one another. There is a trade-off between simplicity and complexity. A simple model that captures the essential features of the system in question is often preferable to a more complex model where more assumptions have to be made because there is normally not enough known about parts of the ecosystem.

It is important to remember that a model can never be perfect or 'right'. It is a simplified representation of reality. A good outcome would be for the model to capture large-scale features of the system in question. It is also important to calibrate a model against known data and knowledge, and to statistically assess its accuracy. Only when the uncertainty in a model can be quantified is it of significant use.

Table 5.1: Environmental parameters used to predict habitat suitability [GLODAP = Global Ocean Data Analysis Project; SODA = Simple Ocean Data Assimilation 1.4.2; VGPM = Vertically Generalized Productivity Model; WOA = World Ocean Atlas 2001]

Parameter	Units	Source	Reference
Temperature	°C	WOA	Conkright et al., 2002
Salinity	Pss	WOA	Conkright et al., 2002
Depth	m	WOA	Conkright et al., 2002
Surface chlorophyll	μg l^{-1}	WOA	Conkright et al., 2002
Dissolved oxygen	ml l^{-1}	WOA	Conkright et al., 2002
Per cent oxygen saturation	%	WOA	Conkright et al., 2002
Overlying water productivity	mg C m^{-2} yr^{-1}	VGPM	Behrenfeld and Falkowski, 1997
Export primary productivity	g C m^{-2} yr^{-1}	VGPM	Behrenfeld and Falkowski, 1997
Regional current velocity	cm s^{-1}	SODA	Carton et al., 2000
Total alkalinity	μmol kg^{-1}	GLODAP	Key et al., 2004
Total dissolved inorganic carbon	μmol kg^{-1}	GLODAP	Key et al., 2004
Aragonite saturation state	μmol kg^{-1}	Derived from GLODAP data	Key et al., 2004; Orr et al., 2005; Zeebe and Wolf-Gladrow, 2001

USING HABITAT SUITABILITY MODELLING TO PREDICT STONY CORAL DISTRIBUTION

Statistical techniques for the modelling of habitat suitability have been used since the 1970s, and since then have branched into a variety of different approaches (Guisan and Thuiller, 2005). There is no single model that is 'best' in all situations; typically a model is selected because it is thought to be the most appropriate for the type of data, or several competing models are tested against one another.

Crinoid (*Florometra serratissima*) and brisingid seastar on black coral, Davidson Seamount 1 950 m. (NOAA/MBARI)

The modelling technique used in this analysis is 'environmental niche factor analysis' (ENFA), developed by Hirzel et al. (2002). ENFA compares the observed distribution of a species, or group of species, to the background distribution of environmental factors (temperature and salinity, for example). In this way, it assesses how different the environmental niche a taxonomic group occupies is relative to the mean background environment (its 'marginality'), and how narrow this niche is (its 'specialization'). The model also reveals factors that can be important in determining the distribution of the studied organisms. ENFA can then use this information to predict habitat suitability for unsampled regions.

ENFA is ideal when there is reliable presence data, but no reliable absence data (Hirzel et al., 2001; Brotons et al., 2004), as is the case for coral data from seamounts. We know where scleractinians have been found, but even for those seamounts that have been sampled, we cannot infer true absence, since coral species may be living on an unsampled region of the same seamount or coral material has not been identified and sorted from samples. ENFA has been previously used in the marine environment to model coral distributions on the Canadian Atlantic continental shelf (Leverette and Metaxas, 2005). Further details of the model are given in Appendix II.

STONY CORAL DISTRIBUTION AND ENVIRONMENTAL DATA

The location of records of scleractinian corals on seamounts came from the database generated for the analysis of coral distribution (see Chapter 4). These data were then combined with physical, biological and chemical oceanographic data from a variety of sources, as outlined in Table 5.1 (full details in Appendix I). Data on large seamount locations were obtained from the data used for Chapter 2 (Kitchingman and Lai, 2004). The coral data and the seamount locations do not completely match, since some of the coral records come from small seamounts. Thus we cannot model habitat suitability for stony corals on seamounts directly. Instead, we use the coral data to model habitat suitability in various regions and depth zones of the global oceans, initially ignoring the locations of large seamounts. The habitat suitability maps can then be used in two ways: (i) to examine the habitat suitability for as yet unknown seamounts and other sea floor features within a particular region of the marine environment; and (ii) fitted to the summits of known/predicted seamounts. Habitat suitability for scleractinians on seamounts may be very different depending upon whether the corals are sited on the seamount summit or slope, as these are at different depths and potentially in different oceanographic regimes. Caution should therefore be used when interpreting habitat suitability fitted to seamount summits.

The ENFA model assumes that the data span the environmental range of actual scleractinian occurrence, i.e. that Scleractinia do not reside outside the environmental extremes that have been sampled; otherwise, the model will not predict areas of suitable habitat beyond these extremes. This appears to be a reasonable assumption in this instance. Nonetheless, we limited the model to 2 500 m in depth, as below 2 500 m data are more limited by sampling, and there is a marked change in the species composition of the scleractinians (Rogers et al., in press).

PREDICTED HABITAT SUITABILITY FOR STONY CORALS

The predicted habitat suitability for scleractinians found on seamounts is shown in Figures 5.1 to 5.6 in 250-500 m bands from 0 m to 2 500 m depth. The following assessment of these maps refers to the main FAO fishing areas (FAO, 2005) and to the areas beyond national jurisdiction given in the Reference Maps 1 and 2 on the back cover.

In near-surface waters, suitable seamount habitat lies in the southern North Atlantic (mostly FAO area 31), the South Atlantic (FAO area 41), much of the Pacific (especially FAO areas 77, 81and 87), and the southern Indian Ocean (FAO areas 51 and 57). The Southern Ocean and northern North Atlantic are, however, unsuitable. Habitat suitability patterns change substantially below this depth. In depths from 250 m to 750 m, a narrow band around 30ºN ± 10º and a broader band of suitable habitat occur around 40ºS ± 20º (areas 81 and 87 in the South Pacific, 41 and 47 in the South Atlantic, and 51 and 57 in the Indian Ocean). Below 750 m, the North Pacific and northern Indian Ocean become particularly unsuitable. The circum-global band of suitable habitat at around 40ºS narrows with depth (to ± 10º), breaking up into smaller suitable habitat areas around the southeast coast of South America and the tip of South Africa. Suitable habitat remains in parts of the Atlantic to 2 500 m depth (especially the North and tropical West Atlantic, most consistently in FAO areas 31 and 34, with FAO areas 21 and 27 becoming more prominent with depth). The global extent of habitat suitability for stony corals on seamounts was predicted to be at its maximum between 250 m and 750 m (Figure 5.2). The majority of the suitable habitat for stony corals occurs in areas beyond national jurisdiction. However, suitable habitats are also predicted in deeper waters under national jurisdiction, especially in the EEZs of countries (i) between 20ºS and 60ºS off South Africa, South America and the Australian/New Zealand region, (ii) off northwest Africa, and (iii) around 30ºN in the Caribbean.

The results of combining the predicted habitat suitability with the summit depth and location of large seamounts are shown in Figure 5.7. The majority of the large seamounts that could provide suitable habitat on their summits are located in the Atlantic Ocean (all Atlantic FAO areas – 21, 27, 31, 34, 41 and 47). The rest are mostly clustered in a band between 20ºS and 60ºS. A few seamounts elsewhere, such as in the South Pacific, have summits in the high suitability depth range between 0m and 250 m. In the Atlantic, a large proportion of suitable seamount summit habitat is beyond national jurisdiction, whereas in the Pacific it is mostly within EEZs. In the southern Indian Ocean, suitable habitat appears both within and outside of EEZs. When analysing the habitat suitability on the basis of summit depth, it should be

Primnoid coral with shrimp, Davidson Seamount, 1 570 m depth. (NOAA/MBARI)

Table 5.2: Variance explained by the first eight ecological factors in the ENFA model. Factor one explains the marginality, the remainder the specialization. The cumulative explained specialization of the first eight factors is 88.6 per cent.

Factor	1 (Marginality)	2	3	4	5	6	7	8
Explained specialization	*0.12*	*0.19*	*0.17*	*0.12*	*0.10*	*0.08*	*0.06*	*0.05*
Alkalinity	-0.30	0.04	0.22	0.07	0.13	0.23	0.23	0.35
Aragonite saturation state	0.34	0.07	0.06	0.83	0.12	0.00	0.14	0.12
Surface chlorophyll	0.25	0.02	0.13	0.05	0.01	0.00	0.03	0.30
Depth	-0.21	0.15	0.32	0.18	0.05	0.16	0.07	0.07
Dissolved O_2	0.22	0.66	0.11	0.08	0.41	0.48	0.68	0.35
Per cent O_2 saturation	0.27	0.61	0.22	0.41	0.74	0.70	0.46	0.40
Primary productivity	0.46	0.00	0.00	0.06	0.01	0.04	0.08	0.49
Export productivity	0.31	0.02	0.00	0.01	0.01	0.00	0.04	0.09
Salinity	0.24	0.05	0.03	0.13	0.04	0.03	0.16=	0.00
Total CO_2/DIC	-0.29	0.29	0.57	0.12	0.51	0.48	0.04	0.49
Temperature	0.35	0.29	0.49	0.11	0.01	0.09	0.46	0.40
Regional current velocity	-0.03	0.03	0.01	0.07	0.03	0.03	0.03	0.01

remembered that suitable habitat for stony corals might also occur on the slopes of seamounts, i.e. at depths greater than the summit.

WHAT ENVIRONMENTAL FACTORS ARE IMPORTANT IN DETERMINING STONY CORAL DISTRIBUTION?

Table 5.2 shows the importance of each environmental parameter in constraining the distribution of scleractinians on seamounts. The first column (Factor 1) is the marginality of the group, and the remaining factors its specialization (see Appendix II). The predicted value of the marginality is 0.918, which indicates that optimal habitat for scleractinians is quite different from the background mean values. This is true for almost all environmental variables except regional current velocity.

The remaining factors (2-8) show the parameters that are important in driving the observed distribution. The specialization value is 1.369, indicating that stony corals are highly specialized and occupy a relatively narrow environmental niche.

The environmental parameters that are most important in determining suitable habitat for seamount stony corals are dissolved oxygen and per cent oxygen saturation, total dissolved inorganic carbon and the aragonite saturation state. The comparison of Figures 5.8 with Figures 5.2 and 5.3 shows that high levels of aragonite saturation and dissolved oxygen correspond with suitable habitat for scleractinians. Similarly, high values of per cent oxygen saturation and low values of total dissolved inorganic carbon also correspond with suitable habitat. Interestingly, neither surface chlorophyll nor regional current velocities apparently are important in determining global scleractinian distributions on seamounts, although these may have an effect at a smaller spatial scale, such as an individual seamount. That is at a scale not captured by the size of the grid used within the model.

Temporal variability in the environmental factors is not captured by the model, and daily, seasonal and annual changes may all play a role in driving stony coral distributions. It is also worth noting that other important factors may not have been included in the model. For example, biological factors, such as competitive exclusion, are typically not captured by habitat suitability models. Those factors that are included in the model may not actually be responsible for driving the distribution of Scleractinia, but simply correlated with unknown factors. This could mean that even if a region is predicted as being highly suitable for scleractinians, it does not mean that these corals will actually be found there.

The result that dissolved oxygen availability is a major factor affecting habitat suitability for stony corals, and thus influences their distribution, is significant in a global oceanographic context. It means that oxygen minimum zones (Helly and Levin, 2004), which can be extensive in some parts of the worlds oceans, would not be very suitable habitat for these corals.

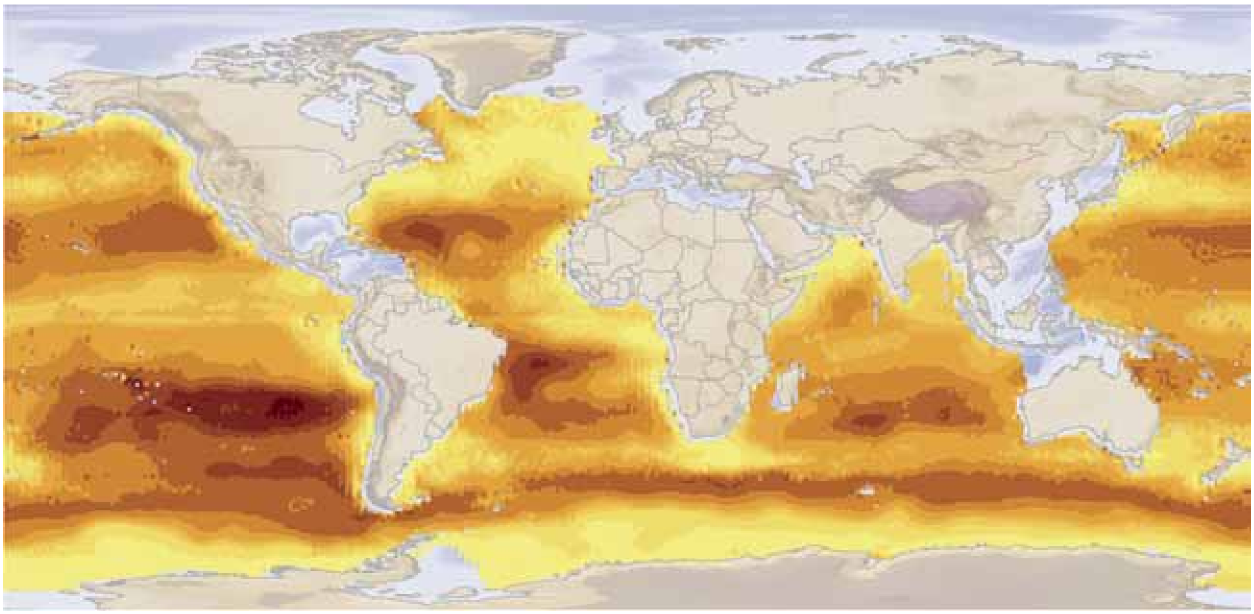


Figure 5.1: Predicted habitat suitability for seamount stony corals from 0-250 m depth.

Key

Habitat suitability %	Habitat suitability %
0-10	50-60
10-20	60-70
20-30	70-80
30-40	80-90
40-50	90-100

High percentage values indicate more suitable habitat.

Aragonite is a form of calcium carbonate that scleractinians use to form their hard skeletons. It has been speculated that stony corals will have their distribution limited by the level of aragonite saturation (Orr et al., 2005; Guinotte et al., 2006). In the oceans, carbon dioxide and carbonate ions react with each other to form bicarbonate (Royal Society, 2005). Increased amounts of aqueous CO_2 (e.g. from anthropogenic sources) cause a decrease in the availability of carbonate ions, which corals and other organisms use to build calcareous skeletons (Royal Society, 2005). Simultaneously, this decreases the pH of the ocean (makes it more acidic). Thus not only are there fewer resources available with which to produce coral skeletons, but they are also dissolved more quickly by the higher acidity (Orr et al., 2005). Thus, we would expect high levels of aragonite saturation to be suitable habitat, and this is indeed the case. Total dissolved inorganic carbon, however, is inversely correlated with aragonite saturation, so low levels provide suitable stony coral habitat.

The model output must be examined in an appropriate context, and the habitat suitability maps in this chapter can be considered as testable hypotheses. If additional sampling were to be carried out and found scleractinians on seamounts outside their current environmental envelope, then this would change the model predictions. The model may perform better in some regions than in others. Furthermore the distribution of deep-sea stony corals in non-seamount regions may be different from that on seamounts.

Previous chapters have built a picture of where seamounts are located, what lives on them – in particular corals – and where corals may be found beyond areas that have been sampled. The next step in the sequence is to look at what fish species occur on seamounts, and where fisheries for them have, or may, occur.

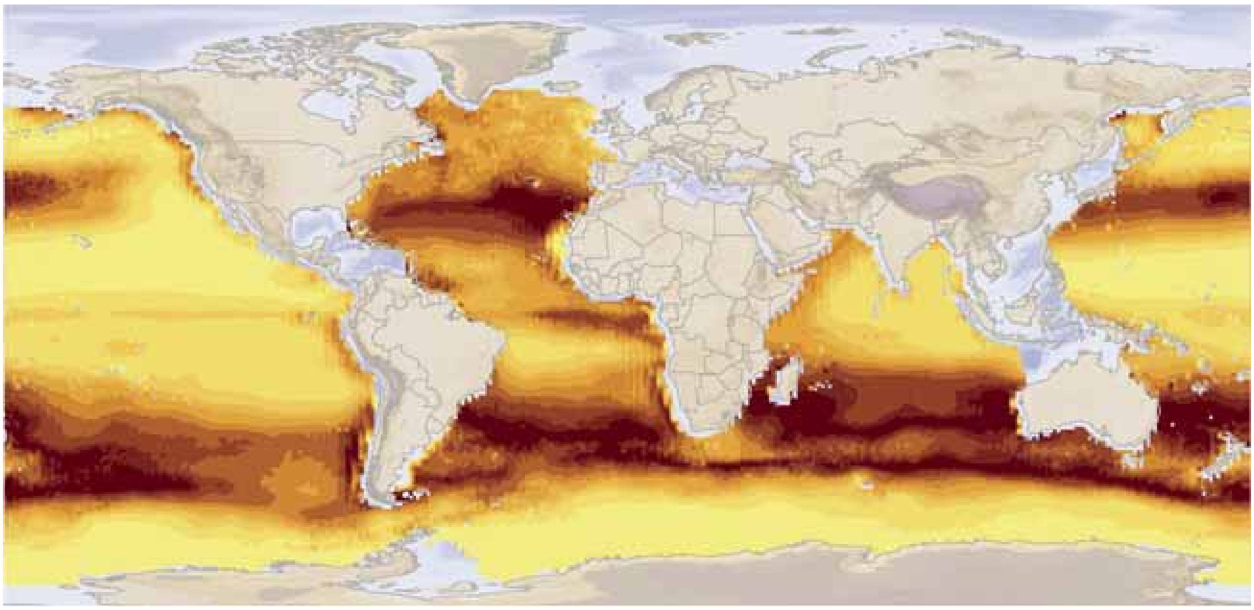


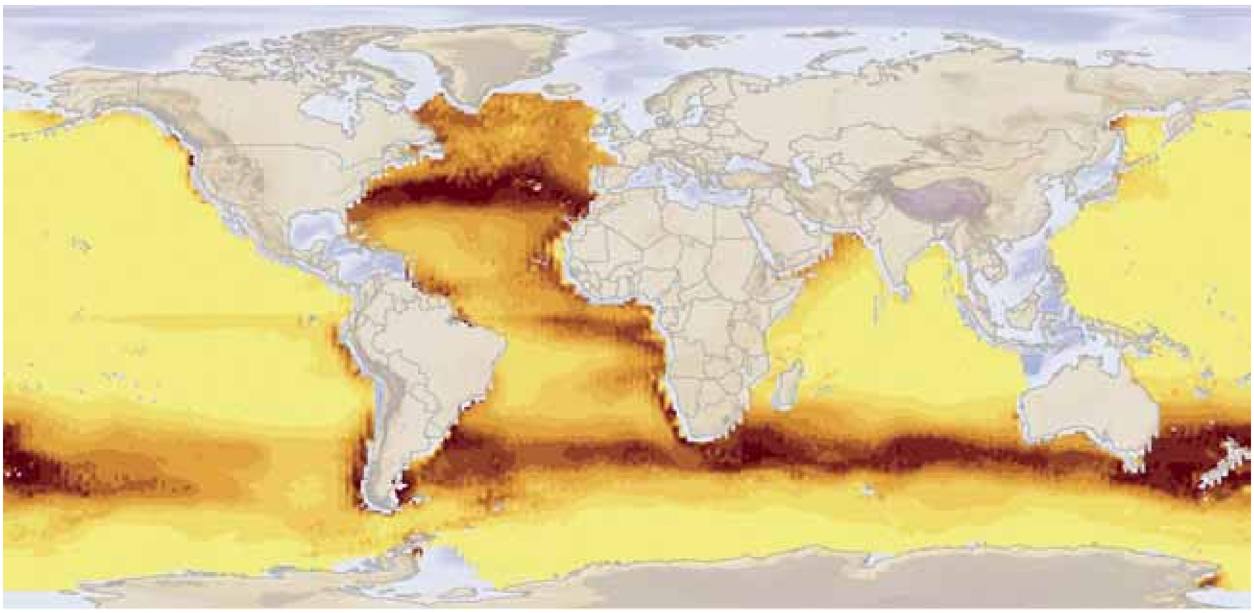
Figure 5.2: Predicted habitat suitability for seamount stony corals from 250-750 m depth.

Key (above and below)

Habitat suitability %	Habitat suitability %
0-10	50-60
10-20	60-70
20-30	70-80
30-40	80-90
40-50	90-100

High percentage values indicate more suitable habitat.

Figure 5.3: Predicted habitat suitability for seamount stony corals from 750-1 250 m depth.



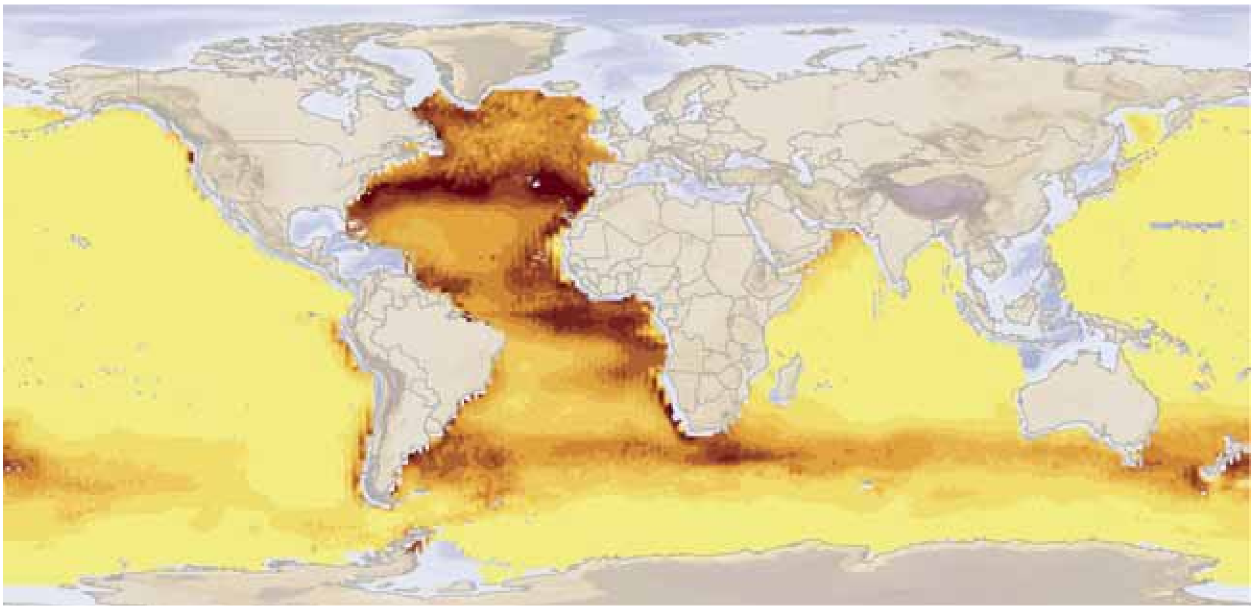


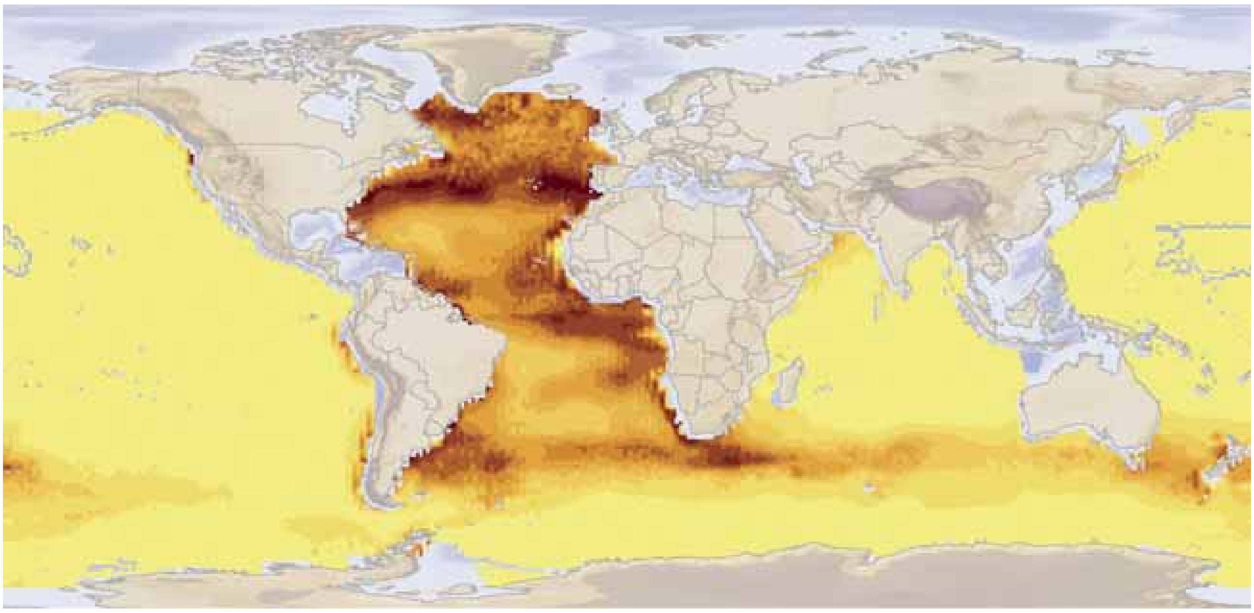
Figure 5.4: Predicted habitat suitability for seamount stony corals from 1 250-1 750 m depth.

Key (above and below)

	Habitat suitability %		Habitat suitability %
	0-10		50-60
	10-20		60-70
	20-30		70-80
	30-40		80-90
	40-50		90-100

High percentage values indicate more suitable habitat.

Figure 5.5: Predicted habitat suitability for seamount stony corals from 1 750-2 250 m depth.



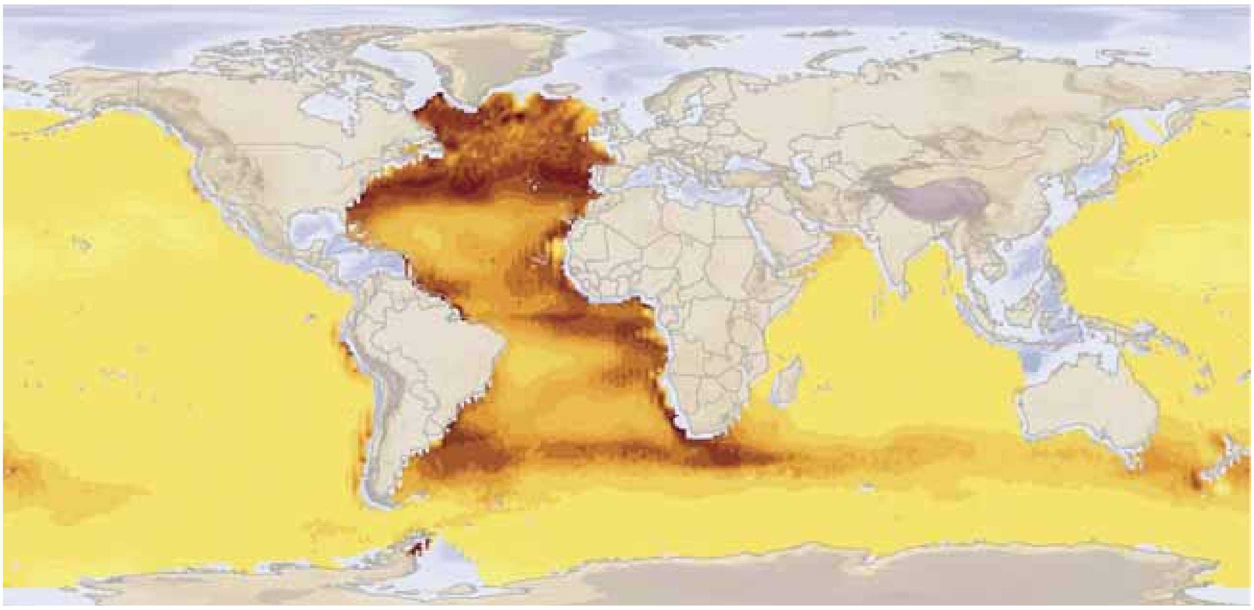


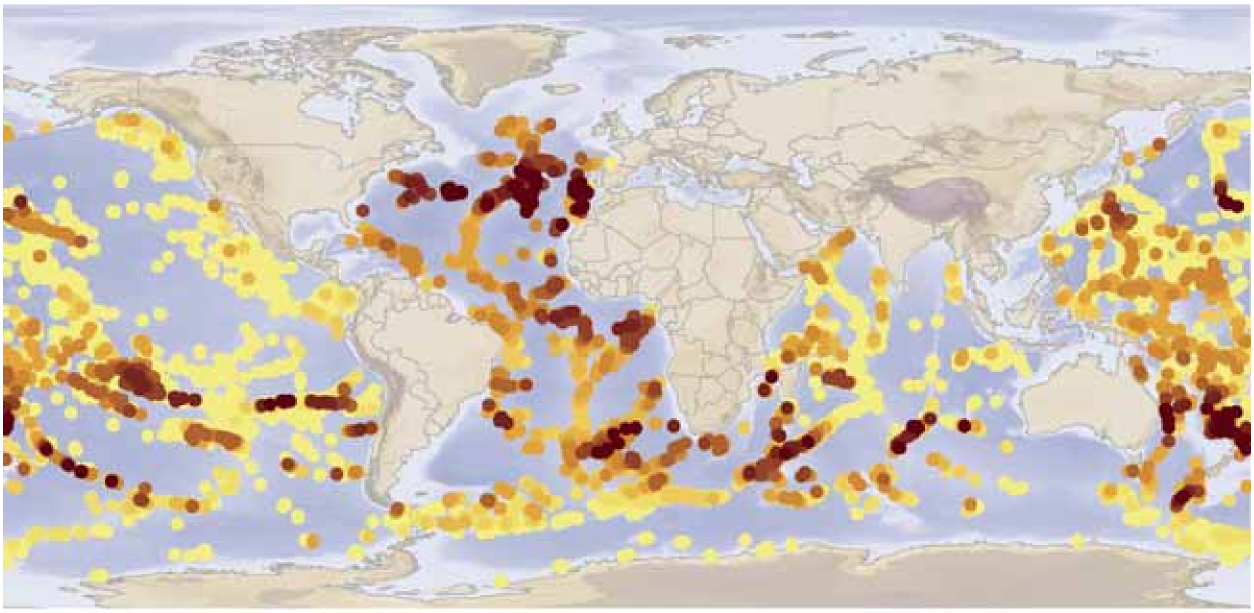
Figure 5.6: Predicted habitat suitability for seamount stony corals from 2 250-2 500 m depth.

Key (above and below)

Habitat suitability %	Habitat suitability %
0-10	50-60
10-20	60-70
20-30	70-80
30-40	80-90
40-50	90-100

High percentage values indicate more suitable habitat.

Figure 5.7: Predicted habitat suitability for stony corals on the summits of predicted large seamounts.



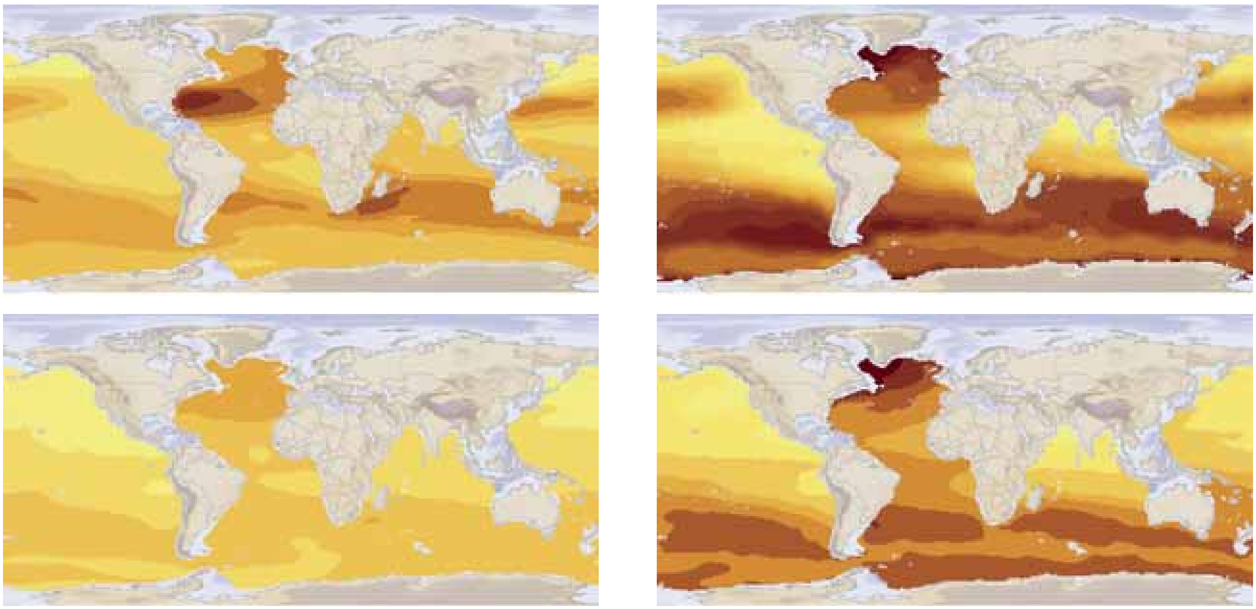


Figure 5.8: Aragonite saturation state (left panels) and dissolved oxygen (right panels). Top panels are at a depth of 500 m, lower panels at 1 000 m.

Key (left upper and lower)
Aragonite (µmol kg^{-1})

-50-25	50-75
-25-0	75-100
0-25	100-125
25-50	125-150

Key (right upper and lower)
Dissolved oxygen (ml l^{-1})

0-0.5	3.5-4.0
0.5-1.0	4.0-4.5
1.0-1.5	4.5-5.0
1.5-2.0	5.0-5.5
2.0-2.5	5.5-6.0
2.5-3.0	6.0-6,5
3.0-3.5	6.5-7.0

6. Seamount fish and fisheries

FISH BIODIVERSITY

Seamounts support a large number and wide diversity of fish species. Wilson and Kaufman (1987) were the first to review seamount biota worldwide and reported about 450 fishes collected from more than 60 seamounts. Rogers (1994) provided a list of 77 commercial species fished on seamounts. Since then, more detailed studies of certain seamounts and seamount chains have provided more comprehensive species lists. Froese and Sampang (2004) compiled a list of 535 fish species, which was augmented by Morato and Pauly (2004) to a total of 798 species. Most of these fish species are not exclusive to seamounts and occur widely on the continental shelf and slope habitat (Morato and Clark, in press). Fish communities around and on seamounts are therefore complex, being composed of pelagic species living in the surface water layers, mesopelagic species such as myctophids occurring in deeper water, and species living close to or on the seabed of the seamount itself (sometimes termed the seamount community; Commonwealth of Australia, 2002). It is known that different elements of these communities may share common prey species, although the trophic relationships between different groups of fish around seamounts are not well understood at present (e.g. Parin and Prut'ko, 1985; Commonwealth of Australia, 2002).

Seamounts can be an important habitat for commercially valuable species that may form dense aggregations for spawning or feeding (Clark, 2001; Roberts, 2002; ICES, 2005), and on which a number of large-scale fisheries have developed. Because many fisheries on seamounts target aggregations, catches can be relatively clean (i.e. they are composed of one or a few species). However, in other cases, the by-catch of seamount fisheries include a variety of other species that are often discarded (Roberts, 2002). Levels of by-catch can be such that non-target species of seamount can become depleted. For example, records over 10 years of the orange roughy fishery on the Chatham Rise showed that 13 out of 17 by-catch species recorded lower biomasses in 1994 compared to 1984. In some cases decreases in biomass were dramatic: for example, populations of Plunket's shark (*Centroscymnus plunketi*) decreased to 6 per cent of their virgin biomass (Clark et al., 2000). Depletion of sharks and rays either by targeted fishing or as by-catch from deep-sea fisheries is a major cause for concern (Lack et al., 2003; Royal Commission on Environmental Pollution, 2005; see also UN General Assembly, 2004b, Paragraphs 47 and 48).

***Bathysaurus mollis*, Davidson Seamount, 2 375 m depth; ambush predator.** (NOAA/MBARI)

DEEP-WATER FISHERIES DATA

Information on distribution and depth ranges of commercial fish species were obtained from global databases available on the Internet, namely FishBase (www.fishbase.org) and Ocean Biogeographic Information System (OBIS; www.iobis.org). Both sources have a number of distributional maps available, based on point locality information. Fish Base also offers facilities to map a projected distribution; however, location data for areas outside of national jurisdiction are often missing, and the maps overestimate the potential distribution for some species. Both types of distributional data were examined, and a subjective assessment was applied based on expertise and experience of one of the contributors to this report (M Clark) to define the likely distribution of the fish species in areas outside of national jurisdiction.

The only international source of global fisheries catch data is that compiled by the FAO. While FAO statistics do not make a distinction between EEZs and areas beyond national jurisdiction, and reporting areas are very large, data available from the FAO provides a useful input for assessing the deep-water catch by species in areas outside of national

Chimaerid, probably *Chimaera monstrosa,* Hatton Bank, Northeast Atlantic. By-catch of this group of fish species is a major concern related to deep-sea fisheries. (DTi SEA Programme, c/o Bhavani Narayanaswamy)

jurisdiction in various parts of the world where seamounts are important fishing grounds. Clark et al. (in press) have used FAO data, together with fisheries statistics and data of Soviet, Russian and Ukrainian scientific research and exploratory cruises, and published reports for some seamount fisheries conducted by Japan, New Zealand, Australia, Spain, other EU countries and Namibia. Personal contacts and data extracted by Clark et al. (in press) were used in some cases to provide 'guesstimates' of likely species composition and catch for some seamount regions. The report by Gianni (2004) on high seas (areas outside of national jurisdiction) fishing in general was examined for some areas where much of the high seas catch was thought to be from seamounts.

The catch figures given in this chapter are known to be incomplete. Some countries' data were not available, there is known to have been misreporting or non-reporting of catches from areas outside of national jurisdiction in the past (e.g. Lack et al., 2003). In addition, many catch statistics (e.g. FAO records; catches from ICES sub-areas) are on a scale that does not allow the approximate location to be determined, let alone assign the catch to a particular seamount. The effect of this variable quality is that some fishing may have occurred outside areas of national jurisdiction, or that effort and catch levels in some areas could be much higher. However, the compilation is the most comprehensive attempted to date for seamount fisheries, and is believed to give a reasonable indication of the general distribution of seamount catch over the last four decades.

GLOBAL DISTRIBUTION OF DEEP-WATER FISHES

Current deep-water trawl fisheries occur in areas beyond national jurisdiction for a number of species. These include alfonsino (*Beryx splendens*); black cardinalfish (*Epigonus telescopus*); orange roughy (*Hoplostethus atlanticus*); boarfish (*Pseudopentaceros richardsoni*); macrourid rattails (primarily roundnose grenadier *Coryphaenoides rupestris*); oreos (several species of the family Oreosomatidae, including smooth oreo (*Pseudocyttus maculatus*), black oreo (*Allocyttus niger*), warty oreo (*Allocyttus verrucosus*) and spiky oreo (*Neocyttus rhomboidalis*). Many of these fisheries use bottom-trawl gear. Other fisheries occur over seamounts, such as those for pelagic species (mainly tunas) and target species for smaller-scale line fisheries (e.g. black scabbardfish *Aphanopus carbo*) (FAO 2004).

The depth distribution of these fish species is given in Table 6.1. Many species cover a very wide depth range, which can vary with the life history stage of the species (e.g. juveniles are often found in shallower depths than adults). Typically, the depth range in which fishing takes place is smaller than the actual range of the species, as fishers target depths where the adult fish often aggregate for spawning or feeding. The depth distribution of most species differs in various parts of the world, as water masses vary. For example, orange roughy typically occurs on seamounts at depths of 800-1 000 m in the Southwest Pacific and southern Indian Ocean, 500-800 m in the South Atlantic, and at greater than 1 000 m in the North Atlantic.

The geographical distribution of the main commercial

Table 6.1: Depth distribution of commercial fish species on seamounts

Species (common name)	Code	Scientific name	Main depth range (m) *	Total depth range (m) *
Alfonsino	BYX	*Beryx splendens*	300-600	25-1 300
Cardinalfish	EPT	*Epigonus telescopus*	500-800	75-1 200
Rubyfish	RBY	*Plagiogenion rubiginosum*	250-450	50-600
Blue ling	LIN	*Molva dypterygia*	250-500	150-1 000
Black scabbardfish	SCB	*Aphanopus carbo*	600-800	200-1 700
Sablefish	SAB	*Anoplopoma fimbria*	500-1 000	300-2 700
Pink maomao	MAO	*Caprodon* spp.	300-450	To 500
Southern boarfish	LBO	*Pseudopentaceros richardsoni*	600-900	To 1 000
Pelagic armourhead	ARM	*Pseudopentaceros wheeleri*	250-600	To 800
Orange roughy	ORH	*Hoplostethus atlanticus*	600-1 200	180-1 800
Oreos	OEO (BOE, SSO)	*Pseudocyttus maculatus, Allocyttus niger*	600-1 200	400-1 500
Bluenose	BNS	*Hyperoglyphe antarctica*	300-700	40-1 500
Redfish	RED	*Sebastes spp. (S. marinus, S. mentella, S. proriger)*	400-800	100-1 000
Roundnose grenadier	RNG	*Coryphaenoides rupestris*	800-1 000	180-2 200
Toothfish	PTO	*Dissostichus* spp.	500-1 500	50-3 850
Notothenid cods	NOT	*Notothenia* spp.	200-600	100-900

** Main depth range refers to the commercial fishing depths; total depth range refers to the full known depth range of adult fish (from FishBase).*

fish species in the world's oceans is summarized in Table 6.2. Many have a widespread occurrence, especially through the Atlantic Ocean, Indian Ocean and South Pacific Ocean. A number of southern hemisphere species are found in the North Atlantic, but do not extend into the North Pacific (e.g. orange roughy, oreos). Some species are more localized to the North Atlantic (e.g. roundnose grenadier, blue ling, and redfishes *Sebastes mentella* and *S. marinus*), and sablefish (*Anoplopoma fimbria*) occur only in the North Pacific. Hence, depending on the target fish species, certain geographic

Table 6.2: Geographical distribution of commercial fish species (+ indicates occurrence in that ocean)

Species (common name)	North Atlantic	South Atlantic	North Pacific	South Pacific	Indian Ocean	Southern Ocean
Alfonsino	+	+	+	+	+	
Cardinalfish	+	+		+	+	
Rubyfish		+		+	+	
Blue ling	+					
Black scabbardfish	+	+	+			
Sablefish			+			
Pink maomao			+	+		
Southern boarfish		+	+	+	+	
Pelagic armourhead		+	+	+	+	
Orange roughy	+	+		+	+	
Oreos		+		+	+	+
Bluenose		+		+	+	
Redfish	+		+			
Roundnose grenadier	+					
Toothfish		+		+	+	+
Notothenid cods		+		+	+	+

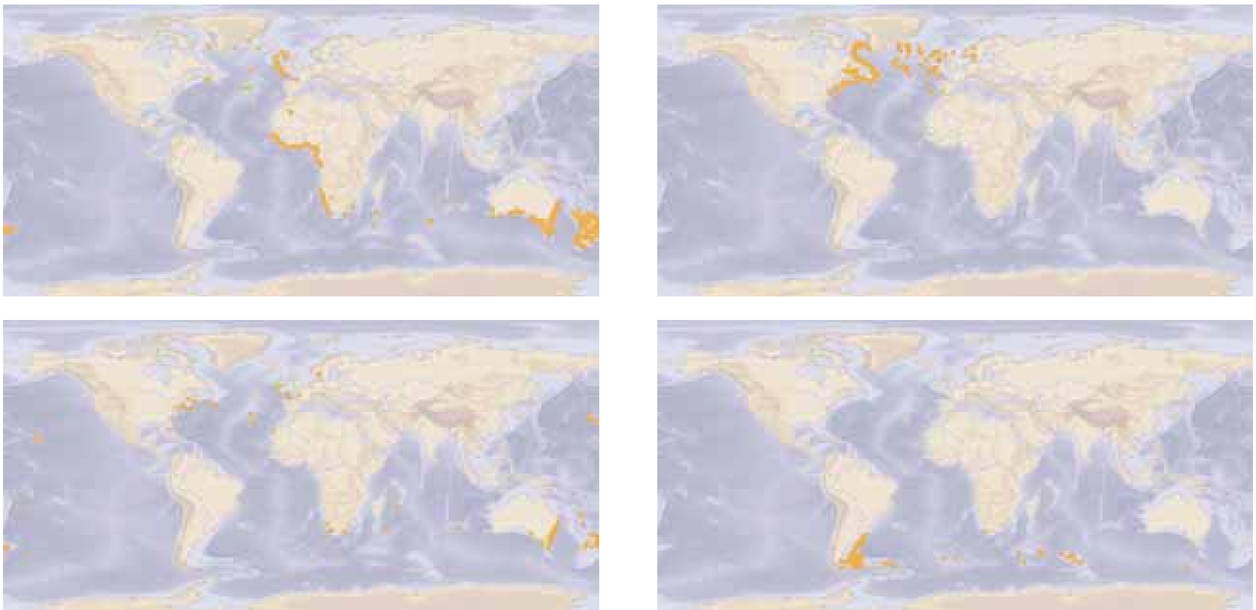


Figure 6.1: Distribution of (clockwise from top left) orange roughy, roundnose grenadier, Patagonian toothfish and alfonsino. *Source: OBIS and FishBase databases*

areas, including parts of areas beyond national jurisdiction, are more likely to be searched by fishing vessels than others.

Distributions of four of the most important (for either their abundance or commercial value) seamount fish species are shown in Figures 6.1 and 6.2. The first shows recorded location data taken from OBIS (which is linked to FishBase), whereas the second shows the distributions modelled and generated with the Aquamap function within FishBase. Location data for areas outside of national jurisdiction are poor, because research vessels work mainly in national waters. The modelled distribution of some of the species is uncertain. The overall distribution and relative densities predicted are based on limited distributional and environmental data. In some cases they are known to be too extensive. However, they do serve as an approximate guide to the likely distribution when viewed together with the actual location data. Orange roughy is widely distributed throughout the North and South Atlantic Oceans (FAO areas 27, 47), the mid-southern Indian Ocean (FAO areas 51, 57) and the South Pacific (FAO areas 81, 87). The species does not extend into the North Pacific, and is unlikely to occur in the northern parts of the Indian Ocean (although the modelling does suggest the latter; cf. Figure 6.2). It is frequently associated with seamounts for spawning or feeding, although it is also widespread over the general continental slope. Alfonsino has a global distribution, being found in all the major oceans. It is a shallower species than orange roughy, occurring mainly at depths of 400 m to 600 m. It is associated with seamount and bank habitat. Roundnose grenadier is restricted to the North Atlantic (FAO areas 21, 27). It occurs on both sides of the North Atlantic, as well as on the Mid-Atlantic Ridge, where aggregations occur over peaks of the ridge. Patagonian toothfish (*Dissostichus eleginoides*) – and in some areas Antarctic toothfish (*Dissostichus mawsoni*) – have a restricted southern distribution (FAO areas 48, 58, 88). Having a very wide depth range, the species is sometimes associated with seamounts, but also general slope and large bank features (Rogers et al., 2006).

GLOBAL DISTRIBUTION OF MAJOR SEAMOUNT TRAWL FISHERIES

The intensive search for fisheries resources on seamounts around the world's oceans was initiated by the former Soviet Union, and soon after by Japan, in the late 1960s and 1970s (Rogers, 1994). Seamounts with concentrations of fish and invertebrates were found initially in the Pacific Ocean but later in other parts of the Atlantic and Indian Oceans, and offshore seamounts became established as important habitat for global fisheries (Figure 6.3). In subsequent decades other countries such as Korea, and later China, Cuba, Australia and New Zealand, and countries in the European Union and southern Africa, also developed fisheries on seamounts. Table 6.3 shows that in total, the international catch of demersal fishes on seamounts by distant-water fishing/trawling fleets is estimated to be about 2 million tonnes of fish since the 1960s (derived from data in Clark et al., in press).

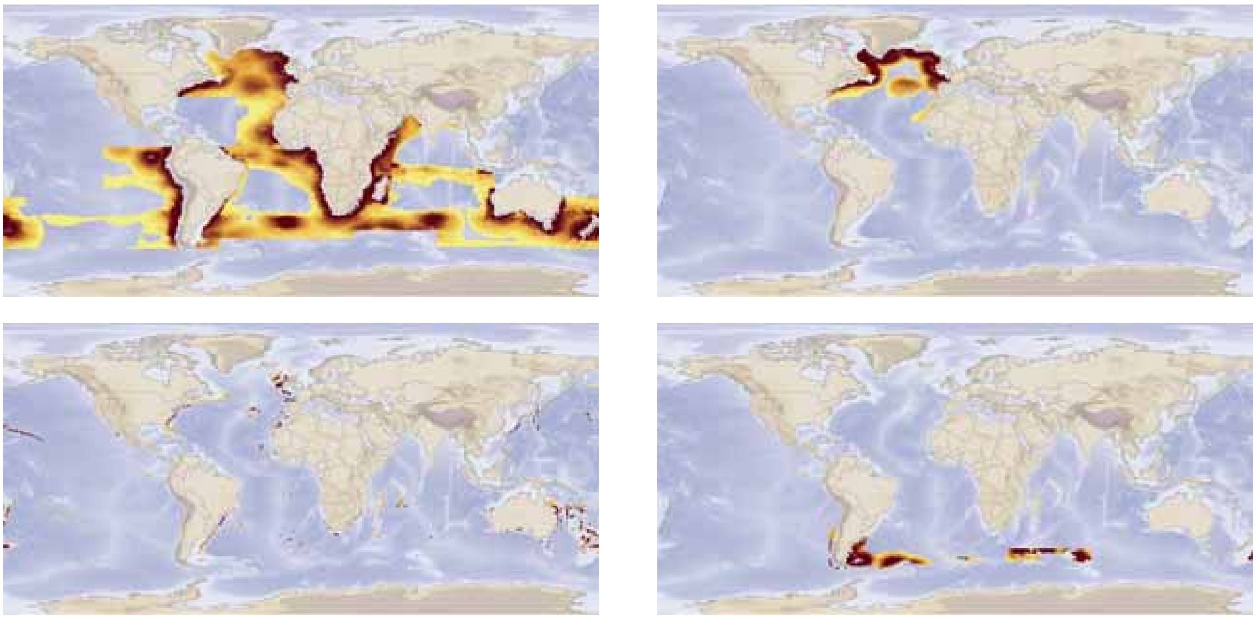


Figure 6.2: Predicted distribution of (clockwise from top left) orange roughy, roundnose grenadier, Patagonian toothfish and alfonsino. High probability of occurrence values indicate more suitable habitat.

Key **(all above)**

Habitat suitability	Habitat suitability
0-0.1	0.5-0.6
0.1-0.2	0.6-0.7
0.2-0.3	0.7-0.8
0.3-0.4	0.8-0.9
0.4-0.5	0.9-1.0

The largest seamount trawl fisheries have occurred in the Pacific Ocean. In the 1960s to 1980s large-scale fisheries for pelagic armourhead and alfonsino occurred on the Hawaiian and Emperor seamount chains in the North Pacific (FAO area 77) (Figure 6.3). In total about 800 000 tonnes of pelagic armourhead were taken, and about 80 000 tonnes of alfonsino. In the southwestern Pacific (FAO areas 81, eastern part of 57), fisheries for orange roughy, oreos and alfonsino have been large, and continue to be locally important. Orange roughy has also been the target of fisheries on seamounts on the Reykjanes Mid-Atlantic Ridge in the North Atlantic, off the west coast of southern Africa, and in the southwestern Indian Ocean. Roundnose grenadier was an important fishery for the Soviet Union in the North Atlantic (FAO area 27), where catches have been over 200 000 tonnes. Smaller fisheries for alfonsino, mackerel and cardinalfish have occurred on various seamounts in the mid-Atlantic and off the coast of North Africa. In the Southern Ocean, fisheries for toothfish, notothenioids and icefish can occur on seamounts as well as slope and bank areas. Most of these seamounts are fished with bottom trawl, but several are also subject to mid-water trawl and long-line fisheries. In most cases it has not been possible to distinguish between bottom trawl and mid-water trawl.

Many of these fisheries are historical. Most of these fisheries have not been sustainably managed, with many examples of 'boom and bust' fisheries, which developed and declined rapidly, sometimes within a few years or a decade (e.g. Uchida and Tagami, 1984; Koslow et al., 2000; Clark, 2001; Lack et al., 2003). A prime example of this, in areas beyond national jurisdiction, is the recent fishery in the Southwest Indian Ocean, which collapsed after only four years in the late 1990s (FAO, 2002; Lack et al., 2003). Recovery of shallow-water fish stocks that have been collapsed or severely depleted have rarely taken place after 15 years (Royal Commission on Environmental Pollution, 2004). The life history characteristics of many deep-water fish species are more conservative than shallow water species (e.g. slow growth rate, low rates of natural mortality in adult fish, late age of sexual maturity, sporadic reproduction, high longevity; Rogers, 1994; Koslow et al., 2000; Lack et al., 2003). This makes the rebuilding and recolonization of previously fished seamounts extremely slow, and many have shown no signs of recovery to date (Tracey and Horn, 1999; Cailliet et al., 2001; Lack et al., 2003).

AREAS OF EXPLORATORY FISHING IN AREAS BEYOND NATIONAL JURISDICTION

Offshore seamount fisheries in international waters generally require large freezer trawlers. Such fleets need to

Table 6.3: Total estimated historic catch of main commercial fish species from seamounts, major fishing periods, and main gear types used in the seamount fisheries

Species	Total historical catch (t)	Main fishery years	Gear type
Alfonsino	166 950	1978-present	Bottom and mid-water trawl, some long-line
Cardinalfish	52 100	1978-present	Bottom (and mid-water trawl)
Rubyfish	1 500	1995-present	Bottom and mid-water trawl
Blue ling	10 000	1979-1980	Bottom trawl
Black scabbard fish	75 000	1973-2002	Bottom and mid-water trawl
Sablefish	1 400	1995-present	(Bottom trawl), line
Pink maomao	2 000	1972-1976	Bottom and mid-water trawl
Southern boarfish	9 600	1982-present	Bottom trawl
Pelagic armourhead	800 000	1968-1982	Bottom and mid-water trawl
Orange roughy	419 100	1978-present	Bottom trawl
Oreos	145 150	1970-present	Bottom trawl
Bluenose	2 500	1990-present	Bottom and mid-water trawl
Redfish	54 450	1996-present	Bottom and mid-water trawl
Roundnose grenadier	217 000	1974-present	Bottom and mid-water trawl
Toothfish	12 250	1990-present	Bottom trawl, long-line
Notothenid cods	36 250	1974-1991	Bottom trawl
Mackerel species	148 200	1970-1995	(Bottom) and mid-water trawl
Total	**2 153 470**		

Source: Clark et al. (in press)

target aggregations of high-value species in order to operate economically. For this reason we have presented distribution maps of orange roughy, toothfish and alfonsino, which are all relatively valuable species. Roundnose grenadier is of lesser value, but can occur in large quantities, and the North Atlantic region, where this species is most commonly found, is readily accessible to trawlers compared with the southern hemisphere oceans.

Over the last decade, exploratory fishing for deep-water species in many areas beyond national jurisdiction has focused on alfonsino and orange roughy on seamounts. Toothfish have also been targeted, although this species occurs in areas under the management of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), and illegal, unreported and unregulated (IUU) fishing in waters of the Southern Ocean is the focus of major international preventative measures. Hence, we do not cover this species here. The two fisheries for alfonsino and orange roughy are, to an extent, discrete in that they operate at different depths on seamounts.

Alfonsino fisheries: approximately 250-750 m. Commercially valuable by-catch species include black cardinalfish, southern boarfish, bluenose.

Orange roughy fisheries: approximately 750-1 250 m. Commercially valuable by-catch species include various oreos (black, smooth and sometimes spiky).

This depth difference, although not clear-cut, can help when trying to evaluate seamounts that could be of commercial interest. Seamounts with a summit shallower than the species distribution may still have that species present down its slopes, i.e. at greater depth than the summit. Hence seamounts with summits shallower than 750 m can have orange roughy at 750 m and deeper down their flanks. However, although caution needs to be exercised, summit depth is a useful parameter to examine against the distribution of seamounts in areas beyond national jurisdiction. The distribution of large ones with summit depths in the two depth ranges are shown in Figures 6.4 and 6.5.

At alfonsino depths (250-750 m), there are seamount chains in the central and eastern Pacific that are beyond areas of national jurisdiction, near the Challenger Fracture Zone and along the Sala y Gomez Ridge respectively (FAO area 87). Further areas with fishable seamounts are at the southwestern end of the Walvis Ridge and in the Gulf of Guinea (FAO area 47) in the South Atlantic; in the Indian

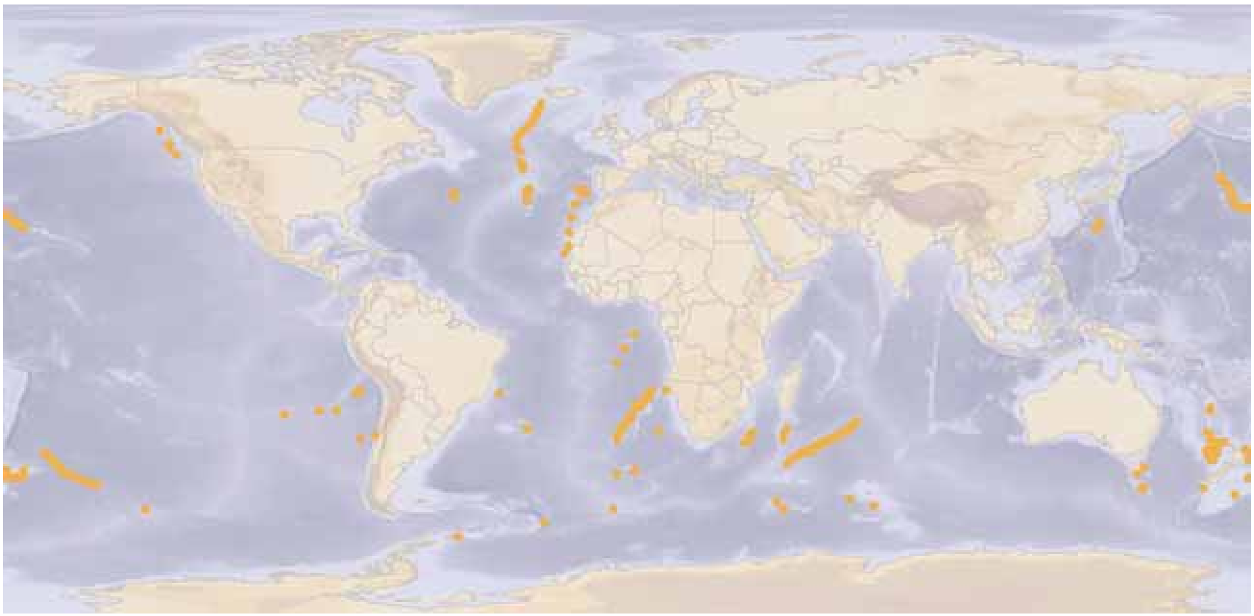
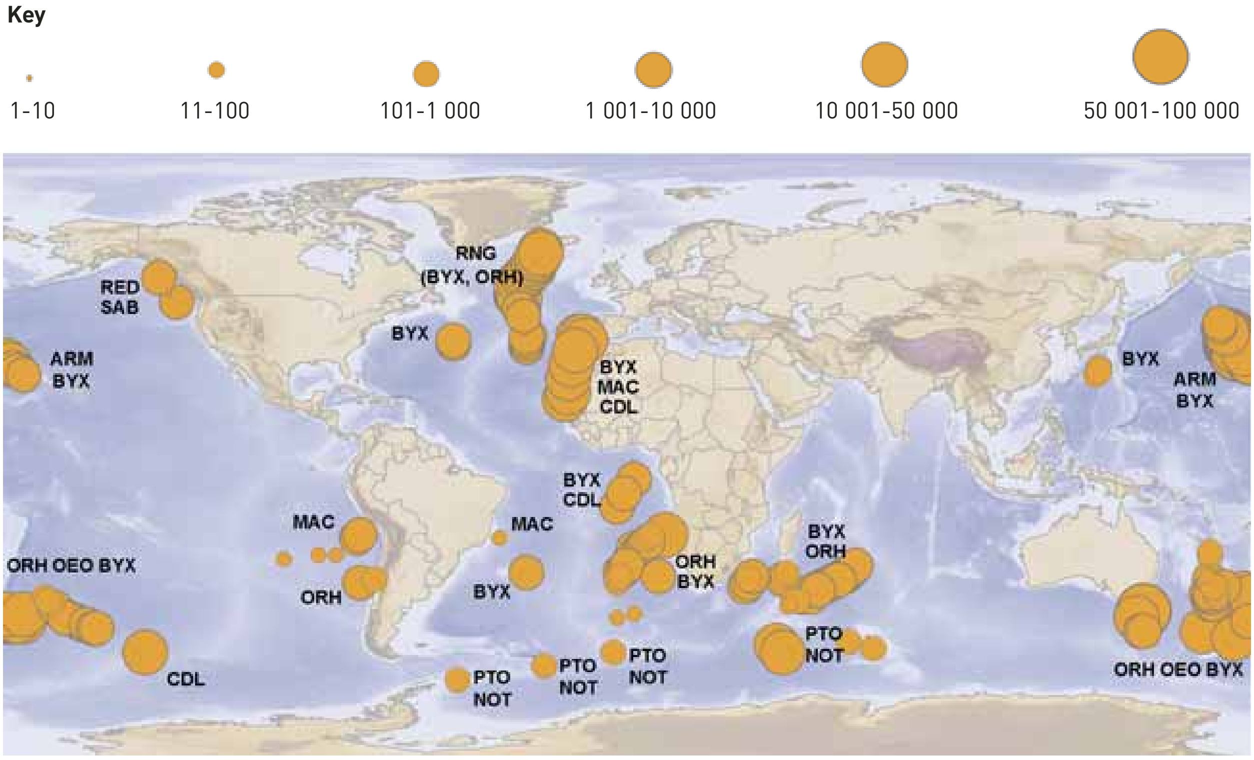


Figure 6.3: Distribution (top panel) and relative size (bottom panel) of major historical seamount fisheries. Circle size in the bottom panel is proportional to the total catch for that one-degree grid square, maximum is 85 000 tonnes. See Table 6.1 for codes to the fish species.



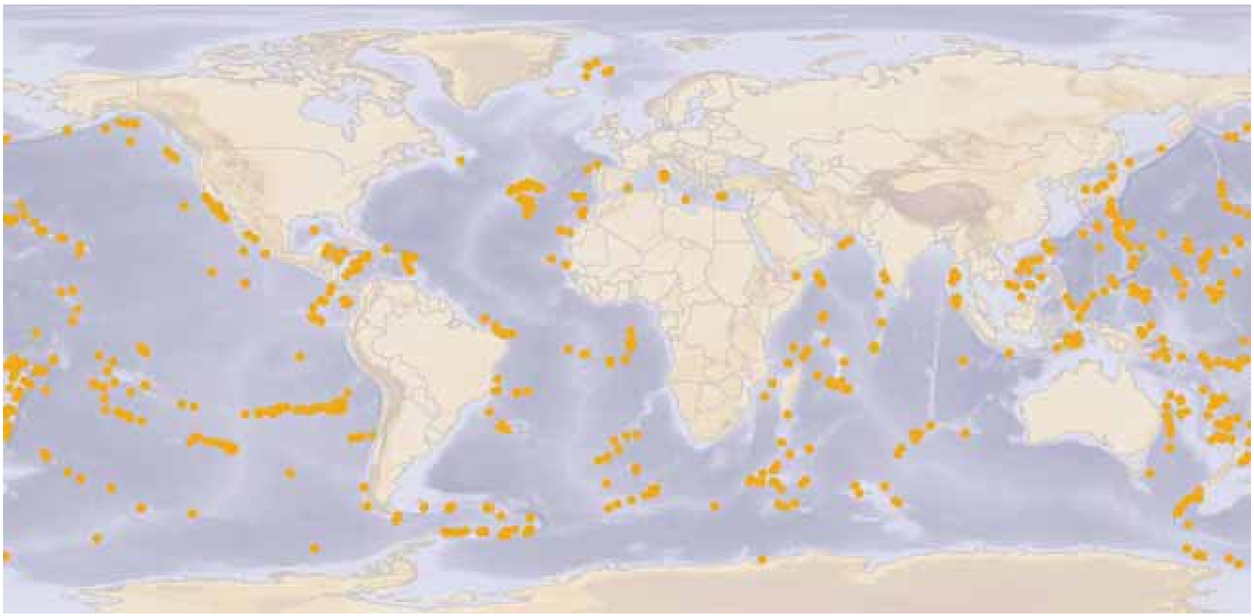


Figure 6.4: Location of predicted large seamounts with summit depths between 250 m and 750 m, the main depth range for alfonsino fisheries.

Ocean along the Southwest Indian Ocean Ridge (FAO area 51) and near the Ninety East Ridge (FAO area 57); along the Emperor Seamount chain (FAO area 77) in the North Pacific; and south of the Azores in the North Atlantic (FAO areas 27, 34). Most of these areas are thought to have been explored, or commercially exploited, already.

At orange roughy depths (750-1 200 m), there are seamounts in the South Pacific Ocean, along the Louisville Ridge (FAO area 81), and further east near the Challenger Fracture Zone and Sala y Gomez Ridge (FAO area 87). The Walvis Ridge, Atlantic-Indian Ridge, and southern end of the Mid-Atlantic Ridge (all FAO area 47) also have seamounts at appropriate depths. In the Indian Ocean, areas of the South-west Indian Ridge, Ninety East Ridge, and Broken Ridge (FAO areas 51, 57) are also at orange roughy depths, but towards the northern limit of the species distribution. In the North Atlantic, there are features along the Mid-Atlantic Ridge from about 30°N northwards. Seamounts further south into the northern South Atlantic are getting outside the geographical distribution of orange roughy.

It is difficult to determine which areas outside national jurisdiction have been extensively explored. The data sources used by Clark et al. (in press) are known to be incomplete, and FAO catch reporting is on a spatial scale that does not allow individual seamounts, clusters or chains to be identified. Clark et al. (in press) have determined that some of the areas of potential seamount fisheries have been searched in the late 1980s to 1990s and early 2000s. Where large-scale fisheries have not developed, it may be a sign that commercial concentrations of target species are not there. Alternatively, rough patches of sea floor are common on seamounts, and bottom trawling may have been unsuccessful due to gear damage or the bottom being too rough to even attempt trawling. Modern deep-water trawls have large bobbin or rock-hopper ground gear, and together with advances in navigational and electronic fishing aids since the 1980s, these have made trawling on rough seamounts much more feasible than 20 years ago (Roberts, 2002; Lack et al., 2003). Small seamounts and trawlable paths can routinely be located and fished. Nevertheless, there are still some limitations on fishers' ability to bottom trawl on seamounts. When clusters of seamounts occur,

***Spectrunculus grandis*, Davidson Seamount, 2 677 m depth, 60 cm long.** (NOAA/MBARI)

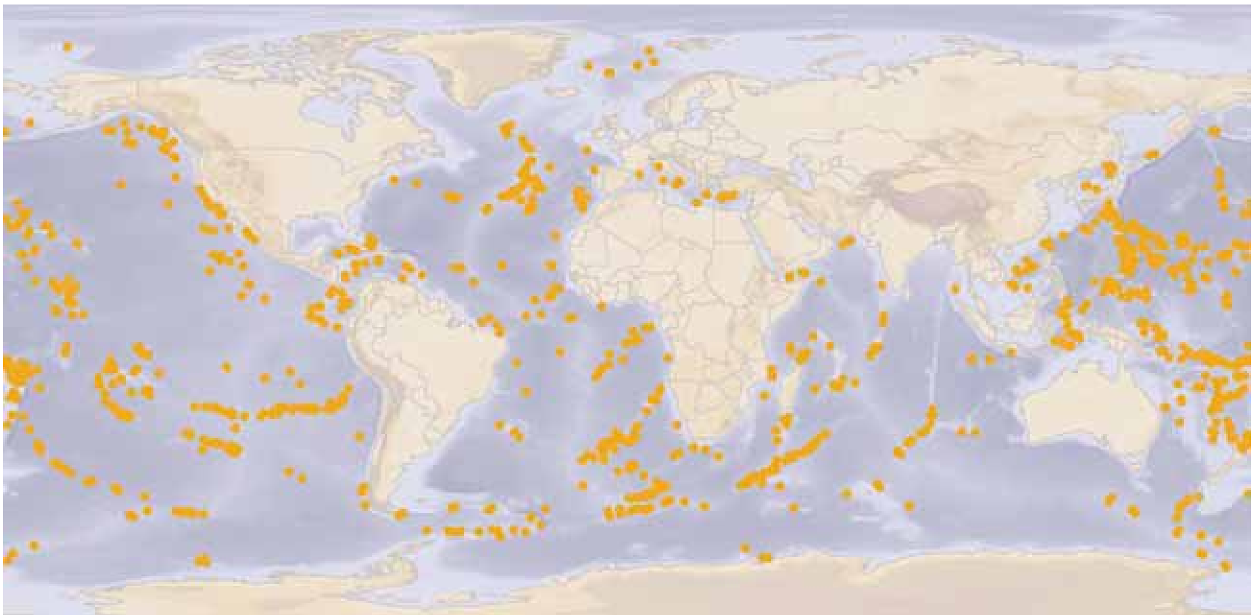


Fig 6.5: Location of predicted large seamounts with summit depths between 750 m and 1 200 m, the main depth range for orange roughy fisheries.

fish may not be distributed evenly between them, or may only be evident at certain times of the day or year, and so intensive trawling may be required to locate commercial quantities. Operating costs of large offshore vessels are relatively high, and if there are no signs of fish, the vessel may move on rather than continue to explore a small area. Therefore, even where fishing has occurred, there may be potential for small stocks of deep-water species to exist, and to support future exploratory fishing operations.

The depth and geographical distribution of the alfonsino and orange roughy trawl fisheries overlap with the predicted distribution of large seamounts and deep-sea coral distribution. The next chapter will discuss the results of the previous chapters, and bring various sources of information together to evaluate the vulnerability of seamount benthic communities to deep-water fishing activities.

7. Assessing the vulnerability of stony corals on seamounts

RATIONALE

Corals are a prominent component of the seamount fauna, which can be highly diverse and abundant, and may be associated with many species new to science. Deep-sea corals can form complex biological structures on the seabed and thus provide crucial habitat for a diversity of associated invertebrates and fish. Up to 100 000 large seamounts may exist in the world's oceans, but the fauna of only a small fraction has been documented.

Commercial fishing has targeted numerous fish species on seamounts, and there is mounting concern over the damage that deep-sea trawling can cause to the benthic communities that live on them. The biology and life histories of deep-sea corals make them highly vulnerable to bottom trawling. Their destruction can potentially have knock-on effects for seamount ecosystems.

Many seamounts are located in areas beyond national jurisdiction, and are increasingly targeted by commercial fishing activities taking place on the high seas. In the light of concern about the impacts and ecological ramifications of fishing on seamount habitats and the biological communities in these areas, countries and some stakeholders called on intergovernmental bodies to discuss and develop appropriate multilateral action on a regional and/or global scale.

The United Nations General Assembly (UNGA) has repeatedly addressed the issue (UN General Assembly, 2003, 2004a, 2004b, 2005a, 2005b, 2006). In the resolutions on 'oceans and the law of the sea' and 'sustainable fisheries', the UNGA has called upon States and international organizations to urgently take action to address destructive practices that have adverse impacts on marine biodiversity and vulnerable ecosystems, and to consider the interim prohibition of such destructive fishing practices. Common to all of these calls was (i) the need to take action on a scientific basis, and (ii) the specific mentioning of seamounts and cold-water corals as examples of vulnerable marine biodiversity and ecosystems.

Protection of marine biodiversity in coastal areas within EEZs and particularly on the high seas has been weak (e.g. Royal Commission on Environmental Pollution, 2004), and only 0.5 per cent of the world's marine environment is currently protected (Kimball, 2005). However, there are general obligations in the 1982 United Nations Convention on the Law of the Sea (UNCLOS) to protect and preserve the marine environment and to conserve and manage high seas living resources (Kimball, 2005). These obligations apply both within and beyond waters of national jurisdiction. The enforcement of international legal regimes on vessels is the responsibility of flag states. Obligations under UNCLOS are also implemented through regional agreements and, in the case of fisheries, through Regional Fisheries Management Organizations (RFMOs). UNCLOS (Kimball, 2005), regional agreements (e.g. OSPAR; see Johnston, 2004) and RFMOs have all emphasized the requirement to base conservation measures on the best scientific information available. This may be justified because of the risk of displacing harmful activities, such as deep-sea trawling, to as yet unexplored but potentially more sensitive habitats if decisions are made without sufficient scientific information (ICES, 2006). However, lack of scientific data should not be used as an excuse for inactivity and should also be balanced by the application of the precautionary principal through ecosystem-based management practices (Vierros et al., 2006; WWF, 2006).

A trawled seamount off Tasmania. (T Koslow, CSIRO Marine and Atmospheric Research)

The ecological importance of corals on seamounts has been clearly demonstrated through a growing body of

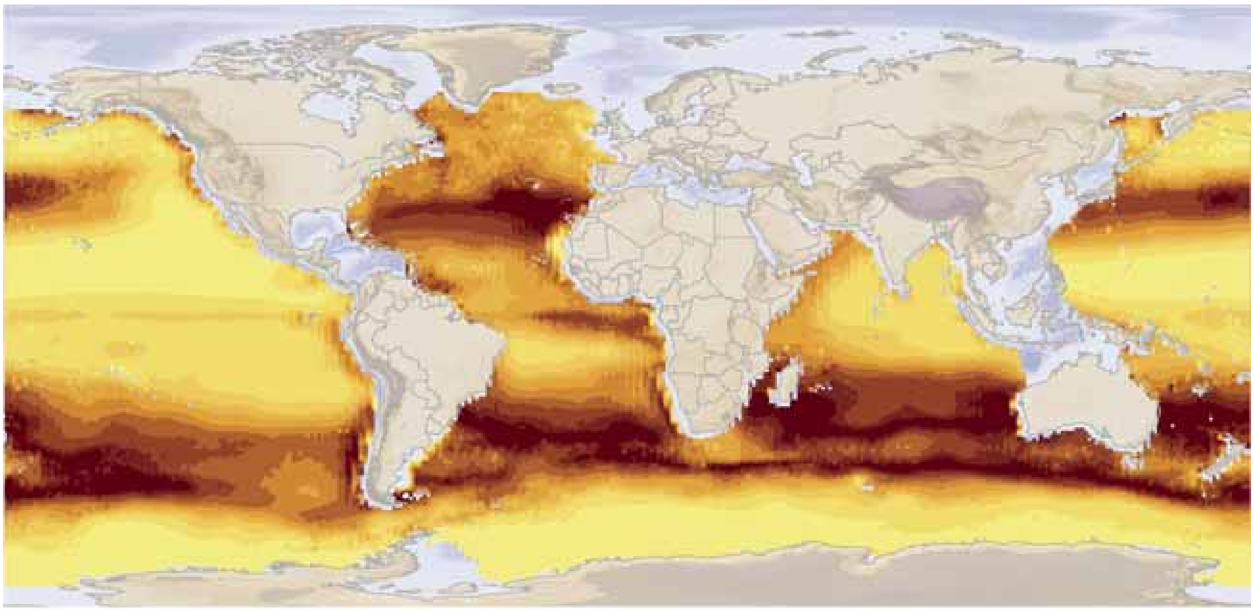


Figure 7.1: Main areas under risk from alfonsino seamount fisheries (250-750 m depth horizon).
Above: Predicted habitat suitability for stony corals in 250-750 m depth. High percentage values indicate more suitable habitat.
Upper, opposite page: Predicted seamount summit depths 250-750 m depth.
Lower, opposite page: Seamounts with known historical alfonsino group catches.

Key (above)

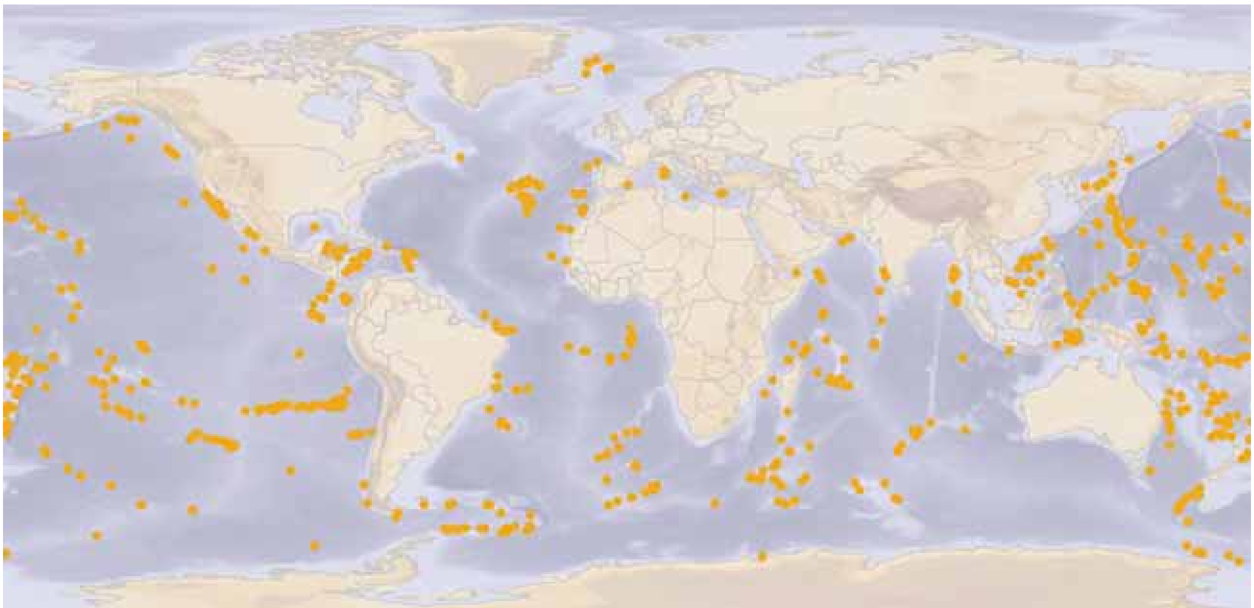
Habitat suitability %	Habitat suitability %
0-10	50-60
10-20	60-70
20-30	70-80
30-40	80-90
40-50	90-100

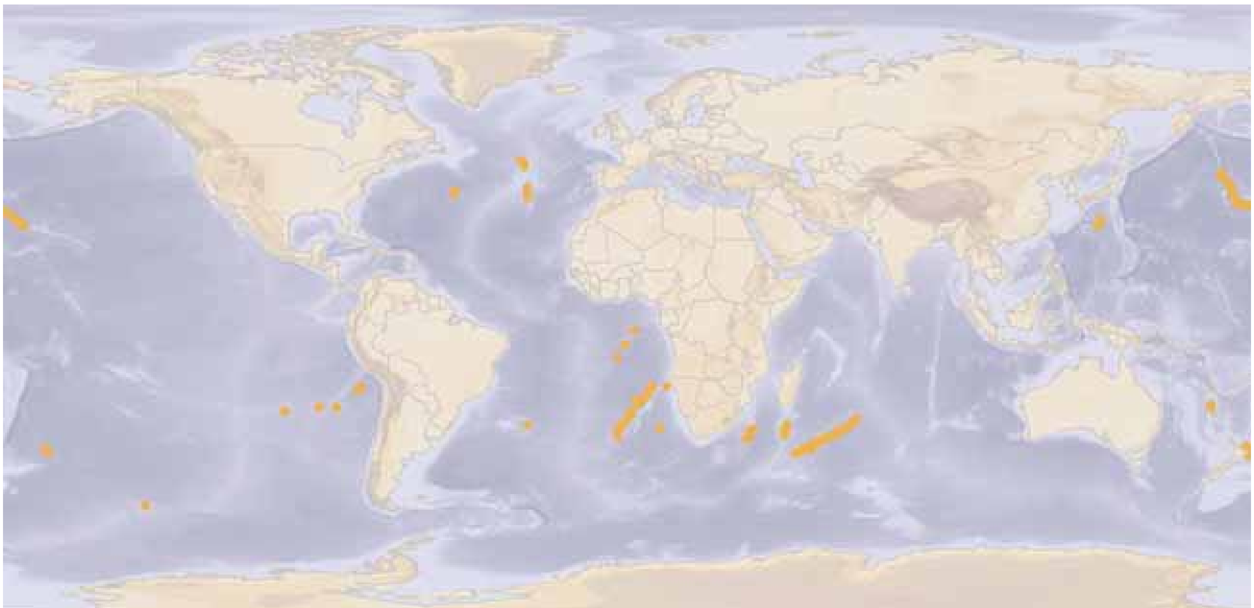
scientific evidence. Scientific investigations have also identified that these organisms and their associated biological communities are highly vulnerable to fishing. To evaluate the vulnerability of seamounts to putative impacts by trawling, the distribution of coral habitat needs to be compared with that of seamount fisheries worldwide. However, corals have only been sampled from a small fraction of seamounts worldwide, whilst because of the rapid expansion of deep-sea fisheries, a global perspective on seamount conservation is required. Scientific surveys of seamount communities are extremely expensive and time-consuming and are unlikely in the short to medium term (tens of years) to identify the majority of seamount habitats that require protection from harmful activities. In the present report, a new approach to identifying the occurrence of marine habitats that are sensitive to particular activities – in this case fishing, primarily by deep-sea bottom trawling – has been adopted by scientists within the CenSeam programme. This approach was to use modelling – based on existing observations of the occurrence of stony corals – to predict where seamounts with favourable environmental conditions for the development of diverse coral communities are likely to occur. Combining this information with the known geographical occurrence of commercially valuable seamount fish species identifies which seamounts are in urgent need of measures to protect biodiversity. A note of caution here is that other types of corals, particularly octocorals, and other organisms, such as sponges, form diverse biological communities and have markedly different distributions from that of stony corals. Thus, whilst large areas of the North Pacific may be relatively unsuitable for stony corals, the area is suitable for octocorals, which form coral gardens with a high diversity of associated species. Octocoral gardens are as vulnerable to fishing activities as cold-water coral reefs formed by stony corals.

OVERLAP BETWEEN STONY CORALS AND FISHERIES

A key finding from the qualitative comparisons of the predicted global distribution of stony coral habitat on seamounts with the distribution of seamount fisheries is the considerable spatial overlap between the likely distribution of stony corals and past, current and potential future seamount fisheries.

The predicted distribution of seamount habitat suitable





for stony corals (scleractinians) is extensive on a global scale. The majority of this suitable habitat is located in areas beyond national jurisdiction, mainly at depths between 250 m and 750 m. High levels of oxygen saturation and aragonite (a form of calcium carbonate used by corals to form hard skeletons) are among the most important environmental factors in determining habitat suitability for stony corals.

Predicted habitat suitability indicates that seamounts provide coral habitat mainly in a band across all oceans between 20ºS and 60ºS, and in other areas of the Atlantic Ocean. In the Atlantic, a large proportion of suitable seamount coral habitat lies beyond areas of national jurisdiction, whereas in the Pacific it lies mostly within national EEZs. In the southern Indian Ocean, suitable coral habitat on seamounts appears both within and outside of areas of national jurisdiction.

Examinations of seamount fisheries information revealed that the main deep-sea fish species of commercial value have a widespread distribution, and for at least parts of their life history can be found associated with seamounts. The two fish species of highest commercial value that are targeted on seamounts in areas beyond national jurisdiction are alfonsino and orange roughy. Fisheries for these two species are, to an extent, discrete in that they operate at different depths: the alfonsino fishery operates primarily between 250 m and 750 m, whilst the fishery for orange roughy occurs largely at water depths of 750-1 200 m.

Throughout the world's oceans, there are numerous large seamounts that a) have summits within the depth range of the fish and fisheries; b) are located outside of areas of national jurisdiction; and c) lie within the known or predicted distribution of alfonsino and orange roughy. Most of the areas where these seamounts occur are thought to have already been explored or commercially exploited, but, especially at orange roughy depths, there are seamounts in some areas that appear to be within the distributional and depth range of the species that may not yet have been the subject of extensive fishing.

VULNERABILITY OF CORALS ON SEAMOUNTS TO BOTTOM TRAWLING

Many long-lived epibenthic animals such as corals have an important structural role within sea floor communities, providing essential habitat for a large number of species (Rogers, 1999; Freiwald et al., 2004; Roberts et al., 2006). Consequently, the loss of such key structural species lowers survivorship and recolonization of the associated fauna, and has spawned analogies with forest clear-felling on land (e.g. Watling, 2005). Such comparisons stem principally from destructive fishing practices that are mostly in the form of bottom-contact trawling. A considerable body of evidence on the ecological impacts of trawling is available for shallow waters (e.g. Watling and Norse, 1998; Hall, 1999; Kaiser and de Groot, 2000), but scientific information on the effects of fishing on deep-sea seamount ecosystems is much more limited.

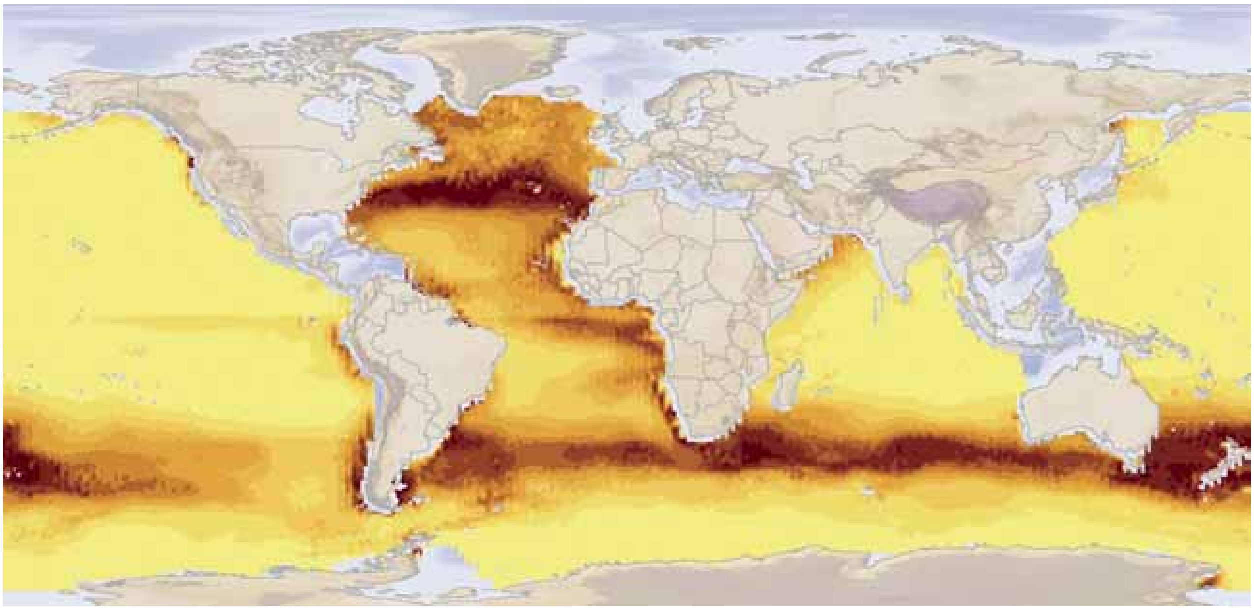
The scientific literature of the effects of fishing on seamount habitat is summarized by Clark and Koslow (in press). Their key findings include:

1. The impacts of trawling on seamounts have been studied most intensively within the EEZs of Australia and New Zealand (e.g. Koslow et al., 2001; Clark and O'Driscoll, 2003).
2. On seamounts off Tasmania (Australia), the fished seamounts had typically fewer species (reduced by about

Figure 7.2: Main areas under risk from orange roughy seamount fisheries (750-1 250 m depth horizon).
Below: Predicted habitat suitability for stony corals in 750-1 250 m depth. High percentage values indicate more suitable habitat.
Upper, opposite page: Predicted seamount summit depths between 750-1 250 m depth.
Lower, opposite page: Seamounts with known historical orange roughy group catches.

Key (below)

Habitat suitability %	Habitat suitability %
0-10	50-60
10-20	60-70
20-30	70-80
30-40	80-90
40-50	90-100

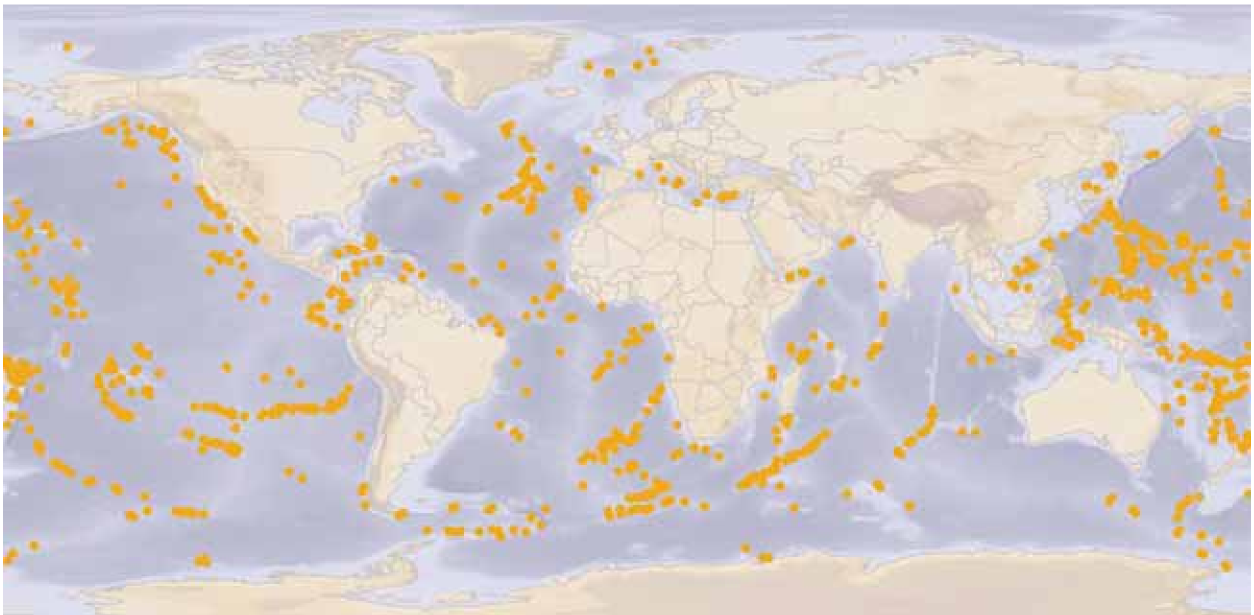


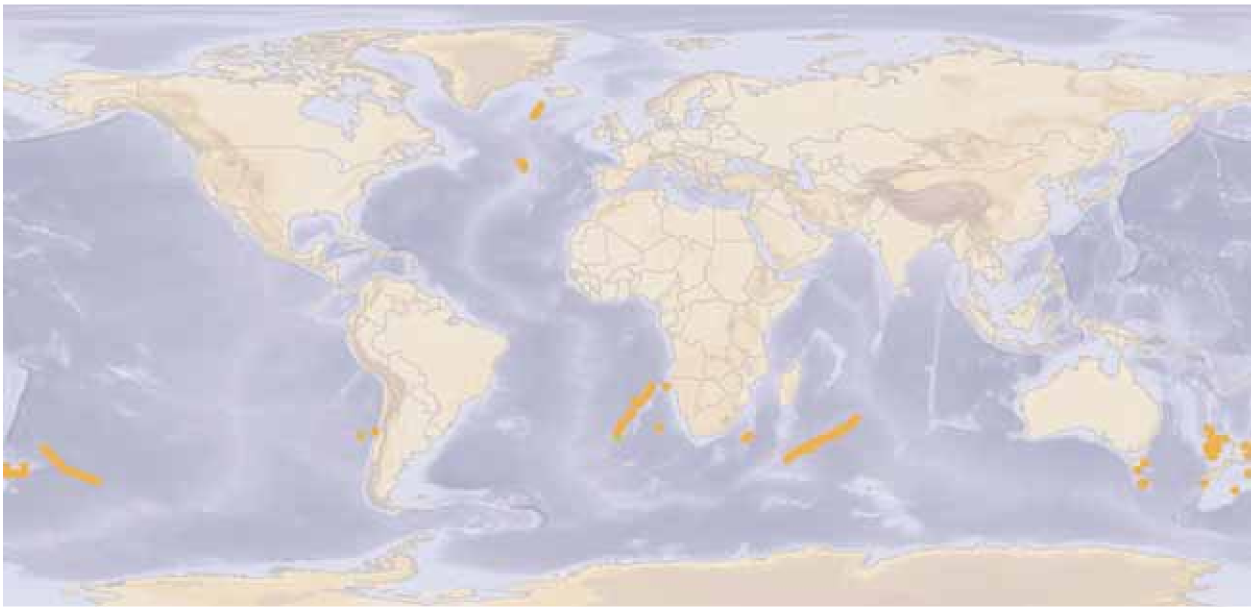
half) and had lower biomass of benthic invertebrates (by about seven times) (Koslow and Gowlett-Holmes, 1998; Koslow et al., 2001).

3. On New Zealand seamounts, the composition of larger benthic invertebrates was different on 'fished' seamounts, which had a smaller amount of coral habitat formed by live *Solenosmilia variabilis* and *Madrepora oculata* than on 'unfished' seamounts. In addition, trawl marks were observed over six times more frequently on seabed images from 'fished' seamounts (Clark and O'Driscoll, 2003, Rowden et al., 2004).

The intensity of trawling on seamounts can be very high. For example, Soviet fishing effort for pelagic armourhead on relatively few seamounts in the Southern Emperor and Northern Hawaiian Ridge system was around 18 000 trawler days during the period from 1969 to 1975 (Borets, 1975). Koslow et al. (2001) and Clark and O'Driscoll (2003) have reported that between several hundred and several thousand trawls have been carried out on small seamount features in the orange roughy fisheries around Australia and New Zealand.

Similarly, O'Driscoll and Clark (2005) documented that





the total length of bottom tows per square kilometre of seamount area off New Zealand averages 130 km of trawled sea floor. Such intense fishing means that the same area of the sea floor can be repeatedly trawled, causing long-term damage to the coral communities and preventing any recovery or recolonization.

The impact of trawling on sea floor biota can differ depending on the gear type used. Information about the potential impact of trawling practices for alfonsino, where mid-water trawls are often used on seamounts, is currently lacking. Mid-water trawls may have only a small impact if they are deployed well above the sea floor. However, in many cases the gear is most effective when fished very close to, or even lightly touching, the bottom. Thus, it is likely that the effects of the alfonsino fisheries on the benthic fauna would be similar to that of the orange roughy fisheries.

WHERE ARE THE MAIN AREAS OF RISK AND CONCERN?

The spatial extent of the likely vulnerability of seamount biodiversity on seamounts in areas beyond national jurisdiction can be gauged by combining the three sets of information (Figures 7.1 and 7.2) produced in this study:

1. the predicted global distribution of suitable habitat for stony (scleractinian) corals;
2. the location of predicted large seamounts with summits in depth ranges of the fishery for alfonsino (250 m-750 m) and orange roughy (750 m-1 250 m); and
3. the distribution of the fishing activity on seamounts for these two species.

The spatial overlaps highlight a broad band of the southern Atlantic, Pacific and Indian Oceans between about 30°S and 50°S where there are numerous seamounts at fishable depths, and high habitat suitability for corals at depths between 250 m and 750 m, and again (but somewhat narrower) between 750 m and 1 250 m depth. There are also some areas of overlap in the North Atlantic Ocean.

This spatial concordance of fishable seamounts within the depth band of orange roughy suggests there could be further commercial exploration for orange roughy fisheries on seamounts in the central-eastern southern Indian Ocean (as evidenced by the Southwest Indian Ocean fisheries rush between 1998 and 2003), the southern portions of the Mid-Atlantic Ridge in the South Atlantic, and some regions of the southern-central Pacific Ocean. Importantly, since these areas also contain habitat suitable for stony coral, impacts on deep-water corals – and seamount ecosystems in general – are likely to arise in such a scenario. It is uncertain whether fisheries exploration will expand further. Often, fish aggregations are very localized, and given the large number of seamounts and smaller features in the oceans, they may be difficult to locate. Hence, there may be further fisheries potential, but if stocks are small and localized, they may not currently be economic.

Thus, this study has for the first time revealed the global scale of the likely vulnerability of stony (scleractinian) corals on seamounts – including habitat-forming species, and by proxy a diverse assemblage of other species – to the impacts of trawling on seamounts in areas beyond national jurisdiction. This report provides some of the best scientific evidence to date to support the need for management practices on the high seas to protect seamounts vulnerable to the adverse effects of deep-water fishing.

8. A Way Forward

HOW CAN THE IMPACT OF FISHING ON SEAMOUNTS BE MANAGED IN AREAS BEYOND NATIONAL JURISDICTION?

The Report of the Secretary-General on Oceans and the Law of the Sea (2003), Paragraph 183, states:

> *'...fisheries governance has focused its attention on reducing fishing efforts, improving compliance with and enforcement of conservation and management measures established by regional fisheries bodies.... The international community has yet to devote sufficient attention to the protection of vulnerable marine ecosystems from the adverse impacts of fishing and non-fishing activities, an important step towards fisheries conservation within an ecosystem-based management of capture fisheries.'*

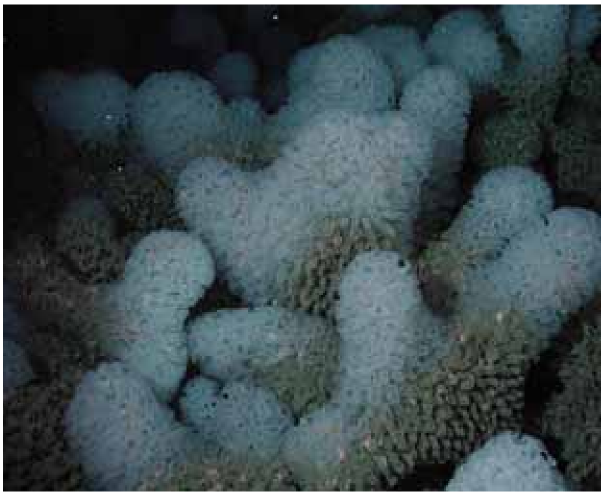
Examples of vulnerable marine ecosystems in this document include seamounts (Report of the Secretary-General, 2003, Paragraph 180). In 2005 the Secretary-General published a further report detailing deep-sea ecosystems, threats to the marine environment and the legal framework associated with protecting the marine environment both within and beyond waters of national jurisdiction (Report of the Secretary General, 2005).

This report has reviewed scientific evidence that where seamounts, deep-sea corals and fisheries come together, there is a need for management. It has also demonstrated that deep-sea corals, and by proxy benthic communities, on as yet unexplored/unfished seamounts in areas beyond national jurisdiction are at risk from the potential expansion of alfonsino and orange roughy fisheries. Consequently, it is sensible for appropriate management strategies to be in place prior to these fisheries being established, so as to prevent the adverse effects of fishing on these seamount ecosystems.

Management initiatives for seamount fisheries within national EEZs have increased in recent years. Several countries, such as New Zealand and Australia, have closed seamounts to fisheries, established habitat exclusion areas and stipulated method restrictions, depth limits, individual seamount catch quotas and by-catch quotas (e.g., Smith, 2001; Commonwealth of Australia, 2002; Gianni, 2004; Gjerde, 2006; Brodie and Clark, 2004; Melo and Menezes, 2003).

In comparison, fisheries beyond areas of national jurisdiction have often been entirely unregulated (FAO, 2004; Gianni, 2004; Gjerde, 2006). There are 12 Regional Fisheries Management Organizations (RFMOs) with responsibility to agree on binding measures that cover areas beyond national jurisdiction (Kimball, 2005), including some of the geographical areas identified in this report that might see further expansion of exploratory fishing for alfonsino and orange roughy on seamounts. However, it should be noted that only the five RFMOs for the Southern Ocean (CCAMLR), Northwest Atlantic (NAFO), Northeast Atlantic (NEAFC), Southeast Atlantic (SEAFO) and the Mediterranean (GFCM[I]) currently have the legal competence to manage most or all fisheries resources within their areas of application, including the management of deep-sea stocks beyond national jurisdiction (Kimball, 2005). The other RFMOs have competence only with respect to particular target species like tuna or salmon (Kimball, 2005). SEAFO covers parts of the eastern South Atlantic where exploratory fishing has occurred in recent decades, and where further trawling could occur. However, the western side of the South Atlantic is not similarly covered by an international management organization. There have been recent efforts to improve cooperative management of fisheries in the Indian Ocean, although there are no areas covered by an RMFO. In addition, efforts are underway, for example in the South Pacific, to establish a new regional fisheries convention and body that would fill a large gap in global fisheries management.

***Benthodytes* sp. (sea cucumber), Davidson Seamount, 2 789 m.** (NOAA/MBARI)



***Farrea* sp., a sponge that blankets large areas at or near crests on Davidson Seamount (1 400 m); associated with crabs, basket stars, seastars and brittle stars.**
(NOAA/MBARI)

In light of the recent international dialogues concerning the conservation and sustainable management and use of biodiversity in areas beyond national jurisdiction held within and outside the United Nations system (Report of the Secretary-General, 2003 and 2005; CBD, 2004; Kimball, 2005), various fisheries bodies (e.g. NEAFC, NAFO, SEAFO) are more actively updating their mandates and including benthic protection measures as part of their fisheries management portfolio. Very recent initiatives include the formation of a Southwest Indian Ocean Fisheries Commission. There have also been recent proposals by industry to designate large voluntary Benthic Protection Areas (BPAs). These are areas that are closed to bottom trawling primarily to protect the benthic fauna but also to preserve areas of outstanding scientific interest and potentially to act as a refuge for commercial fish species. In general, they have been proposed to give a wide representative coverage of geological structures, sediment overlays, bottom types and benthic habitat types. The New Zealand deep-water fishing industry has proposed BPAs mainly inside the New Zealand EEZ but some of which also encompass areas outside of the national EEZ. The Southern Indian Ocean Deepwater Fisheries Operators Association (SIODFOA) has also proposed a number of BPAs in the southern Indian Ocean.

It appears that a growing legislation and policy framework, including an expanding RFMO network, particularly in the southern hemisphere, could enable the adequate protection of and management of the risks to vulnerable seamount ecosystems and resources identified in this report. In order to be successful, a number of challenges will have to be overcome, including:

1. Establishing adequate data reporting requirements for commercial fishing fleets. Some unregulated and unreported fishing activities take place, even in areas where there are well-defined fishery codes of practice and allowable catch limits (e.g. Patagonian toothfish fishery). Some countries require vessels registered to them to report detailed catch and effort data, but many do not. Therefore it is difficult at times to know where certain landings have been taken.

2. Ensuring compliance with measures, especially in areas that are far offshore and where vessels are difficult to detect. Compliance monitoring is also an acute problem in southern hemisphere high seas areas, where there are no quotas for offshore fisheries.

3. Facilitating RFMOs, where necessary, to undertake ecosystem-based management of fisheries on the high seas.

4. Establishing, where appropriate, dialogue to ensure free exchange of information between RFMOs, governments, conservation bodies, the fishing industry and scientists working on benthic ecosystems.

The experiences gained by countries in the protection of seamount environments in their EEZs and in the management of their national deep-water fisheries can provide useful case examples for the approach to be taken under RFMOs. Other regional bodies, such as Regional Sea Conventions and Action Plans, might be able to provide lessons learned from regional cooperation to conserve, protect and use coastal marine ecosystems and resources sustainably, including the implementation of an ecosystem approach in oceans management and the establishment of marine protected areas (MPAs) (Johnston and Santillo, 2004). Regional Sea Conventions and Action Plans also provide a framework for raising awareness of coral habitats in deep water areas under national jurisdiction, and coordinating and supporting the efforts of individual countries to conserve and manage these ecosystems and resources sustainably (e.g. ICES, 2005, 2006).

In calling for urgent action to address the impact of destructive fishing practices on vulnerable marine ecosystems, Paragraph 66 of UN General Assembly Resolution 59/25 (UN General Assembly, 2005b) places a strong emphasis on the need to consider the question of bottom-trawl fishing on seamounts and other vulnerable marine ecosystems on a scientific and precautionary basis, consistent with international law. In this regard, it is important to recognize the role of science and the extent that scientific information, or lack thereof, is a prerequisite for management action.

The UN Fish Stocks Agreement (FSA) Articles 5 and 6 – 'General principles' and the 'Application of the precautionary approach' (Kimball, 2005) also establish clear obligations for fisheries conservation and the protection of marine biodiversity and the marine environment from destructive fishing practices. The Articles also establish that the use of science is essential to meeting these objectives and obligations.

Article 5(k) calls on States to promote and conduct scientific research in support of fishery conservation and management, and Article 6.3(a) requires States to improve decision making by obtaining and sharing the best scientific information available and implementing improved techniques for dealing with risk and uncertainty. Article 5(d) calls on States to assess the impacts of fishing on target stocks and species belonging to the same ecosystem, or those associated with or dependent upon the target stocks. And Article 6.3(d) calls for the development of data collection and research programmes to assess the impact of fishing on non-target and associated or dependent species and their environment, and for adopting plans necessary to ensure the conservation of such species and to protect habitats of special concern (Kimball, 2005).

At the same time, the FSA recognizes that scientific understanding may not be complete or comprehensive, and in such circumstances, caution must be exercised. Articles 6.2 and 6.3(c) require taking into account uncertainties relating to the impact of fishing activities on non-target and associated or dependent species – that States be 'more cautious' when information is uncertain, unreliable or inadequate. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures.

A precautionary approach, consistent with the general principles for fisheries conservation contained in the FSA, as well as the UN FAO Code of Conduct for Responsible Fisheries and the principles and obligations for biodiversity conservation in the Convention on Biological Diversity (Kimball, 2005), would require the exercise of considerable caution in relation to permitting or regulating bottom-trawl fishing on the high seas on seamounts. This is because of the widespread distribution of stony corals and associated assemblages on seamounts in many high seas regions, and the likelihood that seamounts at fishable depths may also contain other species vulnerable to deep-sea bottom trawling even in the absence of stony corals. In this regard, a prudent approach to the management of bottom-trawl fisheries on seamounts on the high seas would be to first ascertain whether vulnerable species and ecosystems are associated with a particular area of seamounts of potential interest for fishing, and only then permitting well-regulated fishing activity provided that no vulnerable ecosystems would be adversely impacted.

FURTHER AND IMPROVED SEAMOUNT RESEARCH

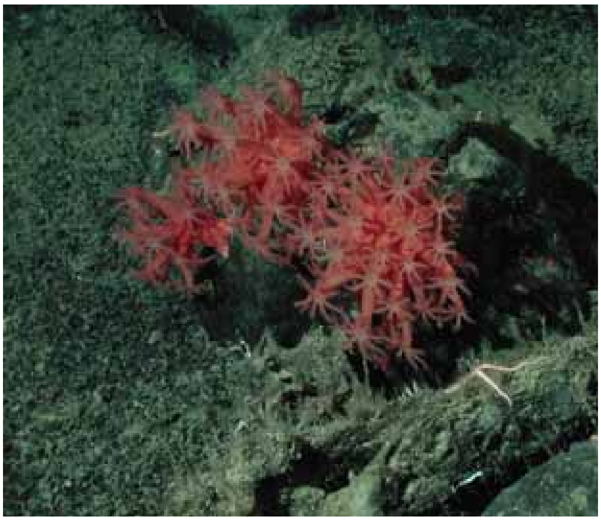
The conclusions of this report apply only to the association of stony corals with large seamounts. In order to consider other taxonomic groups on a wider range of seamounts, further sampling and research is required.

Development, implementation and review of effective management measures rely on sound scientific data and assessments. As already acknowledged in Principle 15 of the Rio Declaration on Environment and Development (Agenda 21), gaps in information and knowledge often cause a lack of full scientific certainty, and a precautionary approach has to be applied to protect the environment from threats of serious or irreversible damage and to prevent environmental degradation. UN General Resolutions 59/24 (Paragraph 81) and 60/30 (Paragraph 85) (UN General Assembly, 2005a, 2006) call for scientific research to:

> *'...improve understanding and knowledge of the deep sea, including, in particular, the extent and vulnerability of deep-sea biodiversity and ecosystems...'*

The preparation of this report has identified a number of shortcomings and gaps in the data and in our knowledge of seamounts, deep-sea corals and fisheries. These gaps need to be addressed and closed in order to answer questions from policy makers, managers and scientists – answers that at present cannot be provided at the required level of certainty.

***Anthomastus* sp. (mushroom soft coral), Davidson Seamount, 1 580 m.** (NOAA/MBARI)



These include:

1. *Obtain better seamount location information:* The two most recent seamount position datasets, based on satellite altimetry measures, both contain location information for about 15 000 predicted large seamounts. This number is thought to be an underestimate, with extrapolative techniques predicting the global seamount number to be 100 000. Fisheries often operate on much smaller seamounts, but such seamounts cannot be identified by large-scale remote sensing methods. However, it will be possible, with more extensive satellite measurements of the Earth's ocean surface with improved altimetry technology (to reduce loss of signal by wave 'noise') and closer spacing of satellite tracks, to greatly improve location data for large seamounts.

2. *Address geographic data gaps:* Fewer than 300 seamounts have been biologically surveyed worldwide, which represents a very small (less than 2 per cent) fraction of existing seamounts in the world's oceans. Only 80 of these seamounts have had at least a moderate level of sampling, and far fewer have received sampling sufficient to characterize the biological communities present. Thus, the fauna on the vast majority of seamounts remains unknown. Past surveys have tended to concentrate on a few geographic areas (e.g. North Atlantic, Southwest Pacific), while few data exist for seamounts in other regions such as the Indian Ocean and the Southern Ocean. Although seamounts are particularly common in the tropics, existing data come mostly from temperate regions at higher latitudes, and therefore the biological communities of tropical seamounts remain poorly documented for large parts of the oceans. Most biological surveys on seamounts have been relatively shallow (e.g. mostly less than 1 500 m), and thus the great majority of deeper seamounts remains largely unexplored. Field programmes are required to address these deficiencies.

3. *Inclusion of other deep-sea habitats:* To assess to what degree seamounts present 'unique' ecosystems, comparative data are required from other deep-sea environments such as the abyssal plains surrounding seamounts, and direct comparisons with slope environments – particularly island slopes and continental margins. Thus, field programmes should target both seamounts and such comparative environments whenever possible.

4. *Assessment of the spatial scale of variability:* The distribution of deep-sea corals and other benthic invertebrate fauna on seamounts is likely to be patchy at a range of spatial scales – for example, on a seamount, and within and between seamounts on different clusters and chains. Very few individual seamounts have been comprehensively surveyed to determine the variability of faunal assemblages within a single seamount, where, for example, small-scale differences may occur between hard and soft substrates. It is important to understand the spatial scales at which variation in fauna community composition occurs, in order to develop management strategies that ensure the effective protection of this level of biodiversity and associated ecosystem function.

5. *Availability of data:* For many seamount studies, only summary data are publicly available. Analysis of species distribution patterns and studies on assemblage composition across different seamounts and regions does, however, require access to species catch data for individual stations and/or samples (i.e. non-aggregated data). In addition, many seamount studies are contained in the 'grey literature' and not always readily accessible. Increased accessibility of full (non-aggregated) datasets from seamount expeditions (after an appropriate time to publish) through searchable, integrated databases like SeamountsOnline and the Ocean Biogeography Information System (OBIS) is required.

6. *Collection methods:* While different gear types are required to sample different types of faunal assemblages (e.g. otter trawls for fish, benthic sleds and dredges for macro-invertebrates), past studies have also used different gear types for the same faunal group. Since different collecting gears have different performances, often compounded by differences in deployment techniques and operations, direct comparisons of data may be confounded to some (unknown) degree. A minimum set of standardized seamount sampling protocols should be adopted as widely as possible by seamount sampling programmes.

7. *Taxonomic resolution:* Different taxonomists (scientists who classify living things) or different groups of taxonomists often work on collections from different seamount studies. In fact, much of past and current seamount research relies fundamentally on the availability of specialized taxonomic expertise, a critical resource that continues to decline globally. Datasets may need careful taxonomic intercalibration before regional and global analysis can be undertaken with confidence. Similarly, for some faunal groups, few taxonomic specialists are available, often limiting the scope of analysis. More funding for existing taxonomic experts and training of new taxonomists – particularly

for faunal groups that are currently poorly analysed globally – is required. This provision should also enable the research community to analyse specimens collected across multiple seamounts in multiple programmes.

8. *Increase genetic studies:* One of the critical questions for seamount conservation is whether they support isolated populations and, if so, on what scale that isolation occurs. Genetic studies can inform, for example, whether a single seamount is an appropriate scale for protection, or whether multiple seamounts in a chain have connected populations and should be protected.

9. *Assessment of trawling impacts:* Better studies on the impacts of trawling are needed. Studies to date on seamounts and in the deep sea have been limited. More and improved studies would improve our understanding of the extent to which the large fauna associated with corals and other structure-forming organisms are impacted. Studies should also investigate the nature of impact from different gear types, so that fishing gear can be optimized to reduce damage to the benthic fauna, while still catching fish effectively.

10. *Recovery from trawling impacts:* Bottom fishing undoubtedly has severe impacts on seamount biota, particularly corals. The physical destruction caused by bottom-contact fishing gear is clearly visible on the seabed, and the removal of corals has significant consequences for the biodiversity and biomass of the associated fauna. It is, however, not known how long these communities take to recover from fishing impacts and what the trajectory of any such recovery may be. Based on the slow growth and longevity of deep-sea corals, recovery of corals is predicted to be extremely slow, but is essentially unknown for field situations. However, such information on the time and nature of recovery (if any) is essential for ecosystem-based fisheries management on seamounts, and for evaluating the efficiency of MPAs on seamounts. Thus it is essential that the time frames and nature of recovery be documented.

11. *Functional understanding:* Our understanding of seamount biota has improved over the last few decades, but many of these advances have been made in documenting structural properties of seamount communities (e.g. species composition, distribution, growth rates, etc.). By contrast, much less is known about the processes operating in seamount ecosystems and how functional aspects of seamount assemblages may be altered by human activities. Therefore, future research should include aspects of community and ecosystem processes such as:
    - ❍ food-web architecture on and above seamounts;
    - ❍ linkages of the bottom fauna with water-column and geological processes;
    - ❍ mechanisms and rates of recruitment (addition of organisms through reproduction or immigration) to seamount communities (e.g. larval dispersion, retention, oceanographic drivers of recruitment variability, etc.);
    - ❍ processes promoting increased primary and secondary production on seamount and coupling to sea floor communities;
    - ❍ trophic (food-chain) links between seamount-associated fish and prey populations; and
    - ❍ the relative role of corals and other structure-forming fauna in promoting biodiversity and providing essential habitat for fish.

***Neolithodes*, Davidson Seamount, 1 319 m.** (NOAA/MBARI)

12. *Fisheries information:* At present, data collection from fishing vessels operating in areas beyond national jurisdiction is largely ad hoc, and FAO records also appear incomplete for many offshore fisheries. It is important for effective management of such fisheries to obtain accurate information on what is being caught, how much, and where. With seamount fisheries, this requires location data on a small-scale (individual tow data, recorded to at least a 1 minute of a degree accuracy), so that fishing on individual seamounts can be identified.

Without a concerted effort by a number of organizations, institutions, consortia and individuals to attend to the identified gaps in data and understanding, the ability of any body to effectively and responsibly manage and mitigate the impact of fishing on seamount ecosystems will be severely constrained. Considering what this report has revealed about the vulnerability of seamount biota – particularly deep-sea corals – to fishing, now is the time for this collaborative effort to begin in earnest.

Acronyms

CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CoML	Census of Marine Life
DAWG	Data Analysis Working Group
DSL	Deep Scattering Layer
EEZ	Exclusive Economic Zone
ENFA	Environmental Niche Factor Analysis
GLODAP	Global Ocean Data Analysis Project
ETOPO2	Used to describe a 2-minute global bathymetry grid generated from a combination of sources including satellite altimetry observation and shipboard echo-sounding measurements
ERS1	European Remote-Sensing Satellite-1
FAO	Food and Agriculture Organization of the United Nations
GEBCO	General Bathymetric Chart of the Oceans
GFCM	General Fisheries Commission for the Mediterranean
GLM	Generalised Linear Model
GLODAP	Global Ocean Data Analysis Project
ICES	International Council for the Exploration of the Sea
IHO	International Hydrographic Organization
IOC	International Oceanographic Commission
NAFO	Northwest Atlantic Fisheries Organization
NEAFC	Northeast Atlantic Fisheries Commission
OBIS	Ocean Biogeographic Information System
RFMO	Regional Fisheries Management Organizations
SAUP	Sea Around Us Project
SEAFO	Southeast Atlantic Fisheries Organization
SODA	Simple Ocean Data Assimilation
SWIOFC	Southwest Indian Ocean Fisheries Commission
NOAA	National Oceanic and Atmospheric Administration (USA)
UN	United Nations
UNEP	United Nations Environment Programme
UNGA	United Nations General Assembly
VGPM	Vertically Generalized Production Model
WOA	World Ocean Atlas
WOCE	World Ocean Circulation Experiment

Glossary

Algae: a group of plants (i.e. capable of photosynthesis) that occur in aquatic habitats, or in moist environments on land.

Anthozoa: A class of animals within the **Cnidaria** that contains the **corals** and anemones.

Antipatharia: An order within the Anthozoa (sub-class **Hexacorallia**), the so-called black corals.

Aragonite: A form of calcium carbonate used by scleractinian corals to build their skeletons.

Ascidians: a class of animals (Ascidiacea), the sea squirts.

Azooxanthellate: without **Zooxanthellae**.

Beam trawl: A trawl in which the horizontal opening is maintained by a wood or metal beam.

Benthic: Related to the sea floor, includes fauna and flora that live on or in the seabed.

Biodiversity: (1) The number and variety of organisms found within a specified geographic region; (2) The variability among living organisms including within and between species and within and between ecosystems.

Biota: The plant and animal life of a region.

Bottom trawling: Method of **trawling** where the net remains in contact with the sea floor – can comprise multiple nets i.e. twin-rigged trawls.

Chlorophylls: A group of green pigments found in photosynthetic organisms including phyto-plankton that absorb energy from sunlight.

Cnidaria: Phylum of more-or-less radially symmetrical invertebrate animals that lack a true body cavity, possess tentacles studded with nema-tocysts (stinging structures), and include the hydroids, jellyfishes, sea anemones and corals. Synonomous with the **Coelenterates**.

Coelenterates: See **Cnidaria.**

Corals: A group of benthic **anthozoans** that can exist as individuals or in colonies and may secrete calcium carbonate external skeletons. Corals can be found in the photic zone (with symbiotic **zooxanthellae**) as well as in the deep sea, the so called cold-water corals.

Crinoid: Marine animals that make up the class Crinoidea (phylum Echinodermata). Also known as 'sea lilies' or 'feather-stars'.

Deep scattering layer: A relatively thin layer of organisms, composed of migrating plankton forms, which can be detected by echo sounders.

Detritivores: Scavengers that feed on dead plants and animals or their waste.

Dissolved inorganic carbon (DIC): All inorganic carbon dissolved in a volume of water at a given temperature and pressure.

Diversity: (1) The number of taxa in a group or place (species richness) (2) a parameter used to describe richness and evenness within a collection of species.

Echinoderms: A phylum of marine animals found at all depths (from the Greek for spiny skin)

Exclusive economic zone (EEZ): 1) A zone under national jurisdiction (up to 200-nautical miles wide) declared in line with the provisions of the 1982 United Nations Convention of the Law of the Sea, within which the coastal State has the right to explore and exploit, and the responsibility to conserve and manage, the living and non-living resources; 2) The area adjacent to a coastal state which encompasses all waters between: (a) the seaward boundary of that state, (b) a line on which each point is 200 nautical miles (370.40 km) from the baseline from which the territorial sea of the coastal state is measured (except when other international boundaries need to be accommodated), and (c) the maritime boundaries agreed between that state and the neighbouring states.

Endemic: A taxa that is restricted in its distribution, only found in a specific area/region.

Environmental Niche Factor Analysis (ENFA): A habitat suitability modelling technique.

Epipelagic: The part of the oceanic zone into which enough sunlight enters for photosynthesis to take place. See also **euphotic/photic**.

Epibenthic: Living on the bottom or sea floor

Euphotic: The part of the oceanic zone into which enough sunlight enters for photosynthesis to take place. See also **epipelagic/photic**.

Fauna: Animals, especially those of a particular region, considered as a group.

GLM: Generalised Linear Model. A statistical linear model that can relate one dependent factor to one or more independent factors.

Gorgonacea: An order within the **Anthozoa** characterized by having a flexible, often branching skeleton of horny material.

Guyot: Flat topped **seamount** which is often covered in sediments from when they were exposed islands.

Habitat: The area or environment where an organism or ecological community normally lives or occurs.

Hexacorals: A subclass of the **Anthozoans.** Includes the **Antipatharia** and **Scleractinia**.

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

Hydrozoa (hydroids): A class within the phylum **Cnidaria**.

Marginality: An ENFA term indicating how different the optimal habitat for a taxonomic group is from the mean environment.

Mid-water trawling: Method of trawling where the net is towed through mid-water i.e. above, and not in contact with the sea floor.

Modelling: Representing a system through mathematical or statistical equations.

Niche: The role an organism fills in an ecosystem.

Octocorals: A sub-class of corals within the **Anthozoa** which are characterized by having eight tentacles on each polyp.

Otter trawl: A trawl in which the horizontal opening is maintained by a pair of trawl doors (or otter boards).

Pelagic: Of relating to or living in the open sea, away from the sea bottom.

Photic: A zone in the water column that is penetrated by sufficient sunlight for **primary productivity/ production**.

Photosynthesis: The process by which carbohydrates are synthesized from carbon dioxide and water using light as an energy source. Most forms of photosynthesis release oxygen as a byproduct.

Plankton: Minute **pelagic** organisms that float or drift in great numbers in fresh or salt water, especially at or near the surface, and serve as food for fish and other larger organisms.

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

Primary productivity/production: The rate of carbon fixation by phytoplankton (marine photosynthetic organisms).

Seamount: An elevation of the seabed with a summit of limited extent that does not reach the surface. They can have a variety of shapes but are generally conical with a circular, elliptical or elongate base, and do not breach the surface. There is no unified consensus of what does or does not constitute a seamount. Some definitions are based on elevation e.g. must be greater than 1 000 m whilst others will class a seamount as a topographic feature that rises more than 50 m above the sea floor.

Scleractinia: An order within the **Anthozoa** (sub-class **Hexacorallia**), the so called stony corals.

Specialization: An **ENFA** term indicating how stringent are the environmental requirements of a taxonomic group (how narrow a niche it occupies).

Sponge: A phylum (Porifera) of sessile (attached) forms that are spongy or stony to the touch. No obvious animal features and often mistaken for a plant.

Stylasteridae: A family of corals within the class **hydrozoa**.

Taxonomy: The science of classifying living things e.g. Phylum, Class, Order, Family, Genus, Species.

Taylor column: Models predict that the steady flow of a uniform water column past a seamount results in a stationary vortex over the seamount, a so-called a Taylor column. However, stratification of water layers above a seamount may reduce the column to a cap – a **Taylor cap**.

Trawl: Trawls are nets consisting of a cone-shaped body closed by a bag or cod end and extended at the opening by wings. They are actively pulled through the water and kept open in the vertical plane by various methods e.g. floats, and on the horizontal plane e.g. by trawl doors. They can be towed by 1 or 2 boats and according to type, are used on the bottom (demersal) or mid-water (pelagic).

Trophic: Of, or involving, the feeding habits or food relationship of different organisms in a food chain.

Zooxanthellae: Algae that live **symbiotically** within the cells of other organisms e.g. corals in the **photic** zone.

Zooanthid: An order of anemone like hexacorals which have a colonial lifestyle.

Zooplankton: General term for the animal component of the plankton. in aquatic habitats, or in moist environments on land.

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Selection of coral and seamount resources

censeam.niwa.co.nz
CenSeam (a global census of marine life on seamounts) is a Census of Marine Life Field Programme aiming to provide the framework needed to prioritize, integrate, expand and facilitate seamount research efforts.

www.coml.org
The Census of Marine Life (CoML) is a network of researchers in more than 70 nations engaged in a 10-year initiative to assess and explain the diversity, distribution, and abundance of marine life in the oceans – past, present and future.

www.fao.org/DOCREP/003/X2465E/x2465e0h.htm
FAO FISHERIES TECHNICAL PAPER 382 'Guidelines for the Routine Collection of Capture Fishery Data'

www.fishbase.org/search.php
FishBase is a relational database with information to cater to different professionals such as research scientists, fisheries managers, zoologists and many more. FishBase on the web contains practically all fish species known to science. (eds R Froese, D Pauly; version 16 February 2004).

bure.unep-wcmc.org/marine/coldcoral
Global cold-water coral database and GIS, an interactive mapping tool developed by UNEP which provides easy access to a wealth of information on cold-water coral ecosystems, drawing on the data and collective expertise of scientists, national agencies and regional organizations from around the world.

cdiac.ornl.gov/oceans/glodap/Glodap_home.htm
The GLobal Ocean Data Analysis Project (GLODAP) is a cooperative effort to coordinate global synthesis projects funded through the National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Energy (DOE), and the National Science Foundation (NSF) as part of the Joint Global Ocean Flux Study – Synthesis and Modeling Project (JGOFS-SMP).

www.ngdc.noaa.gov/mgg/gebco
General Bathymetric Chart of the Oceans (GEBCO) aims to provide the most authoritative, publicly-available bathymetry datasets for the world's oceans. GEBCO operates under the auspices of the International Hydrographic Organization (IHO) and the United Nations' (UNESCO) Intergovernmental Oceanographic Commission (IOC).

www.eu-hermes.net
Hotspot Ecosystems Research on the Margins of European Seas (HERMES), a multidisciplinary deep-sea research project with 50 partners under the EC Framework Six Programme. HERMES work packages include, inter alia, cold-water coral reefs and carbonate mounds.

www.kgs.ku.edu/Hexacoral/
Biogeoinformatics of Hexacorals is intended to: (1) provide a public information resource of data, interpretation and methods related to the taxonomy, biogeography and habitat characteristics or environmental correlates of the Hexacorallia and allied taxa (2) connect and integrate the activities of the individual and institutional partners (3) keep a wide range of project information updated and available to all interested parties and (4) provide a directory and communication links to participants and related projects.

www.lophelia.org/index.htm
Lophelia.org is dedicated to the cold-water coral Lophelia pertusa and is an information resource on the cold-water coral ecosystems of the deep ocean.

www.mar-eco.no
MAR-ECO (patterns and processes of the ecosystems of the northern mid-Atlantic) is Census of Marine Life Field Programme. MAR-ECO is an international exploratory study of the animals inhabiting the northern mid-Atlantic. Scientists from 16 nations around the northern Atlantic Ocean are participating in research of the waters around the mid-Atlantic Ridge from Iceland to the Azores

oceanexplorer.noaa.gov/
NOAA Ocean Explorer is an educational Internet offering for all who wish to learn about, discover, and virtually explore the ocean realm. It provides public access to current information on a series of NOAA scientific and educational explorations and activities in the marine environment with links to numerous cold-water coral expeditions.

www1.uni-hamburg.de/OASIS
OASIS (Oceanic seamounts: an integrated study) is a European Commission supported project aiming to describe the functioning characteristics of seamount ecosystems.

marine.rutgers.edu/opp
IMCS Ocean Primary Productivity Team's (OPPT) home page aims to provide: (1) Access to datasets of primary productivity measurements based on 14C uptake and stimulated fluorescence techniques, with the hope that these data will be used for productivity model development and testing; (2) Computer source code, input data fields and ocean productivity estimates for the Vertically Generalized Production Model

(VGPM) developed by the OPPT, and; (3) Information on activities of the NASA-sponsored Ocean Primary Productivity Working Group (OPPWG), which has been conducting round-robin algorithm testing exercises since 1994 to compare, in an investigator-independent manner, the performance of various productivity models with the intent of establishing a NASA resident 'consensus' algorithm for the routine generation of ocean productivity maps.

www.seaaroundus.org

The Sea Around Us Project (SAUP) is devoted to studying the impact of fisheries on the world's marine ecosystems. To achieve this, project staff have used a Geographic Information System (GIS) to map global fisheries catches from 1950 to the present, under explicit consideration of coral reefs, seamounts, estuaries and other critical habitats of fish, marine invertebrates, marine mammals and other components of marine biodiversity. The data presented, which are all freely available, are meant to support studies of global fisheries trends and the development of sustainable, ecosystem-based fisheries policies.

seamounts.sdsc.edu

SeamountsOnline is a freely-available online resource of seamount related data. It is a NSF-funded project designed to gather information on species found in seamount habitats, and to provide a freely-available online resource for accessing and downloading these data. It is designed to facilitate research into seamount ecology, and to act as a resource for managers.

earthref.org

The Seamount Catalog (search under databases for the Seamount Catalog) is a digital archive for bathymetric seamount maps that can be viewed and downloaded in various formats. This catalog also contains morphological data and sample information. Related grid and multibeam data files, as well as user-contributed files, can be downloaded as well.

www.nodc.noaa.gov/OC5/WOA01/pr_woa01.html

The World Ocean Atlas 2001 (WOA01) contains ASCII data of statistics and objectively analysed fields for one-degree and five-degree squares generated from World Ocean Database 2001 observed and standard level flagged data. The ocean variables included in the atlas are: in situ temperature, salinity, dissolved oxygen, apparent oxygen utilization, per cent oxygen saturation, dissolved inorganic nutrients (phosphate, nitrate and silicate), chlorophyll at standard depth levels, and plankton biomass sampled from 0-200m.

Appendix I

Physical data

All physical data were compiled onto a one-degree resolution global grid, centred on the midpoint of each degree cell. Physical data were gridded at 0, 500, 1 000, 1 500, 2 000 and 2 500 m depth. These resolutions were chosen to fit with data availability (WOA and GLODAP data are available at this grid resolution). Physical data and primary productivity model output were all long-term annual means. Composite annual data were derived from cruises and sampling covering a variety of time periods; where possible, data were selected from the 1990s.

World Ocean Atlas 2001 data (Conkright et al., 2002) were composite annual objectively analysed means. GLODAP gridded data (Key et al., 2004) were mostly derived from 1990s WOCE (World Ocean Circulation Experiment) cruises. VGPM model outputs (Behrenfeld and Falkowski, 1997) were depth-integrated surface values corrected for cloudiness, derived from data collected between 1977 and 1982. SODA modelled current velocities (Carton et al., 2000) were the grand mean of the annual means for the period 1990-1999, using the 1.4.2 version of the model; the velocity layer nearest to each depth grid layer was used. The aragonite saturation state was calculated using GLODAP data and following the $\Delta[CO_3^{2-}]_A$ method of Orr et al. (2005), with constants as described in Orr et al. (2005) and equations following Zeebe and Wolf-Gladrow (2001). Positive $[CO_3^{2-}]_A$ indicates supersaturation; negative undersaturation. Depth is included as a parameter not because it is important per se, but because it may correlate with unmeasured factors such as pressure.

Appendix II

The habitat suitability model

ENFA is a predictive habitat suitability modelling technique designed to work with presence-only data (Hirzel et al., 2002). We bin scleractinian seamount data records to the one-degree global grid and assign them to the closest depth layer. We used only coral records above 2 500 m depth. Physical data were normalized using the Box-Cox transformation (Sokal and Rohlf, 1995). A mismatch occurs between some coral locations and predicted seamount locations in that some corals are found on seamounts that are not detected by the bathymetric analysis (Kitchingman and Lai, 2004). To resolve this, we model habitat suitability for the whole ocean, but restrict coral presences to seamounts.

We used the geometric mean algorithm in ENFA (Hirzel and Arlettaz, 2003). ENFA outputs species marginality (absolute difference between the global mean and the species mean in the multidimensional environmental space) and specialization (ratio of variance between the global distribution and species distribution). All environmental variables are converted into uncorrelated factors in a manner similar to principal component analysis.

Habitat suitability maps were constructed following Hirzel et al. (2002) using the isopleth method. Eight factors were used to construct habitat suitability maps, following a broken stick distribution (Hirzel et al., 2002).

Assessing model performance presents a different challenge for presence-only models than for presence-absence models (Boyce et al., 2002). In this case, validation for habitat suitability maps was carried out using a cross-validation technique (Boyce et al., 2002). Data were partitioned into four bins followed by a 10-fold cross validation. For each validation subset, area-adjusted frequency was compared with that of a randomly distributed species using Spearman's rank correlation to assess the monotonicity of the curve (Table A1). This coefficient varies between -1 and 1; a value near 1 indicates area-adjusted frequency model predictions monotonically increasing with increasing habitat suitability and deviating from a random curve, suggesting good model performance.

Table A1: Cross-validation results; Spearman's rank coefficient

Replicate	Rs
1	0.8
2	0.8
3	1
4	1
5	1
6	0.8
7	1
8	0.8
9	0.8
10	0.8
Mean	0.88
S. D.	0.10

Key assumptions of ENFA are that data are multinormal, that species occurrence data span the complete environmental range, and that the species is at equilibrium. Hirzel et al. (2002) suggest that ENFA is robust to deviations from normality, and the method has also been shown to be robust to quality and quantity of data (Hirzel et al., 2001). Spatial autocorrelation was not directly accounted for but is unlikely to be a major issue with this data (Leverette and Metaxas, 2005).

REFERENCE MAPS

Map 2. FAO Major marine fishing areas

Area	Name	Area	Name
18	Arctic Sea	57	Indian Ocean, Eastern
21	Atlantic, Northwest	58	Indian Ocean, Antarctic and Southern
27	Atlantic, Northeast	61	Pacific, Northwest
31	Atlantic, Western Central	67	Pacific, Northeast
34	Atlantic, Eastern Central	71	Pacific, Western Central
37	Mediterranean and Black Sea	77	Pacific, Eastern Central
41	Atlantic, Southwest	81	Pacific, Southwest
47	Atlantic, Southeast	87	Pacific, Southeast
48	Atlantic, Antarctic	88	Pacific, Antarctic
51	Indian Ocean, Western		

Map 3. Regional sea conventions and action plans

1	Convention on the Protection of the Marine Environment of the Baltic Sea Area (HELCOM)**[c]**
2	Bucharest Convention and Black Sea Environment Programme**[b]**
3	Cartagena Convention for the Wider Caribbean Region, Caribbean Environment Programme (CEP) and Action Plan**[a]**
4	East Asian Seas Action Plan (COBSEA)**[a]**
5	Nairobi Convention and East African Action Plan**[a]**
6	Barcelona Convention and Mediterranean Action Plan (MAP**[a]**
7	Antigua Convention and North-East Pacific Action Plan**[b]**
8	North West Pacific Action Plan (NOWPAP) **[a]**
9	Jeddah Convention and Red Sea and Gulf of Aden Action Plan (PERSGA)**[b]**
10	Kuwait Convention and ROPME Sea Area Action Plan**[b]**
11	Noumea (or SPREP) Convention and Pacific Action Plan**[b]**
12	South Asian Seas Action Plan (SAS) and South Asian Seas Cooperative Environment Programme (SACEP)**[b]**
13	Lima Convention and South-East Pacific Action Plan (CPPS)**[b]**
14	Abidjan Convention and West and Central Africa Action Plan**[a]**
15	Regional Programme of Action for the Protection of the Arctic Marine Environment from Land-based Activities (PAME)**[H,c]**
16	Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR)**[H,c]**
17	Framework Convention for the Protection of the Marine Environment of the Caspian Sea (Teheran Convention) and Caspian Sea Strategic Action Programme**[c]**
18	OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR)**[H,c]**

H: with a high sea mandate / competence. In general, UNEP administered Conventions and Action Plans apply only to the national waters of member states, incl. EEZs, where appropriate.
a: UNEP administered **b:** Non-UNEP administered **c:** Independent Programme

Map 4. Regional marine fisheries bodies that can directly establish management measures

The map shows only the areas of competence of those Regional Marine Fisheries Bodies that can directly establish management measures. In addition to those listed and displayed, the International Whaling Commission (IWC) is a global bodies without a defined area of competence.

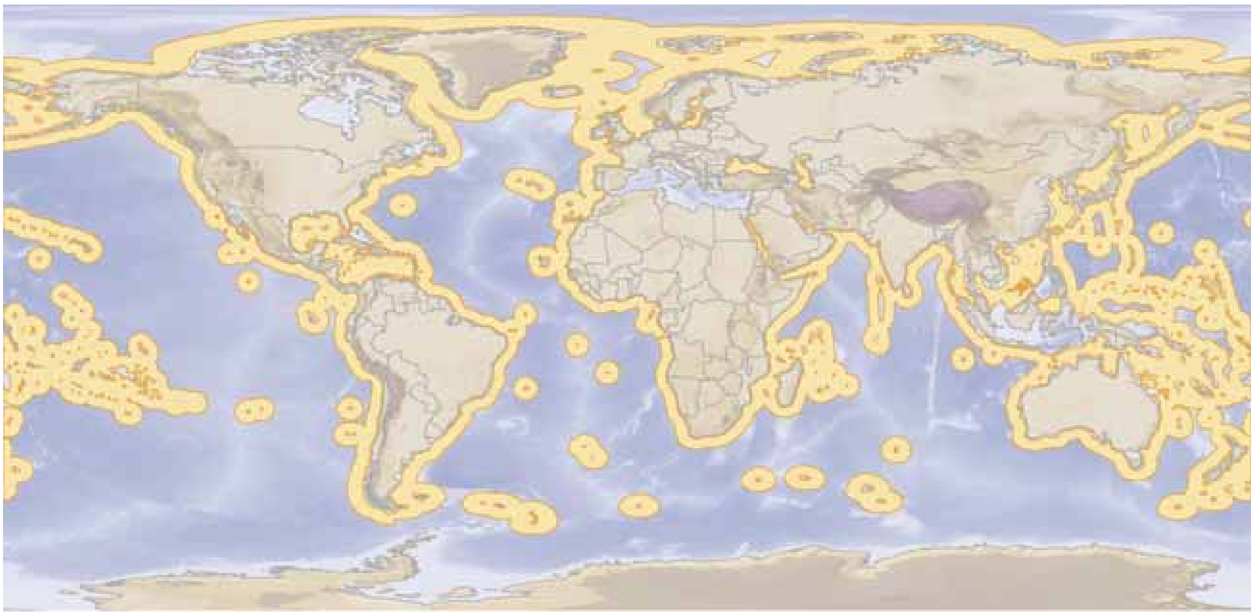
1	Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR)**[b]**
2	Convention on the Conservation and Management of the Pollock Resources in the Central Bering Sea (CCBSP)
3	Commission for the Conservation of Southern Bluefin Tuna (CCSBT)
4	General Fisheries Commission for the Mediterranean (GFCM)**[a,b]**
5	Inter-American Tropical Tuna Commission (IATTC)
6	International Commission for the Conservation of Atlantic Tunas (ICCAT)
7	Indian Ocean Tuna Commission (IOTC)**[a]**
8	International Pacific Halibut Commission (IPHC)
9	Northwest Atlantic Fisheries Organization (NAFO)**[b]**
10	North Atlantic Salmon Conservation Organization (NASCO)
11	North East Atlantic Fisheries Commission (NEAFC)**[b]**
12	North Pacific Anadromous Fish Commission (NPFAC)
13	Pacific Salmon Commission (PSC)
14	South East Atlantic Fisheries Organization (SEAFO)**[b]**
15	South Indian Ocean Fisheries Agreement (SIOFA)**[c]**
16	South Pacific Regional Fisheries Management Organisation (SPRFMO)**[c]**
17	Western and Central Pacific Fisheries Commission (WCPFC)

a: FAO administered
b: legal competence to manage most or all fisheries within their areas of application, including management of deep sea stocks beyond national jurisdiction
c: under negotiation

REFERENCE MAPS

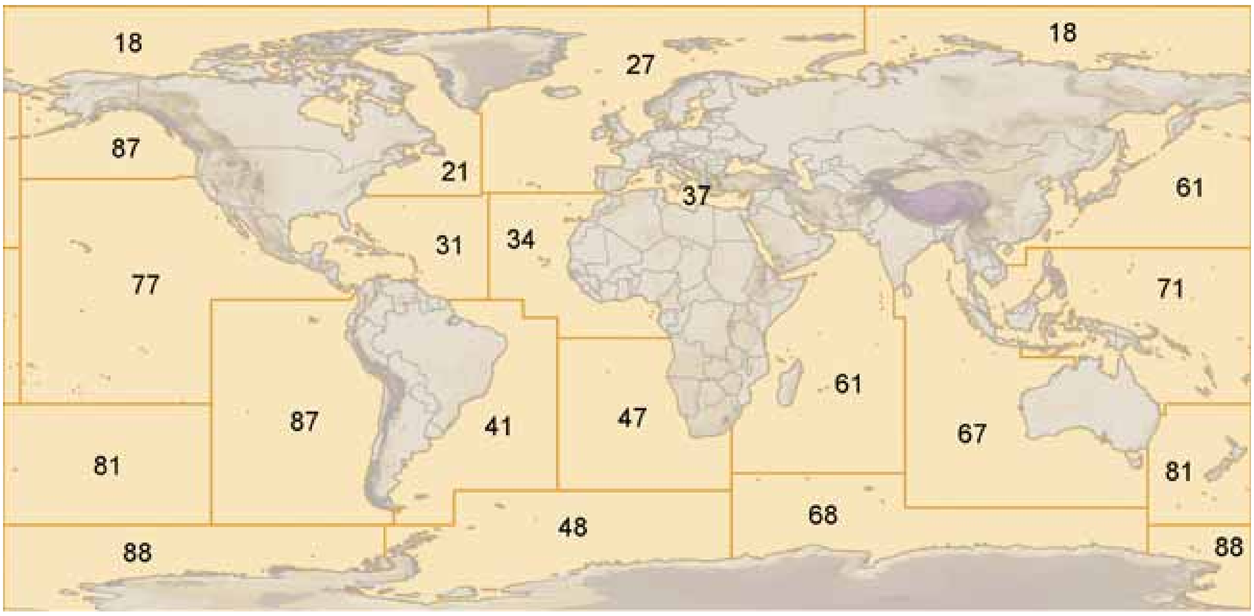
Map 1. Exclusive economic zones

Prepared using the Global Maritime Boundaries Database (February 2006 edition, © General Dynamics Advanced Information Systems, 1998-2006). EEZs and fishing zones in the Mediterranean not displayed.



Map 2. FAO Major marine fishing areas

Source and further information: http://www.fao.org/figis/servlet/static?dom=root&xml=geography/fao_fishing_area.xml



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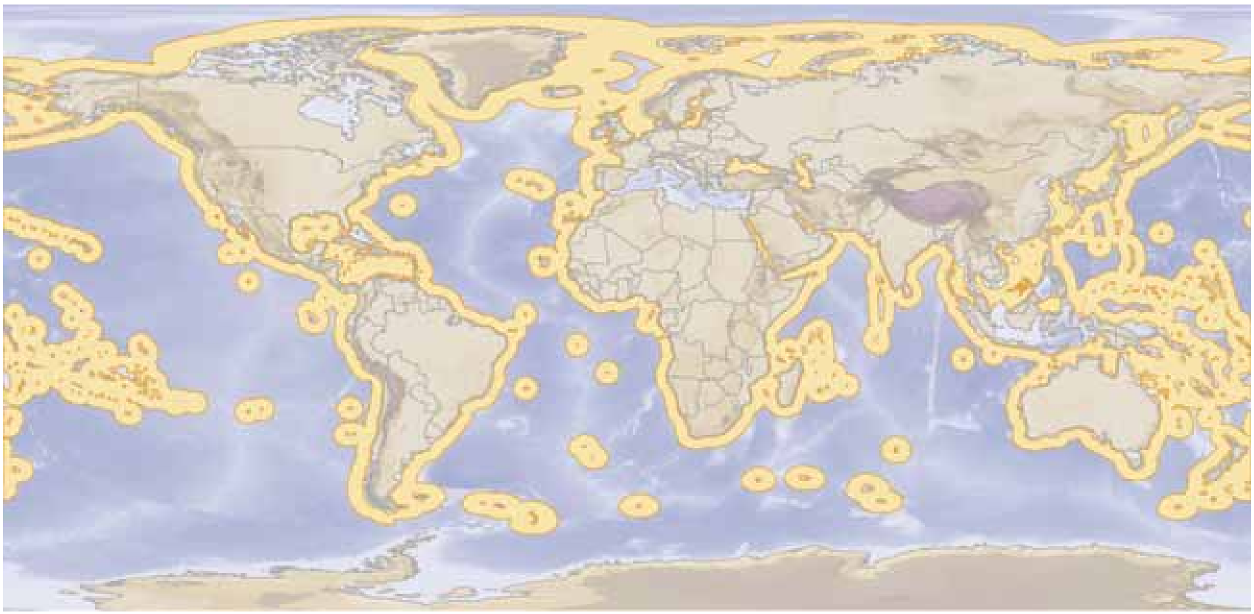

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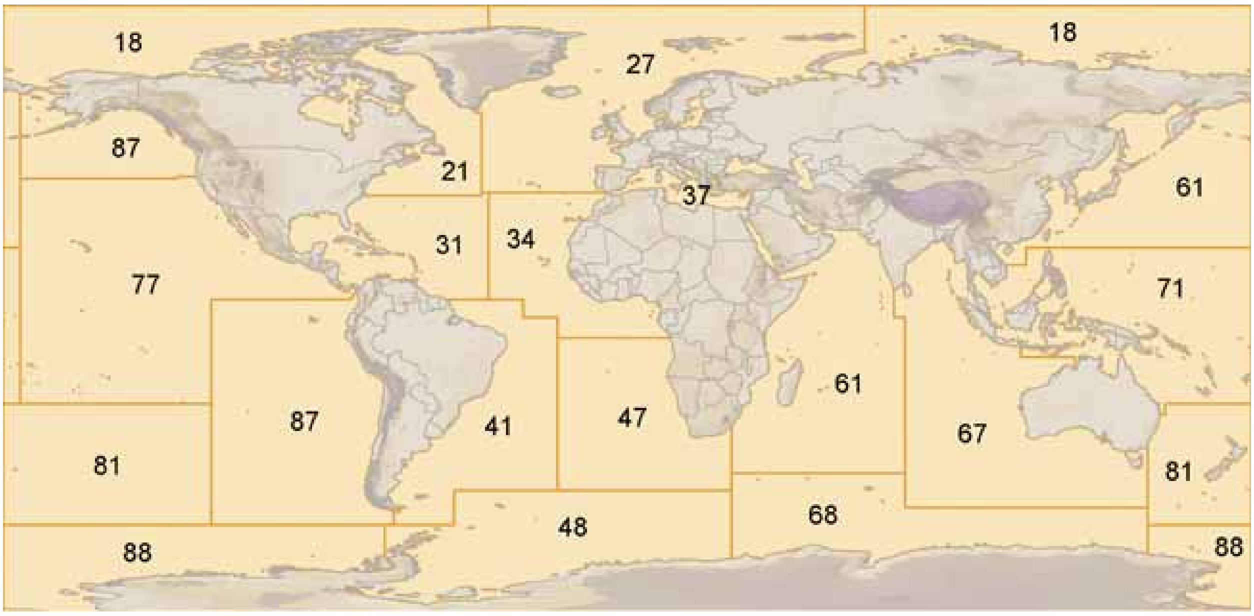
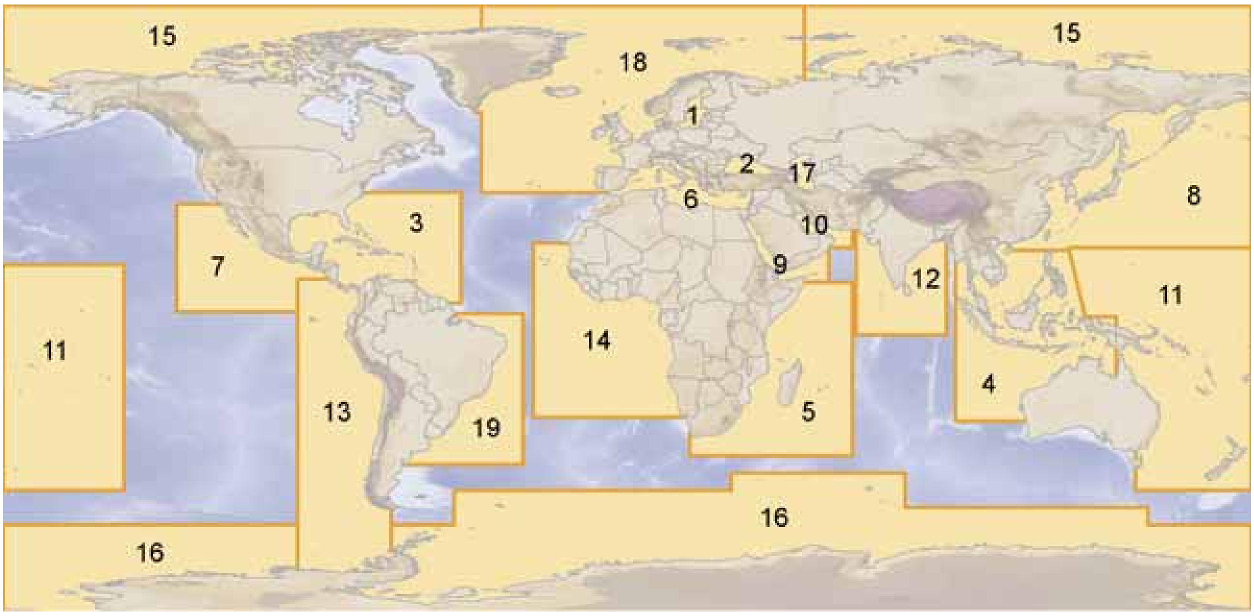


REFERENCE MAPS

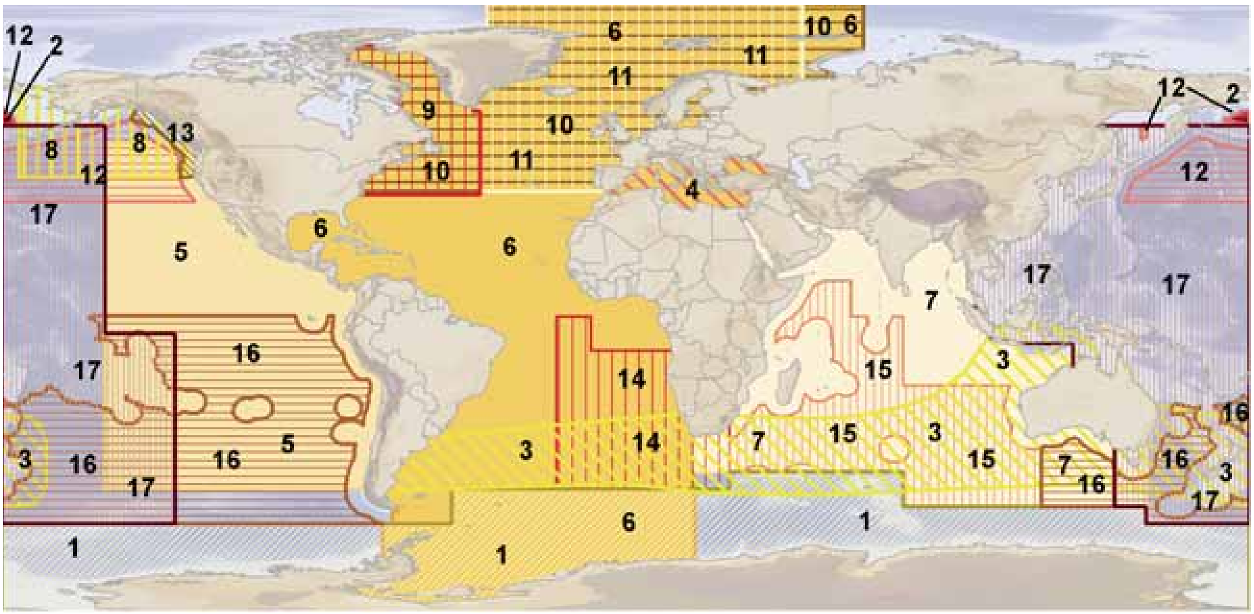
Map 3. Regional sea conventions and action plans

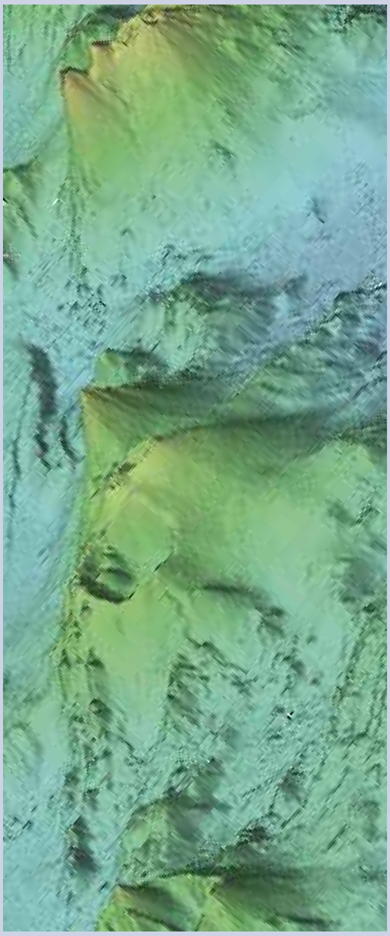
Source and further information: http://www.unep.org/regionalseas/



MAP 4. Regional marine fisheries bodies that can directly establish management measures

Source and further information: FAO, 1999-2006, Regional Fishery Bodies - Map of competence area, http://www.fao.org/fi/body/rfb/index.htm





Seamounts, deep-sea corals and **fisheries**

An ubiquitous ocean floor feature, a key marine ecosystem and an important human activity: together these have created one of the most critical ocean issues.

Seamounts, deep-sea corals and fisheries reveals the global scale of the vulnerability of habitat-forming stony corals on seamounts – and that of associated marine biodiversity and assemblages – to the impacts of trawling, especially in areas beyond national jurisdiction. It provides some of the best scientific evidence to date to support the call for concerted and urgent action on the high seas to protect seamount communities and their associated resources from the adverse effects of deep-water fishing.

Seamounts, deep-sea corals and fisheries describes the results of data analyses that were used to understand the global distribution of deep-sea corals on seamounts, to model the distribution of suitable habitat for stony corals, and to appreciate the extent of trawl fisheries on seamounts in areas beyond national jurisdiction. These results were combined, along with knowledge of the effects of trawling on corals and other seamount species, to identify the main areas at risk from the impact of current and future trawling on the high seas. In particular, seamount ecosystems in the Indian, North and South Atlantic, and South Pacific Oceans are threatened by the expansion of alfonsino (250-750 metres) and orange roughy (750-1 200 metres) fisheries.

Seamounts, deep-sea corals and fisheries aims to raise the awareness of managers, decision makers and stakeholders about the distribution of deep-sea corals on seamounts and their vulnerability to trawling. It provides facts and information to support and guide the international processes within and outside the United Nations system to find solutions for the conservation, protection and sustainable management of seamount ecosystems – before it is too late.

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